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Industrial Pigging Technology

Fundamentals, Components,
Applications



Gerhard Hiltcher, Wolfgang Mühlthaler, Jörg Smits

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WILEY-VCH GmbH & Co. KGaA

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Notation

Symbol	Designation	Unit
A	area, cross-sectional area	m^2
a	distance	m
a	sound velocity	m/s
B	magnetic induction	$T = \text{Wb}/\text{m}^2$
b	width	m, mm
c	velocity	m/s
C	concentration	%, ppm
C_R	residual conc. in the following product	%, ppm
C_v	volume concentration	%, ppm
C_m	molar concentration	%, ppm
D	shear rate, velocity gradient	s^{-1}
D, d	diameter	m, mm
E	modulus of elasticity in tension	N/mm^2
E	kinetic energy	J
F	force	N
f	frequency	Hz
f	deflection	mm
G	modulus of elasticity in shear	N/mm^2
h	height	mm
H	magnetic field intensity	A/m
I	moment of inertia	mm^4
K	constant	—
K	modulus of elasticity in compression	N/mm^2
L^*/d	pig: sealing length/diameter ratio	—
L, l	length	m, mm
L/d	pig: total length/diameter ratio	—
M	molar mass	kg/kmol
m	mass	kg
M_b	bending moment	Nm
n	number	—
O_1	largest possible oversize	mm

Symbol	Designation	Unit
O_s	smallest possible oversize	mm
P	payout	%
P	power	W
p	surface pressure	N/mm ²
p	pressure	Pa, bar
p_D	vapor pressure	Pa, mbar
p_{abs}	absolute pressure	Pa, bar abs
p	gauge pressure	bar g
p_J	Joukowski pressure	bar
R	universal gas constant	kJ/kmol/K
R, r	radius	m, mm
R_a	surface roughness value	μm
r_b	pipe bending radius	mm
Re	Reynolds number	–
R_m	tensile strength	N/mm ²
R_z	surface roughness: peak-to-valley height	μm
s	length, path, wall thickness	m, mm
Sc	Schmidt number	–
Sh	Sherwood number	–
T	absolute temperature	K
T	fitting tolerance	mm
T_f	product flash point	°C
t	time	s
u	velocity	m/s
v	flow velocity	m/s
V_{dead}	dead space	m ³
$\dot{V}$	flow rate	m ³ /s, m ³ /h
V	volume	m ³
W	geometric modulus	mm ³
W	energy	J
x, y, z	cartesian coordinates	–
Y	molar loading	–
y	molar concentration	–
μ	coefficient of sliding friction	–
ν	Poisson's ratio	–
ν	kinematic viscosity	m ² /s
ϕ	relative humidity	%
δ	residual film thickness	μm
τ	shear stress	N/mm ²
ρ	specific weight	kg/m ³
ε	strain	%
ϑ	temperature	°C
σ	tensile stress	N/mm ²

Symbol	Designation	Unit
$\alpha, \beta, \gamma, \varphi$	angle	°
μ_0	abs. permeability	Vs/Am
Δp	pressure drop	bar
μ_r	rel. permeability	–
ϑ	temperature	°C
ζ	flow resistance coefficient	–
η	dynamic viscosity	Pa s
η	efficiency	%
κ	electric conductivity	$S = \Omega^{-1}$

Indices

P	pig
S	station
T	pig trap
0	initial state
1	final state
max	maximum
min	minimum
s	shear
n	normal
tol	tolerable

Other Abbreviations

DN	Nominal Diameter
PN	Nominal Pressure
LEL	Lower Explosion Limit
UEL	Upper Explosion Limit
OPS	One-pig system
TPS	Two-pig system
IPU	Industrial pigging unit
COD	Chemical oxygen demand

Preface

The idea of pigging is both ingenious and simple. Pigging technology, discovered and developed originally by the oil industry more than 100 years ago, has since conquered many other fields.

The term pigging is primarily associated with cleaning. Pigging, however, is more than just cleaning. In the meantime, numerous other fields have been developed for pigging. Pigs can inspect, detect, repair, measure, and check. In many applications pigging has become indispensable: in sterile and food technologies; in the pharmaceutical, life sciences, and cosmetics industries; and in pipeline technology.

Furthermore, pigging contributes significantly to environmental protection. Resources are conserved, energy consumption is lowered, and the wastewater load is reduced. When used correctly pigging results in minimization of capital expenditures. Operating costs are lowered as a result of the reduced wastewater load.

This book gives an overview of the fundamental possibilities of and limits to pigging technology. Additionally, the technical, economic, and quality-oriented operational criteria for the use of a pigging system are described.

Apart from the systematic treatment of the different functions of pigging systems, their individual components and process control are described. Examples of installed systems are also included. Where necessary, the theoretical principles are elucidated in greater detail.

Legal issues, as well as safety and occupational health when operating a pigging system, are described with reference to actual applications.

The aim of this book is to familiarize the reader with pigging technology and to give assistance in planning a pigging system. It thus addresses planners, users, and operators. Empirical knowledge has been gathered for further practical application. Last but not least the book is intended to make pigging technology better known, both in training, at universities, and in industry.

Up to now, there has been no comprehensive book on the entire field of pigging.

Here a structured overview of this field is given for the first time. Terms are defined and distinctions drawn to ensure clear linguistic usage.

The idea for the book originated from requests of many users, who sought an alternative to existing conventional piping systems and required comprehensive information. This led to a first manual in BASF, which, however, was soon out of print.

The present book is a thematically revised and considerably expanded version of this manual. However, even here too it was not possible to deal comprehensively with all aspects; some special fields could only be treated briefly.

A particular interest of the authors is that the book contribute to increasing standardization in the field of pigging.

Each new pigging system has its own peculiarities. Recognizing these and being successful in planning and implementation depend on the commitment of those involved. New approaches are particularly worthwhile here.

The authors would like to thank the companies which provided pictorial material and information. In particular, we would like to mention Butting, I.S.T., Kiesel and Pfeiffer.

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Mannheim, May 2003

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I

Fundamental Principles of Pigging Technology

1

Introduction to Pigging Technology

1.1

Historical Development and Definition

Pigging technology can be regarded as a subdivision of materials-transport and cleaning technology. It is a strongly interdisciplinary field with close contact to fluid mechanics, pipeline technology, and chemical engineering. Theoretical investigations are based on findings from tribology, the theory of friction, lubrication, and wear.

A general definition of pigging is the propulsion through a pipe of a mobile plug pig which can execute certain activities inside the pipe.

Pigging can be used, for example, to clean a pipe mechanically (pig with brushes), to check a channel (pig with video camera), or to inspect the welding seams of pipelines (pig with eddy current sensors).

On the basis of applications in the oil industry (pipelines), which began as early as the late 1800s, from ca. 1970 onwards more precisely cleaning and sealing pigs were introduced in the chemical industry; the first industrial pigging units resulted. The pig was developed into a snug-fitting plug. These pigging units are used primarily to remove a product from a pipeline. Apart from the pig, other components such as pipes, valves, and the control system had to be selected carefully and adapted to each other.

The following, more precise definition is valid mainly for applications in the chemical industry [1]; it defines a pigging procedure in an industrial pigging unit:

In pigging the contents of a pipeline are pushed by a snug-fitting plug (pig) with the goal of removing the product almost completely from the pipeline. The pig is propelled through the pipe by a gas or a liquid (propellant).

The pig can be spherical, elongated, or composed of several parts. The pig is oversized relative to the pipe; thus, the pipe is sealed in front of and behind the pig, and the pig can be driven by a gaseous or a liquid propellant.

The gas most frequently is used compressed air, and the liquid can be e.g. water, cleaning agent or product.

This book primarily deals with industrial pigging units in the chemical industry. However, special chapters treat other branches of pigging such as sterile and pipeline technology.

Table 1–1. Types of pigs

Type of pig	Driving mechanism	Driving energy	Signal transmission	Main application
Snug-fitting, sealing	propellant medium	external pump	magnet sensor	industrial pigging systems
Brush pigs and /or intelligent pigs with sealing effect, body with sealing elements	propellant medium	external pump	magnet/sensor, telemetry, signal storage	industrial pigging systems, pipelines
Driven friction wheels for motion and/or centering, inspection pigs with wheels	electric motor	battery	magnet/sensor, telemetry, signal storage	pipelines, open channels, sewage pipes
Pulled and/or pushed pigs	cable winch	external motor	magnet/sensor, telemetry, signal storage	pipelines, open channels, sewage pipes
Jets with hose attachment	repulsion, pulsed ejections of a liquid	external pump		pipelines, open channels, sewage pipes.

Pigging Unit and Types of Pigs

Often pigging is a one-off procedure, for example, when a pipeline is assembled or inspected. For such purposes mobile pigging units are available.

On the other hand, in industrial pigging units pig runs take place regularly and at short time intervals and the equipment required for pigging is a fixed part of the plant.

Such an industrial pigging unit usually consists of the following components:

- Pig
- Piggable pipe with piggable valves
- Pig loading and unloading station
- Propellant supply
- Control system

In the simplest case the pigging unit (see Fig. 1–1) consists of a single pipe, which is travelled by a pig. The entire pigging line, including the valves, must be piggable.

Pigs, the mobile part of pigging units, are available in innumerable designs, sizes, and materials: From simple spherical pigs, mandrel pigs, separating pigs, and isolating pigs to in-line testing and inspection pigs; and from the fluid-driven pigs to self-driven camera vehicles. The total range of applications of pigs is thus very large.

At the beginning and end of the pigging line, pig stations are located. The control system for the pigging unit can be a component of the overriding distributed control system (DCS) of the plant.

Table 1.1 summarizes of the different types of pigs.

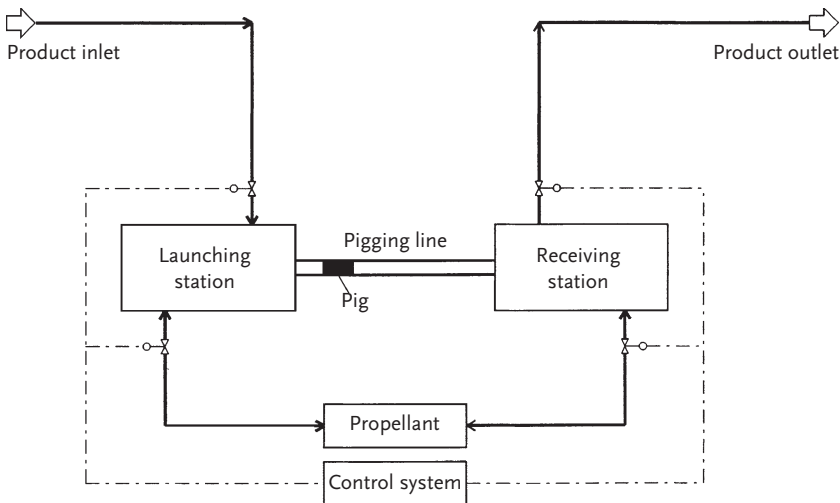


Fig. 1–1. Overview of the components of a pigging unit

1.2

Fields of Application of Pigging Technology

Concerning the piggability of products, in principle you can say: “if you can pump it, you can pig it.”

Gas pipelines must be freed of the condensate that accumulates in low-lying sections, and in crude oil and mineral oil pipelines paraffin deposits must be removed. Apart from cleaning, inspection of these pipelines is also of importance. With pipelines the interior condition, the welding seams, the wall thickness, and the surface quality are checked.

Channels and sewers must be examined and maintained.

In sterile technology frequent cleaning is necessary to maintain quality. In many cases cleaning of the pipes can be performed reliably by pigging [2].

The most important applications of pigging are:

- Sweeping liquids from pipelines.
- Removing incrustations and deposits.
- Removing condensate (gas pipelines).
- Filling/emptying of a pipeline by a plug flow.
- Separation of products pumped one after the other in the same pipeline (e.g., product A – pig 1 – product B – pig 2 – propellant). This process is called “batch pigging”.
- Inspection, detecting and observation.
- Cleaning.
- Measurement and control.
- Repairing.

The applications of industrial pigging units encompass four major tasks:

- Several products are pumped through a single pipe. Instead of many individual lines only one pigging line is required. A pig run is required for each change of product.
- Product is removed from a pipe, i.e., the pipe is cleaned by pushing the product almost completely out. Moreover product can be removed from a pipeline without any slope or from a pipeline with siphons.
- Rinsing a pipeline with a cleaning agent and/or a solvent (e.g., water) contained between two pigs running in the same direction (tandem pigging).
- Foaming is prevented or reduced by a pig in front of the product. For an initially empty pipe, especially one with a downward slope, a pig driven by the product results in gentle transport, and mixing with air is avoided.

In chemical plants pigging can be applied in various locations:

- Between vessels in a production plant (e.g., vessel–filter, reactor–vessel, stirred tank–vessel).
- In the connections of plant sections outside the process building, (e.g., crude plant–pure plant, process plant–tank farm, tank farm–filling facilities).

Since these parts of a plant are usually connected to many individual pipelines, a pigging unit can be valuable here.

In particular with long pipelines, multiproduct plants, and batch operation the economic benefits of pigging become apparent:

- One pipeline for several products (saves on investment costs and space requirement).
- Easy emptying of the pipeline in the case of products which can freeze, condense, decompose, or polymerise.
- No need for insulation and/or tracing.
- Saving of time relative to a manual emptying.
- No rinsing procedures or substantially smaller amounts of cleaning agents (lower chemical oxygen demand (COD), lower incineration costs, reduced losses of valuable product).
- No slope necessary, to empty the pipeline completely, siphons are allowed.

Especially these benefits helped the breakthrough of pigging technology in the chemical industry. However numerous problems have to be solved in this area, such as material resistance and selection of the pig type and the pigging system, so that plant design requires careful coordination with the operator. This is a topic of the following chapters of the book.

2

Pigging Units and Pigging Systems

2.1

Definitions

The following terms are used often in the following chapters, and are of indispensable importance in pigging technology and for understanding of industrial pigging units.

Pigging Line

A pigging pipe (pigging line) can be one that was designed and installed with the pigging process in mind. In exceptional cases, depending on the pigging requirements, standard lines can subsequently be made piggable. This, however, is not recommended.

Pigging Unit

A pigging unit is the total equipment which is required for the execution of a pig travel. It is part of an entire plant that cleans, separates, or removes a liquid from a pipe. A pigging unit consists either of a single piggable line or of several connected piggable lines with at least one launching and one receiving station and one pig unloading station.

Piggable lines are termed coherent if a pig can be propelled to any position in the branched lines without being removed. Hence, parts of a line connected by switches are also regarded as part of a single pigging unit.

Pigging units consisting of a only one piggable line are called simple pigging units. Pigging units with one or more switches are branched pigging units.

Product Feed Direction and Direction of Pig Travel

The product feed direction is the predominant direction of product flow through the product pump, which is apparent from the pump symbol in the pipe and instrumentation diagram (PID).

The pig can travel in the product feed direction (forward pigging), or against it (reverse pigging). Pigs which can travel in both forward and reverse directions are termed bidirectional pigs (BiDis).

Launching and Receiving Stations

The first pig station travelled through in the product feed direction is the launching station, and that which is travelled through last the receiving station. These are the most important pigging valves. A branched pigging unit has several receiving stations (at least two). Further characteristics of these stations, such as loading and unloading of pigs, are described in Section 4.3.1.

Propellant

The propellant is the medium present behind the pig and which drives it.

Pigging System

The term pigging system refers to the different pigging procedure that are possible in a pigging unit, i.e., the temporal sequence of individual operationing steps. A distinction is made between open and closed pigging systems and between one- and two-pig systems [1].

Open/Closed Pigging Systems

In an open pigging system (removable pig) the pig can travel through the pipe only in one direction (Fig. 2.1). At the receiving station the pig is removed and returned externally to its Launching station.

In open pigging systems pigs with conical, cup-shaped seals are generally used, which can be driven only in one direction. Often several pigs are present at the launching station and are collected at the receiving station for return. The cleaning of the pigs is carried out manually outside of the pigging unit.

Open systems are particularly suitable for long pigging lines (> 1 km) in the chemical industry e.g., from a tank farm to a ship loading at a jetty, or for long-distance pipelines. Here, propellant energy is generally not available for returning the pig to the launching station, and the frequency of pig runs is low.

In special cases, if a propellant is available, the pig can be removed, turned manually, and returned again (open system with manual pig turning).

In a closed pigging system the pig remains for its total service life in the pipe. Only pigs whose form permits movement in both direction are suitable. The closed pigging system is versatile, e.g., piggable switches (diverter valves) can be used to construct a branched pigging unit.

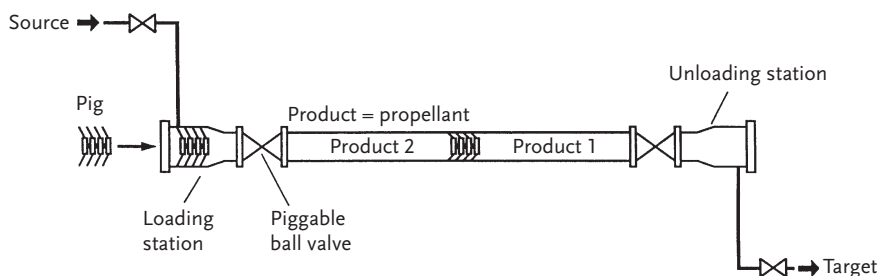


Fig. 2-1. Open pigging system (schematic)

One-Pig Systems (OPS)

One-pig systems (OPS) can be open or closed (Fig. 2-2). With the exception of very long pigging lines, the closed OPS is the most frequently used pigging system. A detailed description follows in Section 2.4.2.

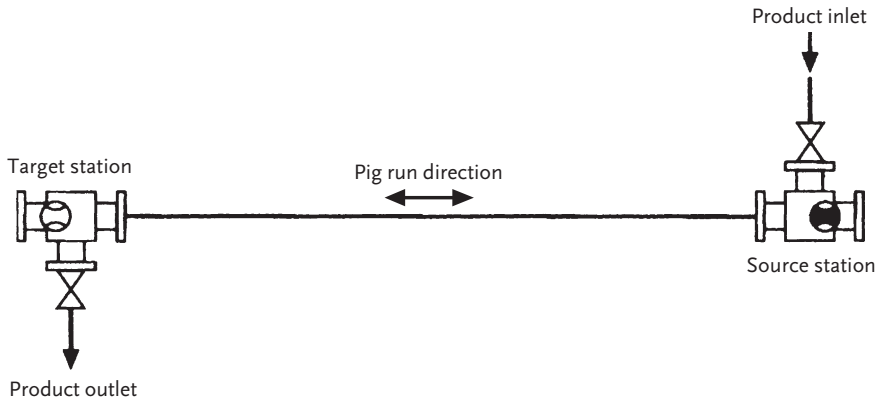


Fig. 2-2. Closed one-pig system

Two-Pig Systems (TPS)

In two-pig systems (TPS, Fig. 2-3) the two pigs can be driven in the same direction with or without interpig spacing or in opposite directions through the line. The functional principle and advantages of TPS are dealt with in Section 2.4.3. In principle units with three, four, or more pigs are also conceivable. However, more than two pigs are relatively rarely in a pigging unit. Multipig units operate similarly to two-pig systems.

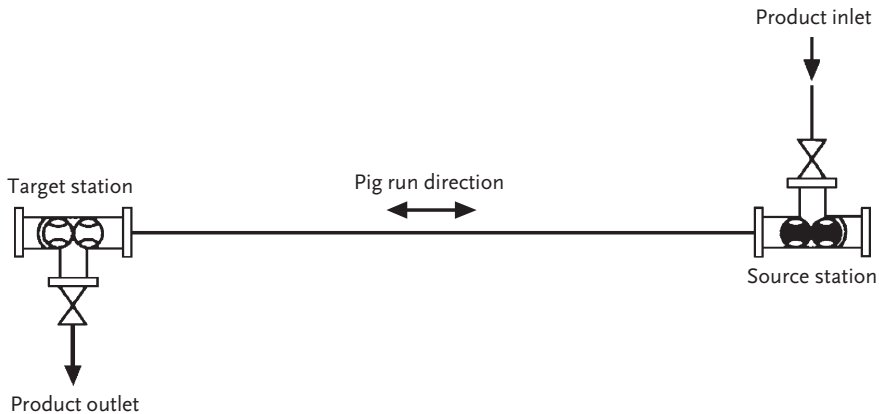


Fig. 2-3. Closed two-pig system

Source and Target Stations

The source and target stations are the start and end station for a given pig travel. Thus, a target station can also act as a station during reverse pigging.

2.2**Selection and Design Criteria**

The important boundary conditions for the selection of a pigging system are described in the following. The considerations which are necessary for defining the sequence of steps in a pig travel lead to the general possibilities treated in Section 2.4.1.

First, the task of the pig run must be clarified:

- Is the pipe to be emptied only to a large extent or must it be completely cleaned by the pig run?
- Are small amounts of residual product in pockets (e.g., between closed ball valve and flange) tolerable?
- How large a degree of inner wall wetting after pig travel is permissible?
- Which contaminations are permissible after product change?

Rinsing procedures with small amounts of cleaning agent solvent are possible only with a TPS.

Next, information on the product properties relevant to the pigging procedure is required. Is a one-product pigging line involved, or are several products to be conveyed by a pigging line? In a one-product pigging line the only possibility is emptying by means of a pig. In a multiproduct pigging unit possible small levels of contamination by the previous product must be considered.

Apart from the readily determined and well-known physical and chemical properties of the product, the tribological properties of the liquid product are also of importance, i.e., the characteristics which affect the sliding and lubrication properties and hence wear and service life. The tribological system pig material/product/pipe must be optimized to give favorable lubrication characteristics at minimum levels of inner-wall wetting. While the adhesive, polymerisation, and hardening tendencies of the product are known, their influence on the gliding ability, i.e., on the development of a hydrodynamic lubricating film, is difficult to predict.

The chemical, physical, and safety-relevant product properties affect the choice of propellant. Air or nitrogen can react with the product and/or lead to the drying out of the pipeline. The product can become hard, and increased wear in subsequent pig travels results. For tribological reasons a dry pig run, i.e., without liquid ahead of the pig, should be avoided.

With foaming products it is often practical to place the pig ahead of the product. This is particularly important for vertical pipe sections if the line is filled with product from above.

The next point to be clarified is which plant sections are to be interconnected. There are the following possibilities:

- Only two sections are interconnected (TS).
- Several sections are connected by T-pieces to the pigging line (SS).
- Several sections are connected by branched pigging lines (BS).

Special attention must be paid to the design of the nonpiggable input and output lines of the pigging line. These pipelines should be:

- A short as possible and free of dead space.
- Easily emptied by gravity flow.
- Rinsable.

In the ideal case these sections would consist only of a valve. For larger distances without downward gradients or the possibility of rinsing, the pigging line must be extended by means of a switch to avoid contamination.

2.3

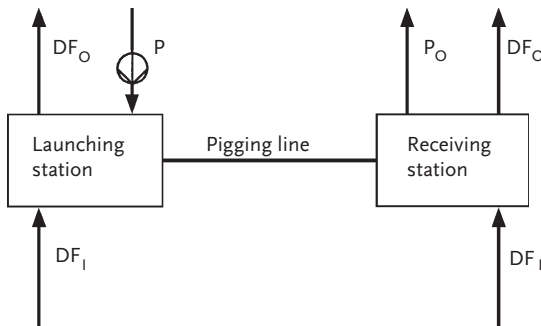
Pigging Units

2.3.1

Pigging Units without Branches

Figure 2–4 shows the principle of a pigging unit without branches, also known as a simple pigging unit (SPU). It consists of one launching and receiving station, from at least one of which the pig can be removed. The product feed direction is indicated by the arrow on the product pump.

The SPU consists of a single, continuous piggable line. The principal purpose of this line is conveyance of the product. The role of the pig is to fulfil certain requirement with respect to product feed (e.g., purity or complete emptying). An example is the pigging of pipelines.



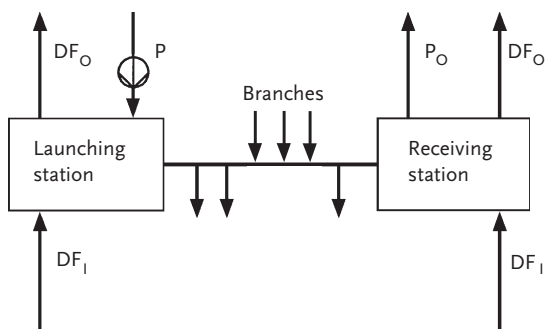
- P_I : Product inlet with product pump
 P_O : Product outlet
 DF_I : Propellant (drive fluid) inlets
 DF_O : Propellant outlets

Fig. 2–4. Principle of a simple pigging unit without branches

2.3.2

Pigging Units with Branches

In a branched pigging unit (BPU) the pigging line has a rake- or comblike design. The branch or tee serves only as a product branch; the pig can move only in the continuous pigging line. Product can be fed into or removed from the pigging line at several locations. A two-pig system with pig traps is necessary in most cases for positioning of the pigs. Removal of product, but not of the pig, requires special valves (see Section 4.3.2). A schematic is shown in Fig. 2–5.



P_I : Product inlet with product pump

P_O : Product outlet

DF_I : Propellant inlets

DF_O : Propellant outlets

Fig. 2–5. Principle of a pigging unit with branches

2.3.3

Pigging Units with Switches

With a pigging unit with one or more switches (diverter valves), i.e., a diverted pigging unit (DPU, Fig. 2–6), the pig can enter different piggable lines via switches. The path can be set manually before the pig run or specified in the control room.

Switches are necessary if:

- Different product destinations must be reached by piggable lines. A frequent application is pigging a tank of a tank farm alternatively to a loading station for tank trucks, to a rail tank car, or to a drum-filling facility.
- A nonpiggable valve, inline instrument, pump, or a pipe section is required for the product feed. The pig can bypass this component only by means of switches. A frequent application is a volumetric or gravimetric measurement in the product line, which is bypassed by a piggable pipe.

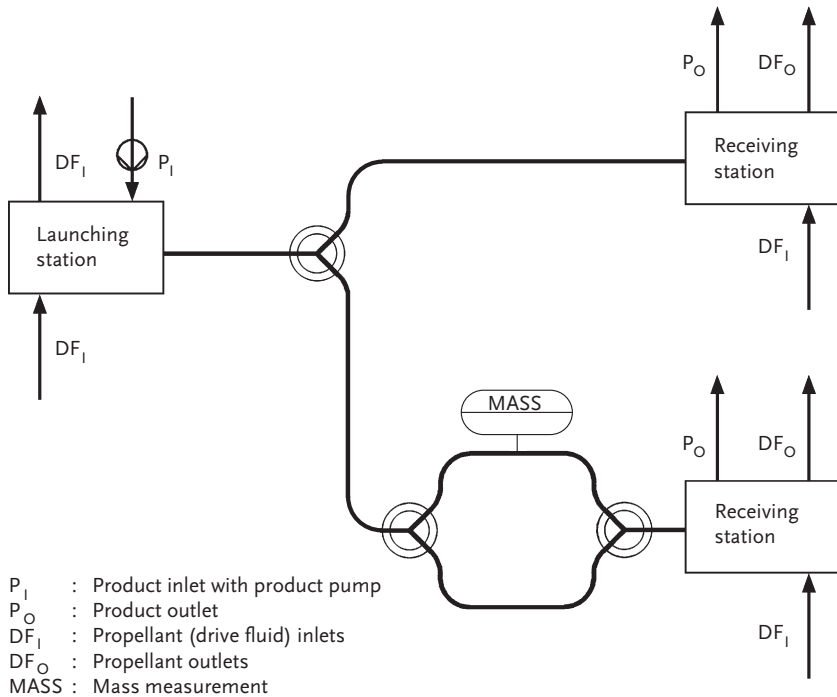


Fig. 2-6. Principle of a diverted pigging unit

2.4

Pigging Systems

Each pigging unit operates according to a certain pigging system (for definition, see Section 2.1); the different pigging systems are distinguished by the mode of operation. The individual steps are systematically described in a process table.

2.4.1

Sequence Tables

When planning a pigging unit careful analysis of the individual operating steps is required. This is best performed in tabular form. The so-called sequence table is an important prerequisite for planning of the pigging unit, in particular with regard to control.

Fundamental procedures in a pigging unit are the individual pig travels and the product feed. However, the initial state, or state of rest, must also be accurately defined. In the following the different possible constellations are described for the example of a simple pigging unit.

Before a pig run begins, the total unit is in the initial state, i.e., the pipelines are pressure-free. The location of the pig (P) in the initial position (starting state) must be defined: the pig can be parked either in the launching station (LS) or in the receiving station (RS). The description of the initial position also includes the medium with which pigging line is filled (e.g., with air, propellant, or product). Note that in the initial position the pigging line is pressure-free, i.e., gases must be pressure-relieved and liquids must not be confined.

Often product pumping can be started without pig travel. The piggable line (PL) in the initial state is already prepared for the product feeding. All pig travels necessary for cleaning take place after this product feeding. In the description of the procedure “product pumping” only the location of the pig must be considered. Generally the pig can be in the launching station, in the receiving station, or at a product branch of the pigging line.

If the pig is in the launching station during the product feeding, then the product volume contained in the pipeline can be driven to the receiving station. In the reverse case (reverse pigging) the product is driven back to the outlet vessel. If the pig is parked just behind a branch, it prevents the product flowing into the remaining pigging line.

After product feeding, the product in the pigging line is to be driven out in the next step by a pig run. For the pig run, the driving direction (from the launching station (LS) to the receiving station (RS) or vice versa) and the propellant are indicated. The propellant can be product, compressed air, water, or a cleaning agent.

In the sequence table for the pig run the column “propellant” indicates not the medium before the pig, but the medium after the pig (the propellant).

A subsequent pig travel from the receiving station to the launching station restores the initial state.

Table 2–1 depicts one of the possible combinations as an example.

Table 2–1. Sequence table of a pigging procedure

Step	Process	Pig position or pig run direction*	Pigging line	
			Content	Propellant
1	initial position	P=LS	air	–
2	pig run	P→RS	–	product
3	product pumping	P=RS	product	–
4	pig run	P→LS	–	air
5	initial position	P=LS	air	–

* P=pig, LS=launching station, RS=receiving station
 =: resting position, →: pig run to

The sequence table provides a formal description, as a function of the individual operating steps and/or states (rows), of the location and/or the driving direction of the pig (column 3) and the medium with which the pigging line is filled (column 4).

This sequence table defines individual operating steps of the pig run. The table is important for the planning and procurement of the pigging unit and serves as basis for the development of the control system of the unit (operating and logic diagrams). Already in the planning phase, the future operator of the unit can recognize and examine the individual operating steps.

2.4.2

One-Pig Systems

The one-pig system can be used when only one vessel each is connected to the launching and receiving stations. Several vessels can be connected by a “spider” and the pipelines can run dry by gravity. Depending on the tolerance for contamination, OPS can be used also for several vessels.

As an example of OPS the pigging line between a tank and a tank truck loading facility is analysed here. Pigging was chosen for this function, since the product must not freeze and must not be heated strongly. When no loading takes place, the pipeline is filled with air.

The measurement equipment (e.g., a mass flow meter) can be installed at the loading station (Tab. 2–2) or at the pump (Tab. 2–3).

In the former case, the product still in the pigging line after completion of the loading procedure can be driven into the tank by a pig. The following sequence table results (Tab. 2–2).

Table 2–2. Sequence table of pigging with measurement in the loading facility

Step	Process	Pig position or pig run direction*	Pigging line	
			Content	Propellant
1	initial position	P=RS	air	–
2	product pumping	P = RS	product	–
3	pig run	P→LS	–	air
4	pig run	P→RS	–	air
5	initial position	P=RS	–	–

* P=pig, LS=launching station, RS=receiving station
=: resting position, →: pig run to

In the latter case the content of the pigging line was already taken into account in the measurement; the content must be driven out into the tank truck (Tab. 2–3).

Table 2–3. Sequence table of pigging with measurement at the pump

Step	Process	Pig position or pig run direction*	Pigging line	
			Content	Propellant
1	initial position	P=LS	air	–
2	product pumping	P = LS	product	–
3	pig run	P→RS	–	air
4	pig run	P→LS	–	air
5	initial position	P=LS	–	–

* P=pig, LS=launching station, RS=receiving station
= : resting position, → : pig run to

2.4.3

Two-Pig Systems

Two-pig systems are used when more than two plant components are to be connected with a pigging line and only low degrees of contamination are permitted. In two-pig systems the pig stations have the appropriate length for two pigs, one after the other. In the initial state both pigs can be in one station or one pig can be in each station.

Typical examples of two-pig systems are:

- The two pigs travel in different directions to a branch and thus empty the pipeline (see Fig. 2–7).
- Solvent and/or a cleaning agent is enclosed between the pigs.

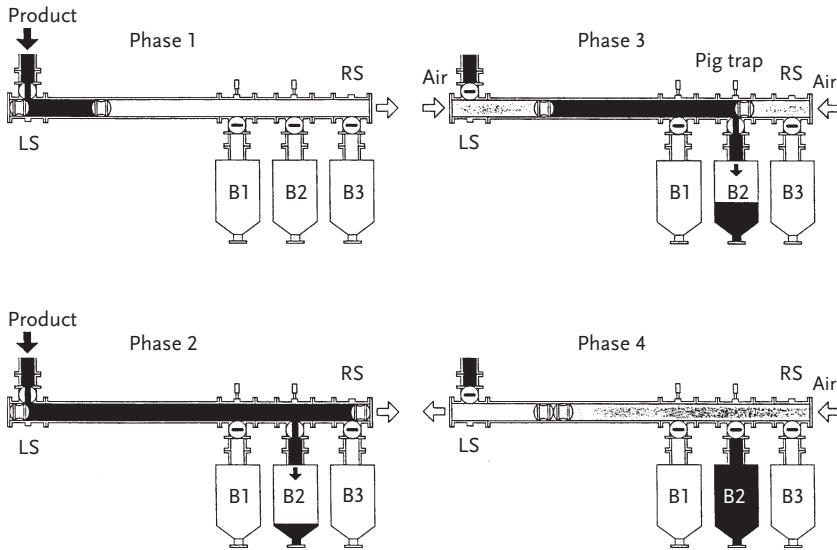
In the first case the pigs are first separated, i.e., the front pig is driven by the product to the next pig station. The total pigging line is now filled with product. Opening a ball valve at a T-piece allows the product to flow out through a certain outlet. Product pumping starts. After product pumping, the two pigs are driven in opposite directions to this branch and thus empty the pigging line. Afterwards, the two pigs can return simultaneously to their initial positions.

In the second case the pigging unit is operated like a one-pig system. For example, water is introduced between the pigs for a length of 2 to 3 m and then the two pigs are driven one after the other by propellant through the pipeline. This procedure can be repeated by driving the two pigs back and forth, until the desired degree of cleaning is achieved. The cleaning agent (solvent) can be collected and used again

or regenerated. The temporal change of the contamination in the cleaning agent (e.g., change in concentration over a month) can be used as measure for the wear of the pig.

An example of the first case is presented in Fig. 2–7, and the corresponding sequence table in Table 2–4.

The pipe is filled with air, and both pigs are in the left station (LS). The product pushes the first pig (RS) up to the pigging station S_2 on the right (phase 1). The tank valve B2 is opened and product pumping begins.



LS = Launching station

RS = Receiving station

Fig. 2–7. Operation of a two-pig system

Table 2–4. Sequence table of a two-pig system

Step	Process	Pig position or pig run direction*	Pigging line	
			Content	Propellant
1	initial position	$P_1=LS, P_2=LS$	air	–
2	pig run	$P_2 \rightarrow RS$	–	product
3	product pumping	$P_1=LS, P_2=RS$	product	–
4	pig trap activated	–	–	–
5	pig run	$P_1 \rightarrow PT, P_2 \rightarrow PT$	–	air
6	pig trap reactivated	–	–	–
7	pig run	$P_1 \rightarrow LS, P_2 \rightarrow LS$	–	air
8	initial position	$P_1=LS, P_2=LS$	air	–

* P=pig, LS=launching station, RS=receiving station, PT=pig trap
 =: resting position, $\rightarrow$: pig run to

The product valve closes, and the pig trap at B2 is set (phase 2). The two pigs travel to the pig trap and push the product out of the pigging line into tank B2 (phase 3). The pig trap is retracted and the two pigs travel together to the left station LS (phase 4). Subsequently, the pigging line is pressure-relieved.

II
Components

3

Pigs

3.1

Pigs for Industrial Pigging Units

The term pigging has its origin in the oil industry, where pipelines were cleaned with metal devices, whereby a screaming noise resulted from the friction of the metal surfaces, reminiscent of squealing pigs. Moreover, after passage through an oil pipeline these devices were highly soiled and looked like dirty pigs, too. Thus, the term pig resulted.

In English, the terms scraper, swabber or go-devil are also common. In German, the pig is called “Molch”, the French term is “picage” or “racleur”.

3.1.1

Function

Pigs are devices which are inserted into and travel through a pipeline, driven by a liquid or gaseous propellant. The pig slides on a thin liquid film, (micrometer range) and cleans thereby the pipeline by means of two or more narrow lips. The pig is thicker than the inside diameter of the pipe and is pressed into the pipeline. The resulting strain, which depends on the diameter and type of pig, is ca. 3 % and prevents aquaplaning. Thus a high degree of cleanliness is ensured. Pigs with lips also ensure tightness in pipe bends and in piggable T-pieces. The length to diameter ratio L/D (Tab. 3–1) plays an important role in the running stability of the pig in the pipe. A permanent magnet can be integrated in the pig to allow for its detection. Section 8.1.2 discusses permanent magnets and sensors.

3.1.2

Fields of Application

Depending on shape and material pigs can be used in the oil industry, colorants industry, chemical industry, cosmetics industry (e.g., skin cream), food industry (e.g., chocolate, beverages), pharmaceutical industry, etc.

Pigs are used for emptying pipes, e.g., to remove valuable product, for separating different products of a product family from products that are compatible with one

Table 3–1. Length to diameter ratio of several pigs.

Company	Pig type	L/D ratio
Kiesel	one-piece pigs	1.2
I.S.T.	solid cast pigs	1.16–1.3
Pfeiffer		1.15–1.2
Kiesel	multi-piece pigs	1.25–1.3
I.S.T.	pigs with replaceable lips	1.16–1.3
Pfeiffer		1.15–1.2
I.S.T.	cleaning pigs	1.4
Kiesel	pigs for hygienic applications	1.25–1.3
I.S.T.		1.16–1.3
Pfeiffer		1.15–1.2
Tuchenhagen		1.0–2.0

another, between product and propellant, and for cleaning pipes in which deposits have formed. Pigs are also used for cutting off product flow in valves.

For bubble-free filling of containers, tank trucks, and rail tanks two pigs are frequently used in tandem operation, i.e., the product is fed between the two pigs.

Pigs for the cosmetic, pharmaceutical, and food and beverage industries must meet hygiene requirements and must be certified. They must be heat resistant and are produced, e.g., from rubber or polyurethane. For sterile technology industrial pigging units with CIP (cleaning in place) and SIP (sterilisation in place) technology are available. The pig and pig stations can be cleaned and/or sterilized in-place (see Chap. 16).

3.2

Materials Selection

The different chemical and physical characteristics of piggable products crucially affect the choice of materials for pigs. The chemical resistance of pig materials is indicated in the Appendix. The data are derived from test results, recommendations of chemical suppliers, and user experience. Nevertheless, they serve only for orientation and are not applicable to all operating conditions. In case of doubt and with newly established applications, the chemical resistance of the selected pig material must be determined by special tests (see Section 3.2.2).

The correct selection of pig materials requires knowledge of the fundamental groups of materials, for example:

- Rubber is a non-crossed-linked but cross-linkable (vulcanizable) polymer, which can be transformed by vulcanization into the rubber-elastic state. Natural and synthetic rubbers are available.
- Elastomers are cross-linked polymers with rubber-elastic properties.
- Thermoplastics are cross-linked polymers that can be deformed under the influence of pressure and temperature.
- Thermosets are cross-linked polymers with very low deformability.

The most important structural features of the polymer materials are described in DIN 7724.

3.2.1

Pig Materials

Depending on the application different pig materials are used. If no suitable pig material is found, then an industrial pigging unit must be dispensed with. The most frequently used materials for pigs are elastomers, as defined in DIN 7724. Table 3–2 compares the properties of some elastomers. Chemical designations, abbreviations according to ASTM, ISO, and DIN, and some common trade names are listed in Tab. 3–3.

Commercial pigs are often made of cast polyurethane (PU, e.g., Vulkollan) or PU foam (e.g., Vulkocell). These materials are preferred over elastomers such as NBR, SBR (Viton), EPDM, EVO, and natural rubber because of their better wear characteristics. Pigs made completely of PTFE cannot be used due to their poor elasticity values. However, coating of a flexible pig body with PTFE is possible.

The materials preferred by manufacturers for the production of pig bodies and lips for pigs with replaceable lips are listed in Tab. 3–8 and 3–9.

Since only users have knowledge about the product which has to be pigged, the pig material must also be specified by the user. The Appendix gives an overview of possible resistant materials prior to testing.

3.2.2

Tests for the Selection of Pig Materials

The action of products and/or propellants on pig materials can lead to physical and chemical reactions. The results of physical processes are revealed by changes in weight, volume, and dimensions, and the influence of chemical reactions by changes in hardness, ultimate tensile strength, and fracture strain.

Preparation

Known data are recorded in the data sheet. Then the duration of the test is specified. This should be carried out with the user and in accordance with the planned application of the pig. The duration should not be less than the residence time of the pig in

Table 3–2. Comparison of properties of some elastomers (Freudenberg, Weinheim, Germany)

Material designation	Shore hardness A	Density g/cm ³	Tensile strength N/mm ²	Stress value 100 N/mm ²	Elongation at break in %	Compression sets 22h/100 °C in %	Compression sets 70h/100 °C in %	Transition temperature T _g in °C	Comments
Acrylonitrile-Butadiene-Rubber (NBR)									
Material for use in air, mineral oils, water, animal or vegetable oils and greases									
70 NBR 888	69	1,20	15,2	4,5	280	18		– 49	Mixtures, flexible i. t. cold and resist. to abrasion in m. used in pressurised air brake systems of heavy goods vehicles
60 NBR 181	60	1,14	12,5	2,1	460	20	25	– 15	Blend is free of softening agent with good DVR (compression set)
50 NBR 253	50	1,12	14,2	1,2	580	25		– 43	Standard material for long-stroke rolling diaphragms
50 NBR 254	51	1,12	12,2	1,4	480	25		– 51	Material especially flexible in the cold for pressure-resistant diaphragms
75 NBR 168350	75	1,20	9,5	5,8	150	36		– 22	Use in contact with foodstuffs possible = FDA registered
70 NBR 150	70	1,16	18,1	4,9	260	12		– 15	Use in drinking water permitted according to DVGW, KTW and WRC
High-Acrylonitril content NBR-Materials									
50 NBR 842	52	1,13	18,4	1,4	660	26		– 17	Special m. for pressurised accumulators
50 NBR 153750	51	1,12	14,6	1,5	480	25		– 18	Blend for use in town gas and natural gas
60 NBR 185695	60	1,18	25,4	1,3	650	30		– 18	Special gas-tight NBR m. with high mechan. resistance for pressurised accumulator diaphragm in the motor vehicle hydraulics industry
Hydrogenated Acrylonitrile-Butadiene-Rubber Materials									
Materials with operating temperature to +140 °C									
70 HNBR 150531	70	1,18	22,5	6,8	312	19 (at 22h/125°)		– 18	Standard material for pump diaphragms with high dynamic loadability
75 HNBR 181070	75	1,18	19,0	3,4	418	20 (at 22h/125°)		– 18	Use in contact with foodstuffs possible = FDA registered
Ethylen-Propylen-Dien-Kautschuk (EPDM)									
Material for use in hot water, steam up to 140 °C, acids, lyes and brake fluids; not resistant to mineral oil									
70 EPDM 281	71	1,10	16,7	6,0	215	10	16	– 42	Drinking water use with KTW, WRC and NSF clearance
60 EPDM 280	62	1,06	15,8	2,9	320	11	15	– 43	Drinking water use with KTW and WRC clearance
60 EPDM 266	58	1,05	11,5	2,0	500	39	49	– 40	For use in rolling diaphragms and in long-stroke rolling diaphragms. For use in heated water and brake fluid

Material designation	Shore hardness A	Density g/cm ³	Tensile strength N/mm ²	Stress value 100 N/mm ²	Elongation at break in %	Compression sets 22h/100 °C in %	Compression sets 70h/100 °C in %	Transition temperature T _g in °C	Comments
75 EPDM 168348	76	1,13	11,8	11,2	115	15		- 42	Use in contact with foodstuffs possible = FDA registered
Chlorobutadiene-Rubber (CR)									
Ageing resistant, can take highly dynamic loads, limited resistance to mineral oils									
50 CR 879	52	1,35	13,5	2,3	500	25	40	- 43	Good ageing and ozone resistance
Fluoro-rubber (FPM) highly thermal and chemical stressable, resistant to fuels									
65 FPM 178975	62	1,84	10,6	3,1	300	20 (at 22h/175°)		- 7	Application in fuel-resistant systems
75 FPM 153740	75	1,83	15,8	-	160	19 (at 22h/175°)		- 7	Standard material constant operating temperature up to 230°C
75 FPM 180497	76	2,06	16,0	8,4	181	18 (at 22h/175°)		- 7	Use in contact with foodstuffs = FDA registered
Perfluoro-Rubber (FFPM) highly thermal and chemical resistant material									
70 FFPM 151400	70	2,03	14,1	5,3	200	20 (at 22h/175°)		- 12	Applications in the chem. industry, with constantly changing media, almost universal media resistance
Butyl- and Chloro-butyl Rubber (IIR/CIIR), gas-tight materials									
62 IIR 869	61	1,24	8,8	2,0	580	50			Standard material for general use
60 CIIR 172153	59	1,18	10,5	2,3	366	25		- 34	Especially gas-tight, material for pressurised accumulator materials in the motor vehicle industry
Epichlorohydrin Rubber (ECO)									
64 ECO 150777	62	1,60	12,5	2,9	680	28	33	- 32	Gas-tight, flexible in cold and mineral material for pressurised accumulator material in the motor vehicle industry
Silicone Rubber (VMQ) for applications of -50 °C up to + 220 °C									
58 VMQ 518	58	1,19	8,9	1,5	490	18 (at 22h/175°)		- 40	For long-stroke rolling diaphragms
60 VMQ 571	60	1,19	9,0	2,2	450	26 (at 22h/175°)		- 42	Special material for general applications, particularly tensile impact resistant mixture
50 VMQ 78599	50	1,18	8,0	1,1	550	18 (at 22h/175°)		- 41	Use in contact with foodstuffs possible = FDA guidelines and BgVV
Fluoro-Silicone Rubber (FVMQ) for applications from -65 °C up to 200 °C, mineral oil resistant									
60 FVMQ 565	63	1,48	8,5	3,1	270	23 (at 22h/175°)		- 66	Broad application specification with fuel contact. The large temperature field brings possibilities in space travel

Table 3 Elastomers for diaphragms

Note: The given values are based on a limited number of tests on normal test-bodies (2 mm sample plates) from laboratory production. Determined data on finished parts can vary from above values depending on the production process and geometry of item.

Table 3–3. Basis polymers, chemical designation, abbreviations according to standards, trade name

Chemical designation	Abbreviations according to standard			Trade name
	ASTM D 1418-72a	ISO R 1629	DIN 3760	
Acrylonitrile-Butadiene-Rubber	NBR	NBR	NB	Perbunan, Hycar, Chemigum, Breon, Butakon, Europrene N, Elaprim, Butacril, Krynac, JSR-N
Acrylate-Rubber	ACM	ACM	AC	Neoprene, Baypren, Butachlor, Denka Chloroprene
Silicon-Rubber	VMQ	MPQ	SI	Cyanacryl, Hycar, Thiacril, Krynac, Elaprim Ar
Fluoro-Rubber	FPM	PFM	FP	Viton, Fluorel, Tecnoflon
Polyurethane	AU	AU	–	Vulkollan, Urepan, Desmopan
Polyether-Urethane	EU	EU	–	Adipren, Estane, Elastothane
Ethyleneoxid-Epichlorhydrine-Rubber	ECO	ECO		Herclor H und C, Hydrin 100 und 200
Styrene-Butadiene-Rubber	SBR	SBR	–	Buna Hüls, Europrene, ACRC, Krylene, Cariflex, Solprene, Philprene
Ethylene-Propylene-Diene-Rubber	EPDM	EPDM	–	Dutral, Keltan, Vistalon, Nordel, Epsyn, Buna AP
Butyl-Rubber	IIR	IIR	–	Bucar, Enjay Butyl, Petro-Tex Butyl, Polysarbutyl
ASTM = American Society for Testing and Materials				
ISO = International Organization for Standardization				
DIN = Deutsches Institut für Normung e.V.				

the product. The test temperature must correspond to the actual operating conditions. Test specimens are stored for three hours at $23 \pm 2^\circ\text{C}$ to ensure that they have the same temperature.

Execution

Testing is based on the German standard DIN 5321 for rubber and elastomers. (Determination of the Behaviour towards Liquids, Vapors, and Gases). They are performed on DIN standard test bars S2 (DIN 53502).

To determine the suitability of pig materials, the following measurements are made before and after the resistance test:

- Linear dimensions
- Mass
- Shore (A) hardness
- Ultimate tensile strength

Since determination of the ultimate tensile strength is a destructive method, two sample sets are required. The first set is used for determining values 1–3 and is then contacted with the product. After the test period tests 1–4 are performed on sample set 1. Sample set 2 is exclusively used for determining the ultimate tensile strength before product contact.

The testing equipment must consist of materials which are resistant to the product and do not have any catalytic effects (e.g., Cu content). The storage vessels must be sealable to prevent evaporation and atmosphere exchange.

The volume of testing agent (product) should be at least 15 and preferably 80 times the test specimen (pig) volume. The testing agent must cover the test specimen on all sides with a layer at least 20 mm thick.

Preferred testing times are 22 ± 0.25 h, 70 ± 2 h, $7 \text{ d} \pm 2$ h, or a multiple of 7 days.

During the test procedure the test specimens and agents are examined visually on a regular basis. Criteria are color changes, undulations, cracks, and bubbles. The test agent is checked for discoloration, turbidity, and sediment formation.

Sampling

The property whose dependence on the action of the test agent is to be determined is measured before contact, directly after contact, and if necessary after a subsequent drying process. Cleaning, drying, and measurement of the test specimen must take place directly after withdrawal from the agent.

Change in Properties

For the hardness the absolute change in the initial value is indicated. For other properties such as dimensions, mass, and ultimate tensile strength, the relative change is indicated in per cent relative to the initial value.

$$X_a = \frac{L - L_0}{L_0} \cdot 100 \%$$

X_a = relative change of property [%]

L_0 = Initial condition [mm; g; MPa]

L = final state [mm; g; MPa]

The accuracy of the determined mass and weights should be equal or better than 0.1 mm or 0.1 g.

Hardness

Hardness is determined according to DIN 53505. Although the test specimens do not fulfil the dimensional requirements of the standard, they can still be used since a qualitative result is sufficient for evaluating the material. The thickness of the sample should be >6 mm. To attain this thickness a maximum of three specimens can be arranged in layers.

DIN 53505 is not applicable to hardness measurements on foamed materials (AU). Since, however, for the evaluation of the resistance of pig materials only the change in hardness is of interest, a comparative measurement can be made. It must, however, always be measured at the same marked position. The measured value is of importance, since chemical attack takes place at the surface of the materials and alters the constitution there. It results in softening or hardening of the outer zone.

Ultimate Tensile Strength

The ultimate tensile strength is determined according to DIN 53504. If a tensile testing device is not available the test can be simplified by applying and measuring the required force with a spring balance (up to ca. 1000 N). The required forces can be expected to lie between 50 and 500 N.

Test Report

All determined data are entered in a test report (see Tab. 3–4)

- Type, designation and delivery form of the test specimens.
- Shape and dimensions.
- Position of the test specimen in the product.
- Test temperature.
- Test duration.
- Rinsing liquid and conditions.
- Drying process and conditions for reconditioning.
- Visible outer changes of the test specimens and the test agent.
- If necessary, investigation of the test agent after the test.
- Characteristic properties of the test specimens before and after contact with the test agent.
- If necessary, depiction of the temporal dependence of the change in a property.
- Test date.
- Name of the tester.

Analysis

In order to analyze the results, the error of the measurements must be known. The length measurement of elastomers is inaccurate, so an error of 0.5 % is acceptable (DIN 7715 T2 M2).

Table 3–4. Test report form for pig material testing.

Worker (name)			
Customer			
Product			
<i>Material and test specimens:</i>			
designation	number		
<i>Piece of test equipment:</i>	test specimens: standard test bars S2 / others		
testing agent	start of test (date)		
duration	test temperature		
drying conditions	volume ratio of test specimen to check agent		
<i>Test results:</i>			
Initial condition		after action	
characteristic value	characteristic value	change relative to initial condition [%]	change relative to initial condition [%]
Change in mass	[g, %]		
Change in linear dimensions	[mm, %]		
Hardness	[Shore A]		
Tensile strength	[MPa]		
Tensile strain	[%]		
Remarks:			
Date:	The material is not /limited/suitable		
	Inspected:		

Given careful sample preparation, weighing depends only on the accuracy of the balance and is therefore the most exact measurement (usually ± 1 N).

The hardness measurement is quite inaccurate. DIN 53505 specifies a repetition accuracy of 2 Shore for a given tester and measuring instrument, and 3 Shore for two examiners and two measuring instruments. A deviation of 5 Shore is permissible.

The ultimate tensile strength depends strongly on the structure and processing of the test specimen. Furthermore, the fact that different test specimens are measured makes deviations of 10–20 % possible. However, since the hardness test only makes comparative statements, this can be tolerated.

Evaluation

A pig material is suitable for a product if their mutual contact results in no change in the measured properties. Any small change in the properties of the material limits its applicability for a certain product. However, the changes must be seen in connection with the operating mode of the pig and the duration of contact with the product.

In the case of a large change the materials is unsuitable. The following values can be regarded as large changes:

- Swelling (linear expansion) $\pm 2 \%$
- Weight change after drying $\pm 2 \%$
- Hardness fluctuations ± 15 Shore
- Change in the ultimate tensile strength $\pm 20 \%$

These values are only guidelines, since in different plants or with other modes of pig travel, values which deviate strongly from the above-mentioned, may become acceptable.

3.2.3

Shear Strength of the Pig Material

An estimate is to be made of the velocity required to drive a core magnet out from the inside of a pig by shearing forces when the moving pig is suddenly brought to a standstill. The calculation assumed collision with a barrier with a circular impact zone, a solid cast pig made of polyurethane, and a core magnet with a mass of $m_M = 160$ g (see Fig. 3–1):

Pig length:	L
Cut section length:	$l_S = L/2$
Shear thickness:	$s = l_S - l_M/2$
Tensile strength:	$R_m = 30 \text{ N/mm}^2$
Magnet diameter:	d_M
Magnet length:	L_m

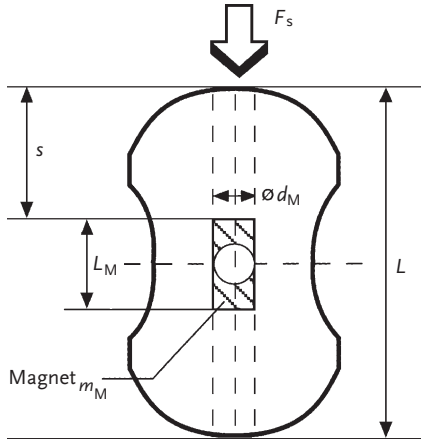


Fig. 3-1. Dimensions of a pig with a core magnet.

The maximum shear force is calculated as:

$$F_{s \max} = A_s \cdot k_s = (l_s \cdot s) \cdot 0.8 \cdot R_m$$

The resulting energy can be estimated by a integration.

$$W = \int_0^{l_s} F_s dx \approx \frac{2}{3} \cdot F_{s \max} \cdot l_s$$

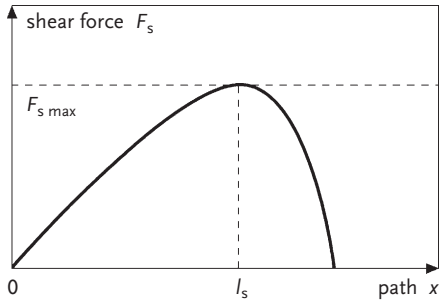


Fig. 3-2. Force-path curve for the determination of the shear force.

$$\frac{1}{2} m_M \cdot c_{\text{scher}}^2 = \frac{2}{3} F_{s \max} \cdot l_s + \frac{1}{2} \cdot s_1 \cdot \frac{\pi \cdot D^2}{L} \cdot \sigma_{\text{zul}}$$

The kinetic energy of the pig is converted on impact with an obstacle into shear energy and stored elastic energy; the frictional heat is neglected.

$$\rightarrow c_{\text{scher}} = \sqrt{\frac{4}{3} F_{s \max} \cdot \frac{l_s}{m_M} + \frac{s_1}{m_M} \cdot \frac{\pi \cdot D^2}{4} \cdot \sigma_{\text{zul}}}$$

Here the tolerable compression s_1 is 50 % of the distance s between the pig head and the magnet.

The material parameters of the pig materials under shear stress should be $R_m = 30 \text{ Nmm}^{-2}$ and $\sigma_{\text{tol}} = 1.5 \text{ Nmm}^{-2}$.

Table 3–5. Permissible speed for pigs without shearing out of the core magnet.

DN	D [mm]	d_M [mm]	m_M [kg]	L_M [mm]	L [mm]	l_s [mm]	s [mm]	s_1 [mm]	$F_{s \text{ max}}$ [N]	c_{shear} [m·s ⁻¹]
50	55.1	25	0.16	40	71	35.5	15.5	7.8	13 206	64
80	82.5	35	0.42	55	103	51.5	24	12	29 664	71
100	102.1	35	0.54	70	126	63	28	14	42 336	83
150	158.3	35	0.66	85	185	92.5	50	25	111 000	148

with	D	inside diameter of the pipe
	d_M	diameter of the core magnet
	m_M	mass of the core magnet
	L_M	length of the core magnet
	L	length of the pig
	l_s	cut section
	s	shear length
	s_1	50 % of s
	$F_{s \text{ max}}$	maximum shear force
	c_{shear}	shear speed

The thus determined critical speeds of the pig for the shearing stability of the installed core magnet (Tab. 3–5) shows that the dimensions of the pig material are the crucial criterion. In practice, sharp edges on piggable valves are to be avoided, since otherwise substantially lower speeds may become sufficient for breaking out the core magnet.

3.2.4

Deformation of a Solid Cast Pig under Pressure

Most pigs are equipped with two or more sealing lips, which have a sealing effect because of the prestressing of the pig due to its oversize relative to the pipe and thus also ensure the desired cleaning effect.

The distance between the sealing lips relative to the inside diameter of the tubing is decisive for running stability, and length to diameter ratios greater than unity prevent tilting or a rotation of the pig in the pipe, in contrast to spherical pigs.

Tilting of the pig leads to an undesirable position in the pipe and thus has an unfavorable influence on the cleaning effect. This is a particular risk in pipe bends, when the L/D ratio is close to unity. Since most pigs are made of flexible materials,

another tilting mechanism is possible, even for L/D ratios > 1 . With increasing pressure on one or both front surfaces of the pig, the material becomes elastically compressed. If the pressure becomes large enough, compression can occur up to an L/D ratio of unity. A test series investigated how high the propellant pressure on the pig must be to compress the material to $L/D=1$, three pigs of different design and shape were inserted into a pipe section and a load F was applied by a plunger via a pressure ring adapted to the shape of the pig.

The load-compression curves were plotted up to $L/D=1$ to give the maximum force and, by using the surface area, the associated pressure. The test revealed material-dependent results, (Fig. 3–3, Tab. 3–6). All pigs were of nominal diameter 2" (DN 50).

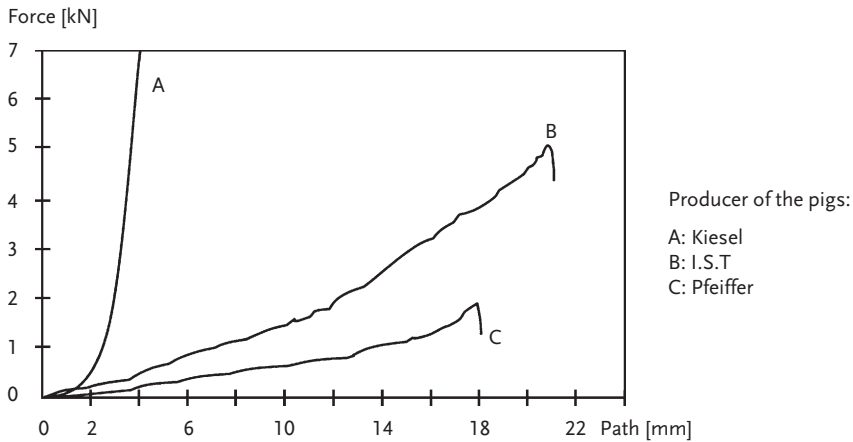


Fig. 3–3. Compression-force curves.

Table 3–6. Results of the deformation tests.

Company	Pig length [mm]	Deformation up to $L/D = 1$ [mm]	Maximum force [N]	Tilting pressure [bar]
I.S.T.	71	21	6100	42
Pfeiffer	68	18	1850	13
Kiesel	79	29	–	–

The materials are to be regarded as linearly elastic, but this does not affect the necessary maximum force. Since the pigs were of different lengths, the forces and compressions up to $L/D=1$ are also different. After achieving the maximum value the test was stopped, so that here the value for the strength can be read from the diagram. With the Kiesel pig the value $L/D=1$ could not be achieved, since its multi-

component construction does not permit the necessary deformation. Only the sealing lips are compressible, but only to a small degree. This pig design therefore prevents tilting in the pipe.

Table 3–7 also lists the corresponding calculated tilting pressure on the pig which is required to achieve $L/D=1$. For this maximum strength was referred to the plate area of the piston plunger.

The difference clearly shows the effect of the material. Although the base material has the same chemical structure, the two pigs behave differently due to their different Shore hardnesses. This depends largely the fraction of pores in the polymerized plastic. Since the propellant pressure, especially in gas-driven units, is clearly under the calculated tilting pressure (Tab. 3–7), there must be another reason for tilting. This results from the kinetic energy of the moving pig. If the pig is abruptly decelerated by an obstacle or by the stick/slip effect (Section 7.1.1) the kinetic energy is converted over a very short distance to a force, which compresses the pig material. Thus, the pig is strongly distorted in the longitudinal direction. If one takes the deformation up to $L/D=1$, the required speed for tilting the pig is obtained if the mass of the pig is known.

Table 3–7. Required tilting speeds.

Company	Tilting pressure [bar]	Pig mass [g]	Tilting speed [m/s]
I.S.T.	42	97	66
Pfeiffer	13	91	35

For the Pfeiffer and I.S.T. solid cast pigs the speeds are listed in Tab. 3–7. As shown in Section 7.1.1 these speeds lie in the range of the expected maximum speeds due to the stick/slip effect. Possible remedies are restriction of the exhaust air outlet or a change in the pig material. Information on the required resistance of the material to deformation by its intrinsic kinetic energy can only be obtained in a compression test.

3.3

Pig Designs

A clear allocation of a pig design to a given application is not possible, since there are areas of overlap between the applications.

The appropriate choice of the pigging system and pigs plays a substantial role in the trouble-free operation of the pigging procedure and the attainable degree of cleaning.

Spherical pigs, solid cast pigs, lipped pigs, cylindrical pigs, pigs with replaceable lips, conical seal pigs, and various specialty pigs are available. Depending on required degree of cleaning, the pipe size, and the system pressure, a suitable pig design is selected.

A distinction can be made between one-piece and multicomponent (mandrel) pigs. In one-piece pigs the main body and the cleaning lips form a single unit, while the multicomponent pigs consist of a central body which can be equipped with various components.

3.3.1

One-Piece Pigs

Spherical Pigs

The spherical pig is the simplest of all pigs. It can turn in the pipeline to be cleaned and driven in any direction. It is not worthwhile enclosing a permanent magnet inside the pig, since its changing orientation during movement prevents optimal alignment of the magnetic field for detection.

There are solid, inflatable, and fillable spherical pigs. They can be filled, among others, with air or a glycol/water mixture. The seamless body of the pig is made of thick-walled polyurethane elastomer and is equipped with one or two back-pressure valves. The valves have the role of maintaining the pressure and emptying the pig. Spherical pigs have above average physical and chemical resistance properties. Spherical pigs made of polyurethane or sponge rubber are used for filling, emptying, separation, drying, and for cleaning and removing different media in pipeline transport (see Chap. 17). They are resistant against gasoline, aromatics, oil, methanol, and water.

Solid spherical pigs are available in sizes of 1.5" to 8", and inflatable pigs in sizes of 3" to 36".

Solid Cast Pigs

Solid cast pigs are among the most frequently used one-piece pigs and were developed from the spherical pigs. Solid cast pigs are standard pigs which meet most requirements for pigging procedures. They are very durable, and have two solid, inflexible lips that clean the pipe. Solid cast pigs are pressed with a pre-stress into the pipe and can be driven bidirectionally. The permissible oversize of the pig lip outside diameter relative to the pipe inside diameter is discussed in Chap. 11. Solid cast pigs, which are available in many material variations (see Tab. 3–8), can achieve prolonged service lives. Polyurethane has the best mechanical properties. Solid cast pigs are offered for nominal pipe diameters of 3/8, 1, 2, 3, and 4 to 6" (DN 10, 25, 50, 80, and 100 to 150 mm). A well known solid cast pig is the I.S.T. DUO-Pig (Fig. 3–4).

The Pfeiffer solid cast pigs are divided in two groups:

- TWIN Type 1 (Fig. 3–5) for high running performance, and
- TWIN Type 2 (Fig. 3–6) for high wiping-off performance.

The pigs are manufactured as solid elastomer bodies with two sealing lips and a pronounced waist. Some of the magnetic designs are manufactured by means of a powder filling (barium ferrite); hence, there is no danger that the permanent magnet can break out of the elastomer body.

Table 3-8. Materials for solid cast pigs.

Company	Pig type	Diameter range [inch]	Material	Hardness [Shore A]	Magnet	Powder filling	Temperature range [°C]
I.S.T.	Duo-Pig	2"-8"	Auzell	550 kg/m ³ **	×	-	+5 to +80
			Vulkollan				
		2"-4"	Vulkozell				
			VMQ red/white *	45 ± 5	×	-	-20 to +230
			NBR black	50 ± 5	×	-	-20 to +120
			NBR-L. light *	45 ± 5	×	-	
			EPDM black	45 ± 5	×	-	-20 to +150
			EPDM-L light *	65 ± 5	×	-	
			NR-L, sand *	50 ± 5	×	-	-20 to + 90
			FKM black	60 ± 5	×	-	-20 to +260
Kiesel	Cylindrical Pig	1/4"-5"	FKM light	60 ± 5	×	-	
			CR black	45 ± 5	×	-	-20 to +110
			Silicon blue *		×	-	-40 to +186
			HNBR black		×	-	-25 to +150
			HNBR white *		×	-	-25 to +150
			FPM (Viton)		×	-	-20 to +240
Pfeiffer	Pig TWIN Type 1	2"-4"	VMQ	≈50	×	×	-20 to +180
			PU	450 kg/m ³ **	×	-	0 to +80
	Pig TWIN Type 2	2"-3"	VMQ	50	×	×	-20 to +200
			EPDM	50	×	×	-20 to +150
			FKM	≈70	×	-	-20 to +200
			others on request				
		2"					

All pigs are available without magnet
* These materials are on recommendation of BGA (Bundesgesundheitsamt) for food stuff industry
** Specific weight, because the hardness is not unambiguously determinable

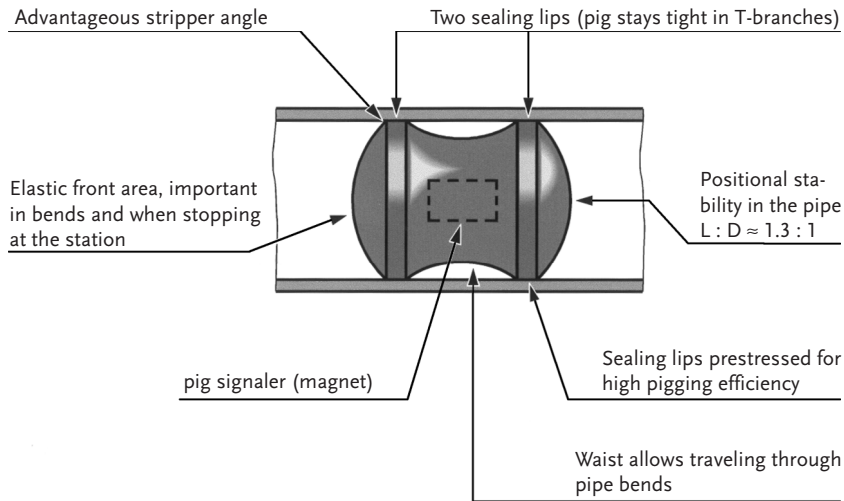


Fig. 3-4. I.S.T. DUO-Pig

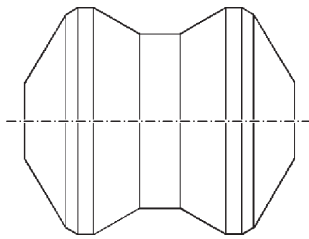


Fig. 3-5. Pig, TWIN Type 1 (Pfeiffer, Kempen, Germany)

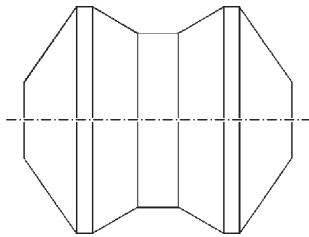


Fig. 3-6. Pig, TWIN Type 2 (Pfeiffer, Kempen, Germany)

The Kiesel cylindrical pig (Fig. 3-7) possesses all positive characteristics of a solid cast pig, and in addition a plastic-bonded magnetic disk can be vulcanised in situ in its interior.

The cleaning effect of the cylindrical pig is good to moderate, depending on the viscosity of the product. The oversize, depending on application and nominal size, is 0.5–2 mm. Since it is cleanable in place (CIP), its main field of application is the food industry, as well as the cosmetic and the chemical industries.

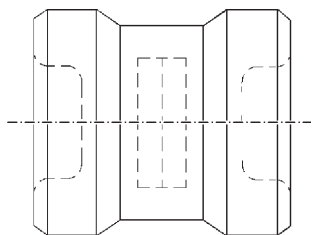


Fig. 3-7. Kiesel cylindrical pig

Lip Pigs

The lip pigs are also one-piece pigs, which were developed from a standard pig. They mostly have two durable guidance lips and two moveable sealing lips. The outer pair of lips is responsible for guiding the pig in the pipe, and the inner pair has the functions of cleaning and sealing (Fig. 3-8 and 3-9). One variation of the lip pig (Fig. 3-10) possesses two pairs of bevelled lips with different diameters. The lips are connected by bars. In a straight pipe only the outer lips are in contact with the surface and act as sealing rings, which strip off the product. The bevelled running surfaces are intended to prevent aquaplaning. The inner lips have a smaller oversize relative to the pipe diameter and hence little wear. The friction losses are negligible,

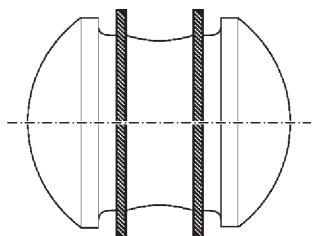


Fig. 3-8. I.S.T. lip pig

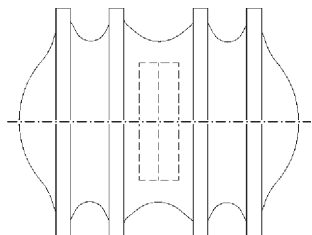


Fig. 3-9. Kiesel compact lip pig

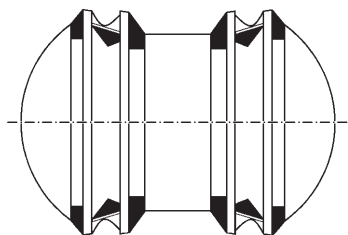


Fig. 3-10. ABK lip pig

so that increased propellant pressure is not required. The major task of the inner lips is sealing in pipe bends. In a curve, the internal lips lie on the pipe wall, while the outer, circular lips are no longer perpendicular to the pipe axis and thus present ellipses in projection. Depending on the wear of the lips a sickle-shaped gap can arise between the lips and the wall, particularly on the inner side of the pipe bend.

3.3.2

Multicomponent Pigs

Pigs with Replaceable Lips

Replaceable-lip pigs have a solid body made of plastic or metal and two replaceable flexible lips (Fig. 3–11). After replacing defective lips the body of the pig can be reused.

The larger the pipe, the more economical is the application of a pig with replaceable lips. Some suitable lip and body materials, are listed in Tab. 3–9. Complete chemical resistance of the lips is not necessary in all applications, since replacement of the lips is relatively cheap. The Pfeiffer TWIN 3 pig (Fig. 3–12) is highly resistant to solvents and other aggressive media. Numerous material combinations for the body and lips are possible.

Pigs with replaceable lips require specially designed pigging systems. A gas–pig–gas driving mode should be avoided or sufficient back-pressure must always be present, so that the driving speed is not too high and can always be kept under control. The differential pressure is to be kept as low as possible. Pigs with replaceable lips can also be used at higher system pressures. The dimensions of the propellant supply system should be sufficiently large that it does not come to stick/slip movement of the pig, which can lead to system and pig damage (see Section 7.1.1). It is advisable to equip such a system whenever possible with automatic control. The pipes should be made of high-quality stainless steel (average roughness 2–5 μm).

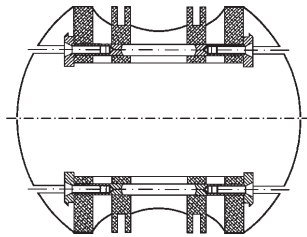


Fig. 3–11. Replaceable-lip pig (I.S.T., Hamburg, Germany)

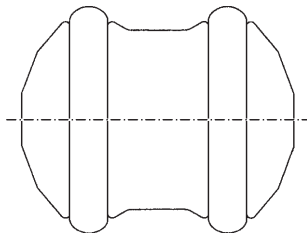


Fig. 3–12. Twin 3 replaceable-lip pig (Pfeiffer, Kempen, Germany)

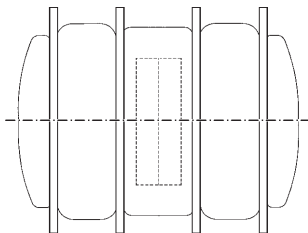


Fig. 3-13. Replaceable-lip pig
(Kiesel, Heilbronn, Germany)

Table 3-9. Material combinations for replaceable-lip pigs.

Company	Body material	Lip material	Diameter range [inch]	Remarks
I.S.T.	PVDE, PP	AU	2"-8"	fastening elements covered
Pfeiffer	PTFE / TFM	NBR, EPDM, VMQ, FPM	2"-4"	lip foot constrained
	RCK 1000	TFM / Silicone - rubber RCH/Silicone - rubber		special pig needs high quality of piping
Kiesel	stainless steel 1.4571 Titanium supporting body POM-Delrin PTFE Auzell	AU-Vulkollan CR-Neoprene NBR-Perbunan	1½"-6"	synthetic boundet support body adjustable optimal cleaning

Solid Lip Pig

The solid lip pig (Fig. 3-14) is a further development of the lip pig. The solid body of the pig is manufactured from a chemically resistant material such as plastic or metal. Inside the solid pigs a permanent magnet can be accommodated. The replaceable lips are exchanged with a special tool. The pre-stressed lips are located in a groove in the solid body of the pig. The pig is guided in the pipe by the two solid lips of the body of the pig. The two replaceable lips are responsible for cleaning. This kind of pig is used with aggressive and abrasive media.

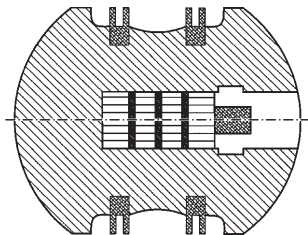


Fig. 3-14. Solid lip pig (I.S.T., Hamburg, Germany)

Conical Seal Pig

Conical or cup seal pigs (Fig. 3–15) consist of a solid or flexible body which can be equipped with several seals depending on the task. The conical seal pig can travel only in one direction. Several pigs are collected at a receiving station, removed, and then returned to the launching station. The seals of the pig are bolted to the body of the pig. At least two, but often also four, seals are used per pig. Depending on the application and shape the seals are made from flexible, abrasion-resistant polyurethane or special polyester/polyurethane mixtures.

Most conical seal pigs are available with outside diameters from 2" to 60". The main fields of application for the conical seal pigs are the petrochemical (see Chap. 17) and the chemical industries. Further branches are the food and beverage industry.

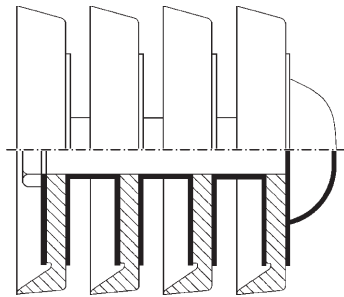


Fig. 3–15. Conical seal pig

3.3.3

Special Pigs

Pigs for Hygienic Applications

Pigs for sterile areas (e.g., Fig. 3–16) must be manufactured of product-compatible, wear-resistant, flexible, and temperature-resistant material. Their shape must permit above all a safe cleaning of the total surface in situ. The surface must be smooth and free of pores. Of course, they must also have the properties required for pigging processing plants. These include dimensional stability and a shape that permits optimal driving through pipe bends and T-pieces. For detection, one or two permanent magnets are incorporated.

Silicone is the material used most frequently in sterile areas. VMQ, NBR-L, EPDM-L, and NR-L are also permitted in the foodstuff sector. Pigs for sterile areas are offered by all major suppliers of pigging units. For further information, see Chap. 16.



Fig. 3–16. TWIN-sphere pig
(Tuchenhagen, Büchen, Germany)

Cleaning Pigs

These pigs are required mainly in the petrochemical industry (see. Chap. 17) for drying and removing lighter deposits before start up of new pipes. For removing harder deposits, silicon carbide strips (see. Section 17.3) or hardened wire brushes are attached to the pig. The company I.S.T. offers nozzle pigs, brush pigs, or a combination thereof for the removal of residues from pipes.

Brush pigs are used for the cleaning of pipes with hardened product residues on their inner walls. Brush pigs contain no permanent magnet, and detection with commercial pigs sensors is not possible.

Brush pigs can travel only in one direction, exclusively in piggable pipes at low speed (max. 1 m/s), preferably driven by a liquid.

For further information about special pigs for pneumatic conveyor lines see Chapter 18.

3.4

Fabrication of Pigs

Because of the required abrasion resistance towards the sometimes rough inner surfaces of pipes, elastomer materials for pigs should combine high mechanical elasticity and resistance to the medium to be pigged. The most frequently used pig materials are noncellular (e.g., Baytec) and cellular polyester polyurethanes (e.g., Vulkollan). In pig production, materials of both groups are cast, and polymerization takes place in the mold. To achieve maximum properties, accurate dosing of the individual

components and heat treatment are required. Magnets are mounted in the center of the mold by a holding device. The elastomer mixture, which totally encloses the magnet, is molded in paste form in an electrically heated steel mold and cross-linked under high pressure at temperatures between 150 and 200 °C. Because of the sometimes large volumes of the pigs, a long cross-linking time may be required. For certain materials further cross-linking in hot air for up to 24 h is required for the pig to achieve its optimal material properties.

The finished pig is removed from the mold. Only a small hole remains in the pig, caused by the magnet holder. This is plugged with an elastomer after finishing.

3.5

Quality Assurance

Each pig has a technical sheet, which is filled out by the supplier and confirmed by his signature. Each pig receives an unmistakable marking that cannot be destroyed by wear. The delivered pig is inspected as part of the quality assurance program. Appearance, agreement with the marking, color, hardness, dimensional accuracy, and field strength and position of the magnet are checked. With some pigging units it is necessary to locate pigs with centimeter accuracy in the piggable pipe. The position of the pigs is determined by detectors. To ensure that all pigs are placed in the same way, the position of the magnet in the pig must be checked. A special testing facility is used for this (see Fig. 3–17).

The success of pigging technology depends on the efficient application of suitable pigs, whose running properties and stability are crucial. Automation requires the reliable detection of the pigs in the pipe. The magnetic field of a permanent magnet in the pig is generally used for this purpose. The pig to be tested is clamped under defined conditions in a testing facility. Two pig detectors are installed for the detec-

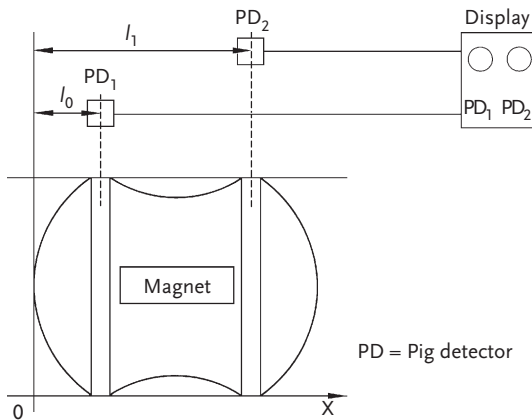
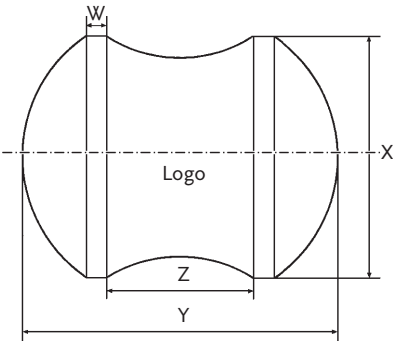


Fig. 3–17. Pig testing facility for a correct magnet location of a solid cast pig.

Pig type: solid cast pig
Pig reference number: DUO-PIG Nr.:



Typ	D				A				B				C			
DN / inch	50 / 2"				80 / 3"				100 / 4"				150 / 6"			
Pipe inside Ø [mm]	54.5 ± 1 %				82.5 ± 1 %				107.1 ± 1 %				158.3 ± 1 %			
Material	Au-zell				Au-zell				Au-zell				Au-zell			
Color																
Magnetic field [mT]	> 2				> 2				> 2				> 2			
Shorehardness																
	W	X	Y	Z	W	X	Y	Z	W	X	Y	Z	W	X	Y	Z
Dimensions [mm]	5	56.0	71	31	5	85	103	48	5	111	127	57	10	163	207	95
Tolerance [%]	± 0.5	± 1	± 1	± 1	± 0.5	± 1	± 1	± 1	± 1	± 1	± 2	± 1	± 2	± 1	± 2	± 1

Product		Remarks
Application site		
Used from / to		
Number of pigging units		
Piping length	[m]	
Running time	[km]	
Average speed	[m/s]	
Temperature	[°C]	

Fig. 3–18. Technical sheet for a solid cast pig.

tion for the magnetic field in an identical arrangement to that in the plant. If the pig was designed and manufactured in accordance with its specification, a positive signal is received from both pig sensors after signal analysis. The result of the investigation is recorded in the technical sheet prepared individually for each pig. If the equality of all used pigs is ensured laborious readjustment of locally installed pig sensors is unnecessary. The engraved identification on the pig is entered in the technical sheet and afterwards archived for the documentation of the used pigs. Further information to be included in the technical sheet is, e.g., location of use, length of the pipe, and product (see Fig. 3–18).

After replacing one or more pigs in a pipe, the documentation can be used to draw conclusions on the service life of the pigs. If the service life is too low, the piggable pipe, including the valves and control system, must be examined or the type of pig changed.

4

Valves

4.1

Function of Piggable Valves

A distinction is made between piggable and nonpiggable valves. Standard commercial valves, stop cocks, ball valves with reduced diameter, etc. are not piggable. In a pigging system they can be used at the outlets of pig launching or receiving stations, for example, for the propellant supply. Valves often form the junctions between the piggable and nonpiggable sections of a plant, e.g., at product in- and outlets.

This chapter is limited to the description of piggable valves in piggable pipes.

In a piggable piping system the selection of the piggable valves is particularly important. They must be optimally adapted for the individual application. The piggable valves simply open or close the pipe; only a switch can change the direction of product flow or pig travel. Apart from the general requirements for valves, such as tightness, low leakage, smoothness of operation, and precision, the piggability of the valves must be ensured, e.g., by having:

- The same inside diameter as the pipe.
- A centerable flange
- Accurate adjustability of plugs in stopcocks and switches.
- Guide bars at branches of the valves.

Important criteria for piggable valves are cleanability and freedom from pockets (no dead space). Definitions of zero- and low-dead-space valves are given in Section 16.2.

The piggable valve must be suitable for the type of pig used (spherical, lip, seal, and solid cast pigs). Furthermore, pig sensors and pressure-relief and ventilation nozzles must be installed accurately. Product properties have a substantial influence on the choice of pig valve, and therefore may also limit the range of application of a valve. Hardening, adhesive, and abrasive products can be problematic. Sometimes standard commercial piggable valves can be modified in such a way that they become suitable for such applications. Special product properties require intensive cooperation between customer and supplier, so that the optimal solution can be found.

4.2

Classification of Piggable Valves

To meet the demands made on pigging systems each manufacturer has its own range of valves. In principle, however, piggable valves can be divided into standard and special valves:

Standard valves:

- Stations
- Branches
- Pig traps
- Switches

Special valves:

- Crossing of two piggable pipes
- Pig receiving station for loading arms
- Pig receiving station for loading valves
- Manifolds
- Valves for hygienic applications (see Chap. 16)

4.3

Examples of Standard Valves

4.3.1

Stations

Stations are devices located at the beginning or end of a piggable pipe. At these stations pigs are inserted or removed, parked, and sent or received. The pig station passed through first in the direction of product flow is called the launching station, and that flowed through at last the receiving station.

Launching and receiving stations can also offer the possibility to load or unload pigs.

The source and target stations are the start and end stations of a pig run. Thus the source station acts as the target station and vice versa during reverse pigging. Source station and target station change depending on the pigging procedure.

Pig Loading and Unloading Station

The pig loading and unloading station can be located at either end of an industrial pigging unit. Here the pig is introduced into or removed from the pigging system and can be driven through the pigging system by a propellant. In this respect a pig loading and unloading station can also act as a launching and receiving station. Before the pig is changed, the valve or the pipe must be completely depressurized or separated from the piping system by a safety valve.

Insertion and removal of pigs must be easy, quick, and safe.

Uncontrolled emergence of the pig or the propellant must not be possible in any position of the valve.

The connections for the propellant should be selected such that the pig loading and unloading station can be used in both one- and two-pig systems. Depending on requirements and the construction of the valve, connections for cleaning agents and

pig sensors or mechanical pig detectors for detecting the pig at the valve can be incorporated. The pigs are loaded and unloaded manually.

Example 1.

The station shown in Fig. 4-1 consists of a pipe section equipped with the necessary fittings for the propellant, pressure relief, and for mounting magnetic-induction pig sensors; a pig loading ball valve with a blind hole which substantially simplifies pig loading and unloading, and a piggable shut-off ball valve as end valve of the station. The ball valve with blind hole can be rotated by 180° for inserting and removing the pig. The diameter of the blind hole is larger than the outside diameter of the pig and the inside diameter of the piggable pipe, so that the pig can be inserted easily. The transition between valve and pipe is conical, so that the pressure of the propellant pushes the pig into the piggable pipe.

The length of the pipe section determines the number of pigs which can be stored therein. This station serves not only for inserting and removing the pig, but also for transferring the pig to the pigging unit.

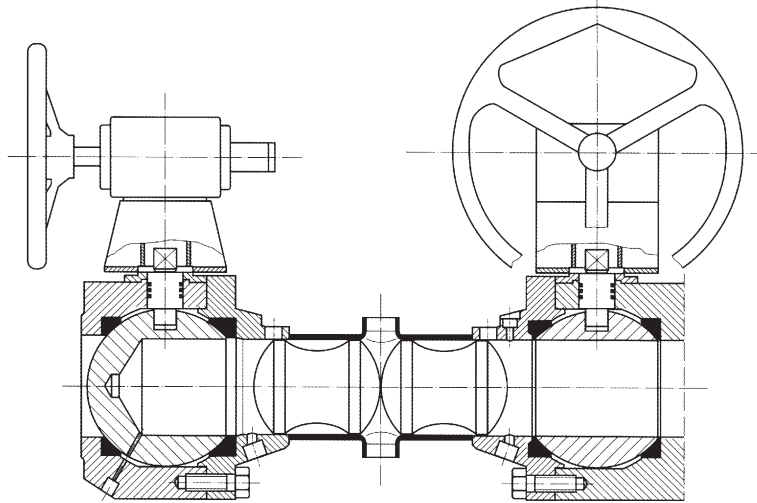


Fig. 4-1. Pig loading and unloading station (Pfeiffer, Kempen, Germany)

Example 2.

The pig loading and unloading station shown in Fig. 4-2 is also a pig launching station and consists of an extended pig chamber with a lateral opening and cap, which is connected to the piggable pipe by a reducing adapter. The pig is pushed into the piggable pipe under pressure via a pneumatic cylinder and can also act as a seal, so that the pig chamber does not fill with product. The valves for propellant inlet and outlet and connections for cleaning are attached to the extended pig chamber. To prevent the pig being conveyed with the product a pig trap with pneumatic actuator is fitted. Alternatively, the station can be sealed by a ball valve.

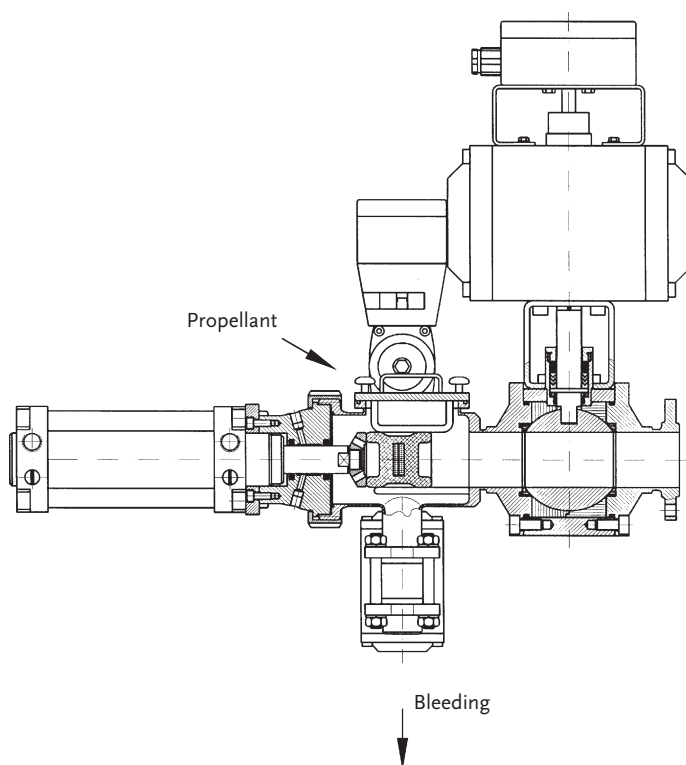


Fig. 4-2. Pig loading and unloading station (Kiesel, Heilbronn, Germany)

Example 3.

The examples in Figs. 4-1 and 4-2 are combined stations, which, by the combination of different valves, can be used as pig loading, unloading, and launching stations.

The valve shown in Fig. 4-3 is a mobile pig loading and unloading station which is coupled to a launching or receiving station as required. It is often used in branched pigging systems, so that several fixed pig loading and unloading stations need not be installed in the different branches. An advantage of this inexpensive station is that it can be mounted easily and quickly via a sliding coupling. It essentially consists of a pipe section whose inner diameter is larger than the maximum outside diameter of the pig.

The inner diameter of the station is connected via a cone to the inner diameter of the piggable pipe, so that the pig can be more easily pressed in. The pipe section is equipped with the flange rings of the sliding coupling, two connecting pipes for pressure relief and propellant inlet, a mechanical pig sensor, and a manometer. The end of the pipe is sealed with a cap which ensures quick pig changing. After the pig has been carried into the piggable pipe, the station is pressure-relieved and can then be uncoupled. The pipe is then plugged with a cap.

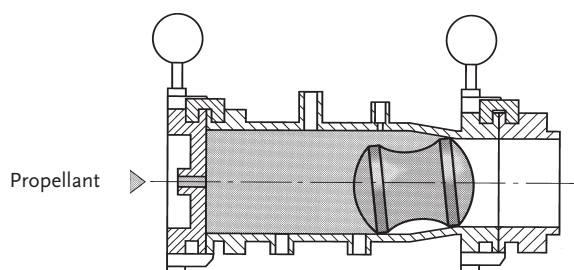


Fig. 4-3. Pig loading and unloading station (I.S.T., Hamburg, Germany)

Launching and Receiving Stations

Launching and receiving stations are installed at the end of a piggable pipe. A closed pigging system always includes a launching and receiving station. After product feed the pig is conveyed by the propellant to the receiving station and the product is thus removed completely from the pipe. One or more pigs are parked in the receiving station until needed. Launching and receiving stations allow pigs to remain in the closed pigging system for their total service life.

Pig receiving stations are fitted with propellant and pressure-relief connections. They are positioned such that accumulating product residues can flow off readily into a pressure-relief vessel. Cleaning connections can also be installed. For pig detection, mechanical pig tracers or magnetic-induction pig sensors are used.

Example 1.

The receiving station shown in Fig. 4-4 is flanged onto the end of a piggable pipe. It consists of a pipe section with the inside diameter of the piggable pipe and a downward branch with a reduced diameter. This outlet branch is fitted with guide bars so that a pig can traverse it without stalling. A specially shaped insert which can be

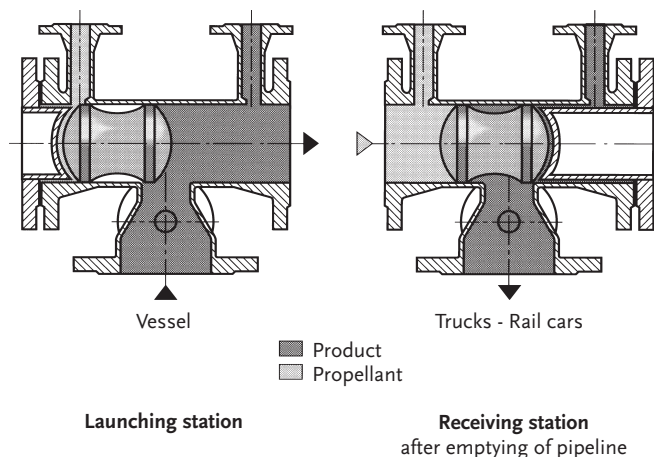


Fig. 4-4. Launching and receiving station (I.S.T., Hamburg, Germany)

varied in length is used to carefully position the pig. The arriving pig drives the product through the outlet. The station is suitable for one- and two-pig systems. The basic body of the station can also be used for the construction of a launching station.

Example 2.

Fig. 4–5 shows a pig receiving station for a one-pig system. The connection valves are equipped with pneumatic actuators. The valve consists of a pipe section with a T-branch and is fitted with flanges. For careful positioning of the pig a pig trap insert is flanged onto the pipe section. The propellant supply is connected to the flange.

The pig is driven by a propellant toward the receiving station and pushes the product over the T-branch and the open valve into a vessel. The pig is positioned such that the total product can run out of the piggable pipe over the ring space behind the pig, without letting through the propellant. Via the same ring space, the propellant presses the pig out of the receiving station. Apart from rinsing connections the usual control systems for pig detection can be installed.

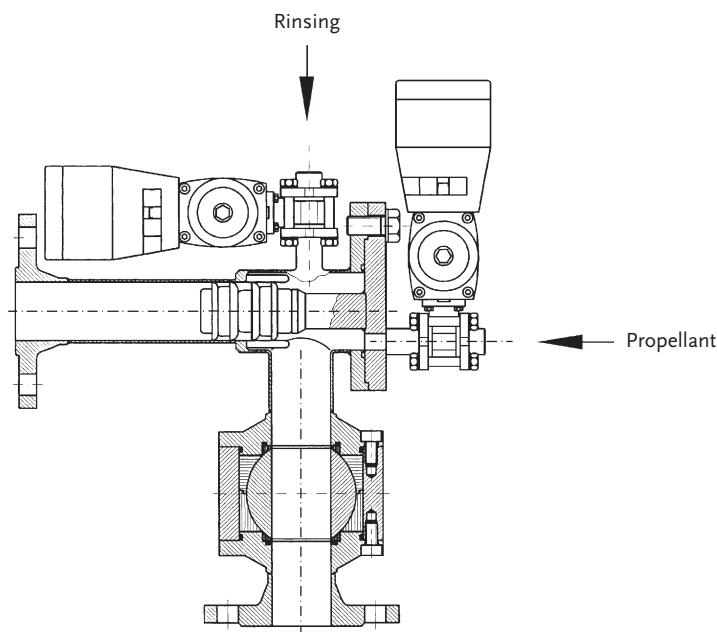


Fig. 4–5. Receiving station (Kiesel, Heilbronn, Germany)

4.3.2

Branches

If product is to be removed from or introduced into a piggable pipe, then a branch is required. Usually the branch is arranged vertically with respect to the pipe axis but, depending on the task, the branch may also be arranged downwards. With difficult

products it is important that the branch has the correct position (upward or downward). The branch has a switching function, generally driven pneumatically. The pneumatic actuator moves a rod or a ring, which reduces the piggable cross section of the valve. If the rod or ring projects into the piggable pipe, pigs can be held on either side and the product thus diverted into the branch. In typical branches the passage through the valve is piggable, but the branch often has a smaller diameter than the piggable pipe and is not piggable.

Example 1: The T-Ring Valve.

The T-ring valve (Fig. 4–6) is a dead-space-free special valve that functions as a check valve, piggable T-piece, and pig trap at the same time. The straight-through passage can be pigged without a dead space, whereby the valve is closed. The T-branch can be shut off by a sliding ring, which also stops the pig. A further check valve at the T-piece is not required.

The sliding ring is driven pneumatically by a piston, and sealed by side pieces, which are pressed onto the ring by springs. The T-ring valve is designed for mounting pig sensors. The total valve is equipped with mounting flanges.

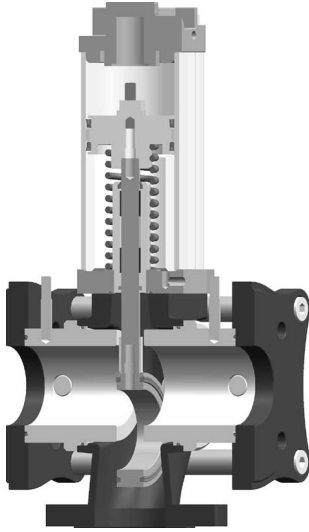
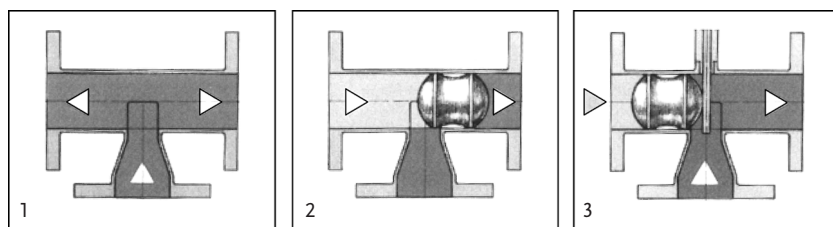


Fig. 4–6. T-ring valve (I.S.T., Hamburg, Germany)

Example 2: T-Piece with Pig Trap.

A T-piece with or without a pig trap (Fig. 4–7) is not free of dead space, since in the outlet up to the nonpiggable check valve small amounts of residual material accumulate. T-pieces have no shut-off function and serve for introduction or removal of product in piggable pipes. The connection of the T-branch to the continuous piggable pipe is designed such that a pig can travel through without problems. In this construction the downwards T-branch can have the same cross section as the piggable pipe.



Product flows in the piggable pipe

After pumping the pig pushes the product to the target vessel

The retractable pig trap can be used to stop one or two pigs

Fig. 4-7. T-piece with pig trap (I.S.T., Hamburg, Germany)

By incorporating a pig trap, the through-flow T-pieces become a pig receiving station. The pig can arrive from either direction, push out the product through the T-branch, and is held by the pig trap in the desired position, so that the propellant can not pass the pig and enter the T-branch. When the task of the pig is fulfilled, it can be returned to its starting position by propellant or product.

The T-branch is usually equipped with a check valve with pneumatic actuator, and pig sensor can also be installed.

Example 3: Metering Valve.

In normal plant design, a metering valve is realized by a T-piece with a ball valve. Here the metering valve is a ball valve, mounted almost free of dead space on the piggable pipe to avoid product residues. In the shut-off position, the ball plug, which would normally project into the piggable pipe, is adapted to the shape of the pipe.

The valve (Fig. 4-8) consists of a T-piece which, due to its construction with an integrated ball valve, is piggable without dead space. Floating bearings press the two seat rings via cup springs onto the ball and thus ensure a high degree of tightness.

The valve has various applications in pigging systems, e.g., as product inlet in single-pig systems, as end station with product in- and/or outlets in two-pig systems, and for metering into the product stream of a two-pig system.

The metering valve can also be combined with a stopper ball valve, mostly for positioning of pigs in two-pig systems. The stable ball bearings allow the pig to be

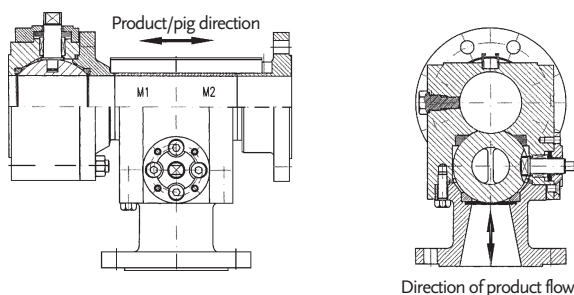


Fig. 4-8. Metering valve with stopper ball valve (Pfeiffer, Kempen, Germany)

positioned trouble-free and accurately, by driving it up to the closed valve. Fittings on the valve permit easy attachment and positioning of pig sensors.

Example 4: Piston Valves.

The piston valve is a dead-space-free, closeable, and flushable branch of a piggable pipe (T-piece with shut-off device).

The piston valve is used for product inlet to and/or from the piggable pipe. In contrast to the T-piece with a ball valve it is completely free of dead space and therefore particularly used in pigging units, in which even the lowest degrees of product mixing and/or contamination must be avoided.

The piston valve (Fig. 4–9) is mounted between the piggable pipes. In the closed state pigging proceeds through the piston valve smoothly, without dead volume. In the open state the piggable pipe is connected with a nonpiggable in- or outgoing pipe, and the product can flow unhindered in the desired direction. The piston valve can be pigged in the closed and open states. The nonpiggable pipe can be rinsed through a flushing connection when the piston valve is closed.

The throughput piston valve (Fig. 4–10) combines the functions of a piston valve and a pig trap in one valve. In the closed state the pig flows smoothly through the

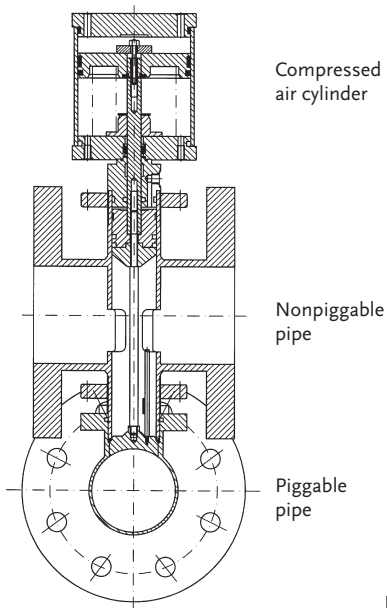


Fig. 4–9. Piston valve (I.S.T., Hamburg, Germany)

piston valve. In the open state, the piston of the valve stops the pig from being propelled by the product flow. This happens, for example, if the valve is positioned behind the pig launching station as a product input. If the product is to be propelled back through the piston valve, pigs can be driven from both sides towards the piston of the opened valve. After closing the branch the pigs travel to the pig launching station, where they can be cleaned.

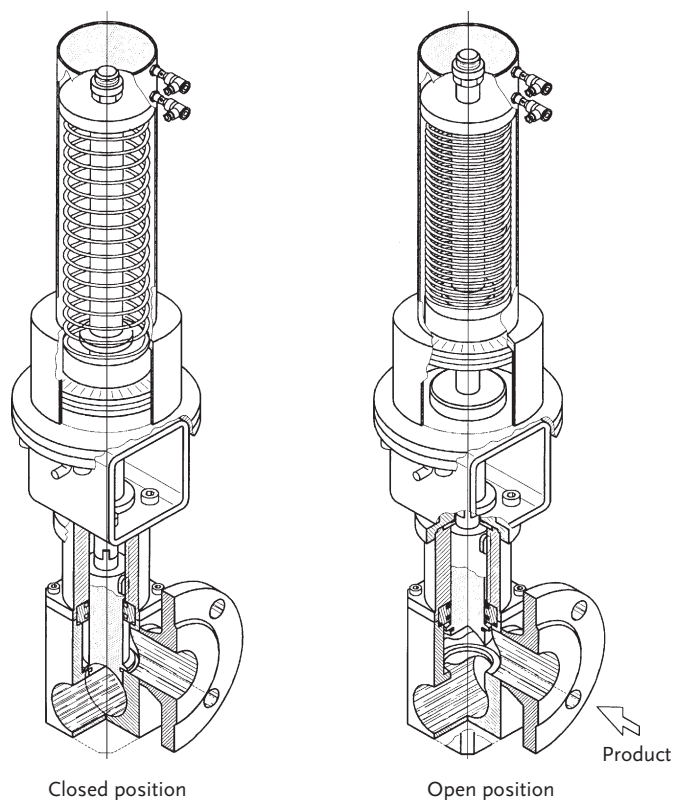


Fig. 4–10. Throughput piston valve (Kiesel, Heilbronn, Germany)

4.3.3

Pig Traps

Pig traps are always installed in combination with a valve, either at a launching or receiving station, or in a T-piece. Pig traps have the function of retaining or positioning one or two pigs, which can come from different directions. This happens when the pig trap is extended into the piggable pipe. When the pig trap is retracted, the passage through the piggable pipe is free. The pig trap itself and the bearing must be sufficiently dimensioned (see Section 4–6). The extended trap should be held in a back support to prevent its bending by the pig.

Commercial pig traps all have similar constructions. The T-piece with the pig trap is flanged between the piggable pipes and represents a branch (Fig. 4–11). A pneumatic drive unit drives the stroke. Proximity initiators monitor the position of the pig trap. The strongly dimensioned pig trap is held in the back support. If the trap is bent and cannot reach its final position, a position alarm unit indicates this.



Fig. 4-11. Pig trap (I.S.T., Hamburg, Germany)

4.3.4

Switches

In contrast to product branches, switches divert both product and pig.

Switches are classified by

- Plug design (ball or cylinder, see Tab. 4-1 and Fig. 4-12).
- Connection type (spatial arrangement of the nozzles).
- Number of ways and switching positions (a/b switches)

Mainly three-way switches are used, but multiway switches are also possible. The boundary between multiway switches and piggable manifolds is fluid.

The three-way switch is one of the most important valve types and is a piggable switching valve which permits the arriving product to be diverted in two directions and then pigged. It is used where a bifurcation is required or different destinations must be reached.

Multiway switches are predominantly used in multiproduct units to reduce the number of required lines between target and source vessels.

The following discussion is limited to the description of three-way switches. Three-way switches are nearly without dead volume. The plug turns past the outlets without overlap. The plug can be cylindrical or spherical. In both cases the pig is diverted in the valve. Thus, the main function lies in the elbow region, and high precision is required during processing and positioning.

Overhanging edges at the transitions between plug and housing must be avoided; otherwise the tangential forces acting on the pig in the elbow region would lead to increased wear.

Table 4–1. Comparison of form sealing components cylinder and ball three-way switch.

Valve shape	Advantages	Disadvantages
Cylinder	simple manufacturing and mounting of the plug simple cover sealing without dead volume	exact forming of the sealing is not necessary protruding, uncovered PTFE requires careful centering or sealing
Ball	the sealings has a circular connecting area on the ball no protruding PTFE simple mounting of the sealing	precise production of the ball free of dead volume only with additional sealing elements uniform tighttering of the screws on the nozzles is required

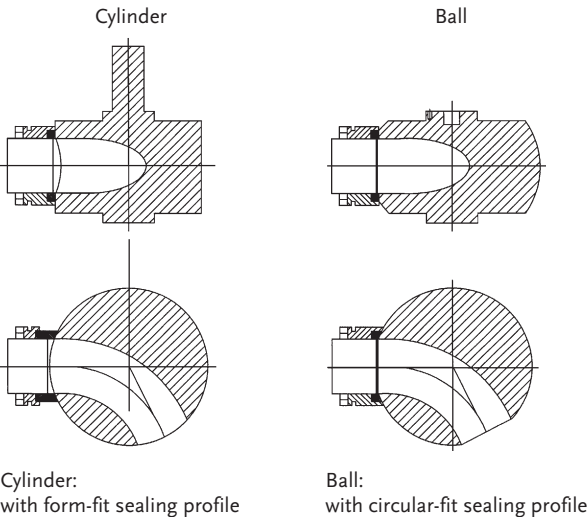


Fig. 4–12. Comparison of form sealing components cylinder and ball three-way switch

The location and/or the available space determines the type of connections to the switch (Fig. 4–13): either 120° star configuration, swallow, or antlers. The swallow form is installed as a T-piece and the antlers form in parallel pipelines.

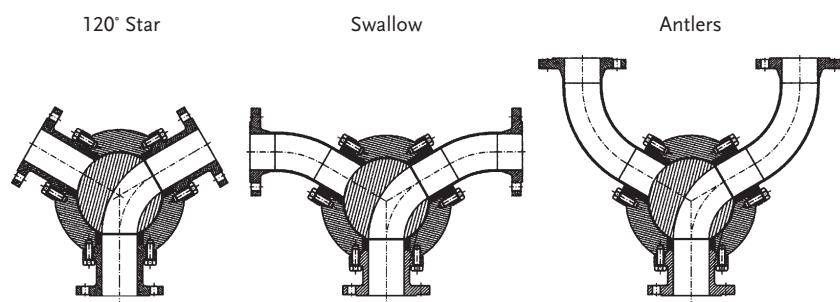


Fig. 4–13. Types of connections to switches

The prefix a/b (e.g., 3/2 switch) specifies the number of ways (a) and switching positions (b). The switches can be equipped with pneumatic actuators for two or three switching positions. Depending on the kind of drive unit, different switching functions result. Each switching function is assigned a fixed initial position (Fig. 4–14).

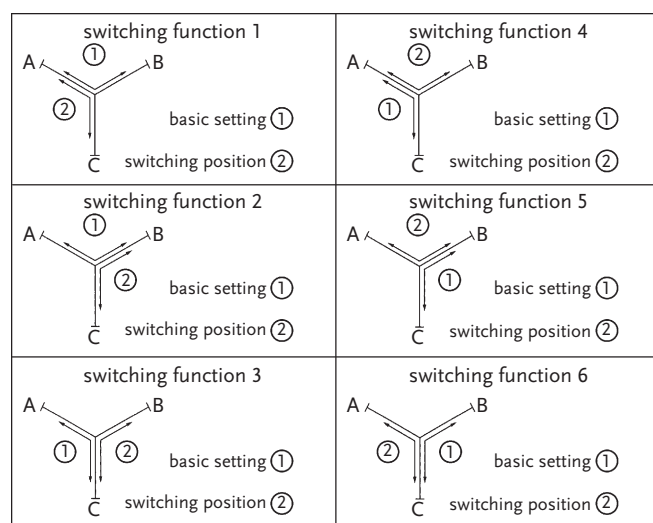


Fig. 4–14. Switching functions of a 3/2 switch

Example 1: Three-Way Switch with Cylindrical Plug.

This three-way switch (Fig. 4–15) is applicable for products, which must not be mixed or for which only low degrees of contamination are permitted. It has a cylindrical plug. All three switching positions are possible, i.e., product streams can be re-

routed in three directions. The cylindrical plug is generally coated with PTFE and enclosed and mounted on both sides with strong trunnions. The cylindrical main gasket (liner) is mounted on flexible O-rings in the region of the valve openings. Additional lateral support is provided by groove rings with gap relaxation (block and bleed). The gaps are provided with openings for checking contamination. No residues remain in the smooth passage through the valve during pigging. Switching by the pneumatic drive unit can be for two or three positions. During switching all outlets are simultaneously closed.

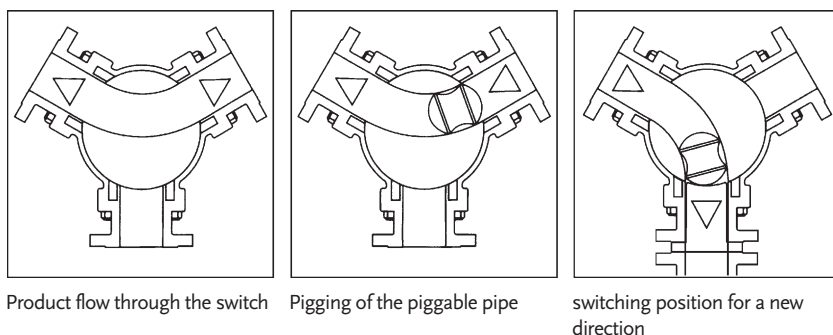


Fig. 4–15. Three-way switch (I.S.T., Hamburg, Germany)

Example 2: Three-Way Switch with Spherical Plug.

The switch in Fig. 4–16 is a 120° three-way valve. The ball is machined to high quality to achieve a high degree of tightness. Depending upon the drive unit, two or three switching positions are possible. The housing is equipped with three bolted-on side covers, sealed on the ball. At the valve all standard position indicators and solenoid valves can be mounted.

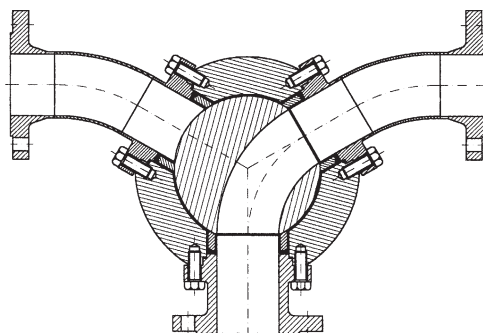


Fig. 4–16. Three-way switch (Pfeiffer, Kempen, Germany)

4.4

Examples of Commercially Available Special Valves

Valves for the sterile areas also belong to this group, but are described in more detail in Chap. 16.

4.4.1

Crossing of Two Piggable Pipes

A crossing is the intersection of two perpendicular piggable pipes. If these are to be interconnected without mechanical displacement or coupling, then special valves must be used. These valves have the function of fully automatic distribution of several incoming and outgoing piggable pipes.

Example: Fig. 4-17, Cross Piston Valve.

The cross piston valve belongs to the family of the piston valves.

It is a combination of the piston valve and the three-way piston valve and is mounted between two vertically to each other running piggable pipes.

In the closed state both piggable pipes run smoothly and without dead volume through the valve. The pipes can pigged independently. In the open state the upper

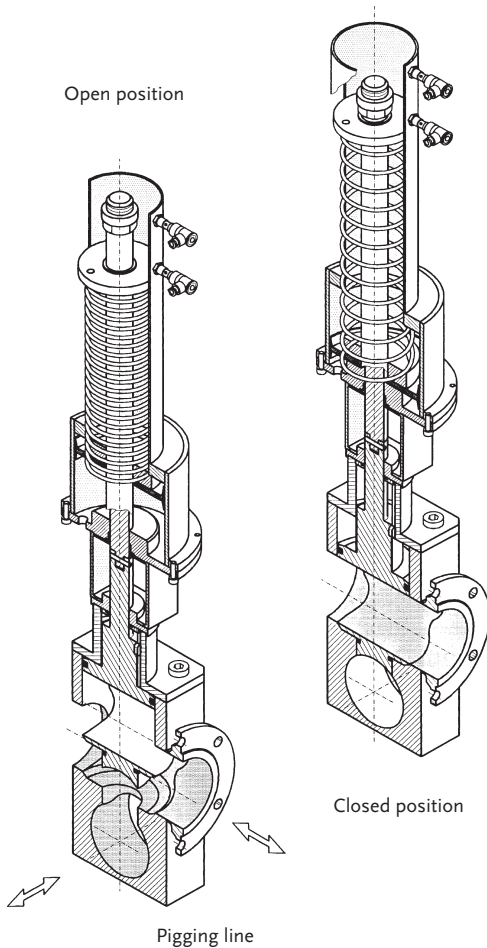


Fig. 4-17. Cross piston valve (Kiesel, Heilbronn, Germany)

piggable pipe is connected with the lower piggable pipe. Opening and closing can be combined with product filling.

The upper pipe can be pigged up to the open piston, and the lower pipe can be completely pigged. Since cross piston valves are very short, they can, e.g., be mounted in the product outlet. Since this line always contains the same product, it need not be pigged.

Depending on the task the appropriate cross valve is opened, and pigging is carried out in the lower pipe from the first cross piston valve to the target station. However, if necessary, the upper line can also be pigged.

4.4.2

Manifolds

Manifolds connect, for example, multiple piggable pipes with pigging lines on a single level. Neither hoses nor couplings are required. The connections can be made manually or automatically. Manifolds are used in multiproduct plants for mixing, filling, and loading procedures. The benefits of manifolds are:

- Closed system
- Small size
- Few moving parts
- System is expandable
- Piggable up to and from connections
- Not restricted to a particular position

Manifolds can be classified as:

- Piggable multidirection manifolds
- Rotary manifolds
- Linear manifolds
- Matrix manifolds
- Full-system manifolds

Rotary, linear, and matrix manifolds are based on the sliding coupling system.

A sliding coupling consists of two smooth half-couplings which slide over one another until they lock. The piggable half-coupling are sealed with O-rings.

Example 1: Modular Multidirection Manifold.

The modular multidirection manifold (Fig. 4–18) transfers the radial arrangement of a multiway switch to a linear plane. This piggable pipeline manifold with constant pipe diameter connects, e.g., 12 inlets to four outlets. At the same time four products can be conveyed. The manifold has a modular construction. This type of manifold is suitable, e.g., for connecting a tank farm to several filling stations. Distribution is performed by four mobile jointed arms. Two slides drive the arms into the desired position. Coupling and uncoupling are performed by pneumatic cylinders. Blind coupling plug the connections not in use. The manifold is controlled by a programmable control system.

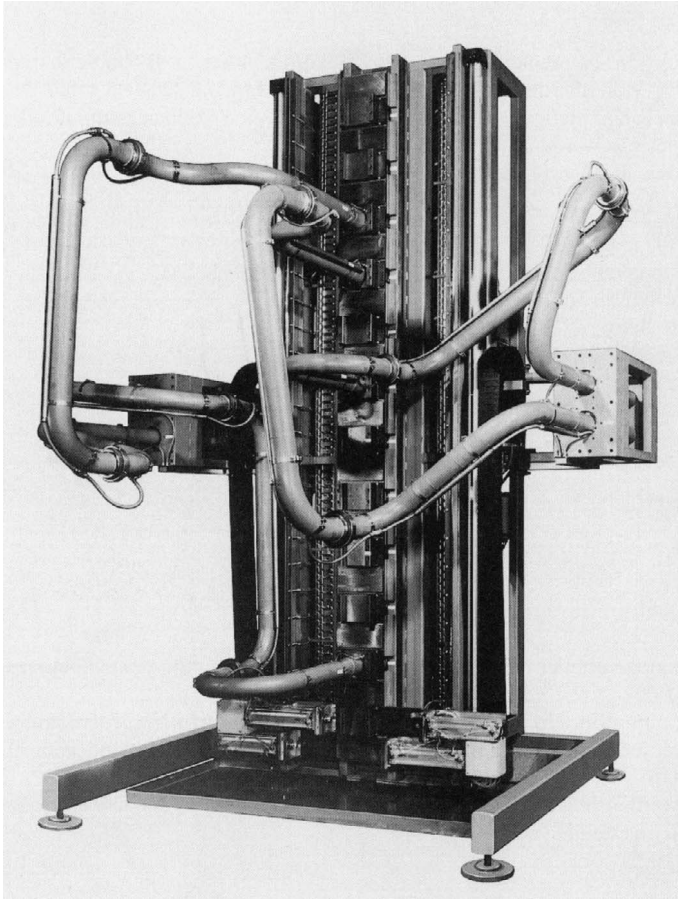


Fig. 4-18. Modular multidirection manifold (I.S.T., Hamburg, Germany)

Example 2: Rotary Manifold.

The rotary manifold (Fig. 4-19; multiway switch with full-system coupling) is integrated in a pigging system between the launching and receiving station and is completely piggable. The rotary manifold is an alternative to hose pipes. Around a pipe socket several sliding couplings are arranged in a circle on a plate. Rotatable U- and S-arms are attached to the central pipe socket. Switching involves unlocking the existing connections, moving the U- or S-arm and locking of the new connections. The arms are moved pneumatically.

Example 3: Full-System Manifold.

The full-system manifold (FSM) (Fig. 4-20) is a completely closed piggable system that optimizes the branching of pipes between the sources and targets. An FSM can be used for mixing and pumping between reservoirs. It is free of hoses, and reliably prevents product losses and erroneous switching.

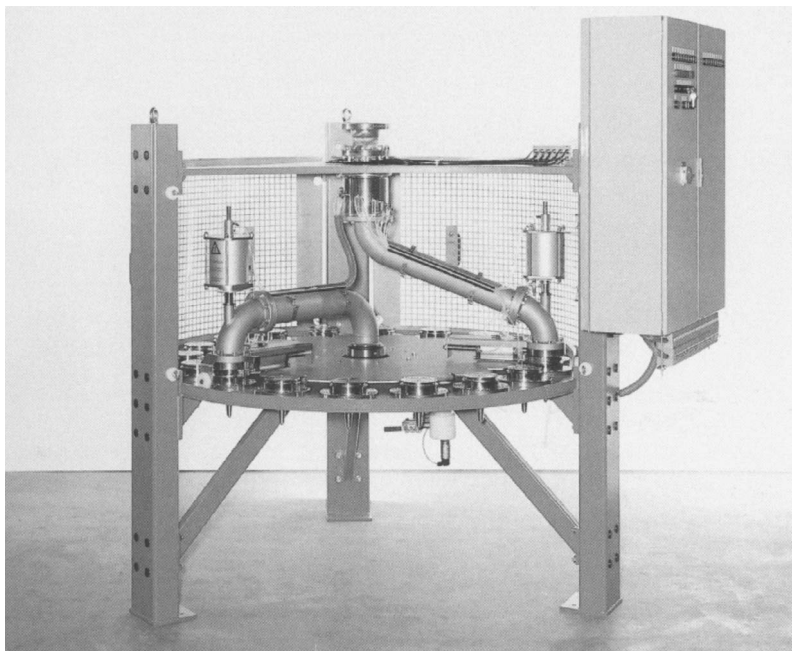


Fig. 4-19. Rotary manifold 2/18 (I.S.T., Hamburg, Germany)

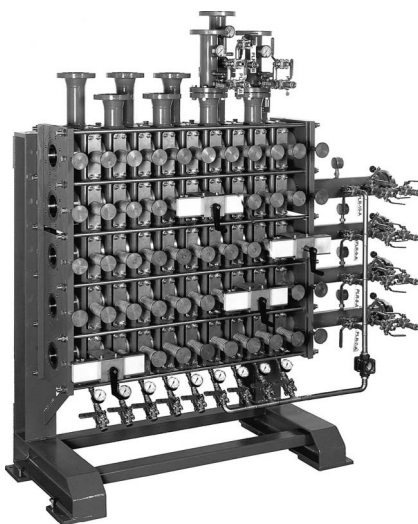


Fig. 4-20. Piggable full-system manifold (I.S.T., Hamburg, Germany)

An FSM also allows pipes of different diameters to be connected to one another. For example, a 2" piggable pipe can be filled beside a 4" piggable pipe and then pigged. FSMs are easily expandable due to their modular construction. In the most advanced stage of development up to 50 nonpiggable pipes and 20 piggable pipes can be combined. The FSM has nonpiggable channels for product inlet. At right-angles to these are the piggable pipes, connected at the intersections by T-ring valves, which open the connection between the product-carrying channel and the piggable pipe. The ring valve also acts as a pig trap. The valves are opened manually or by pneumatic actuators. A slide drives the actuator parallel over the piggable pipe to the desired product-carrying channel. Thus, only one actuator per piggable pipe is necessary, and control is simplified.

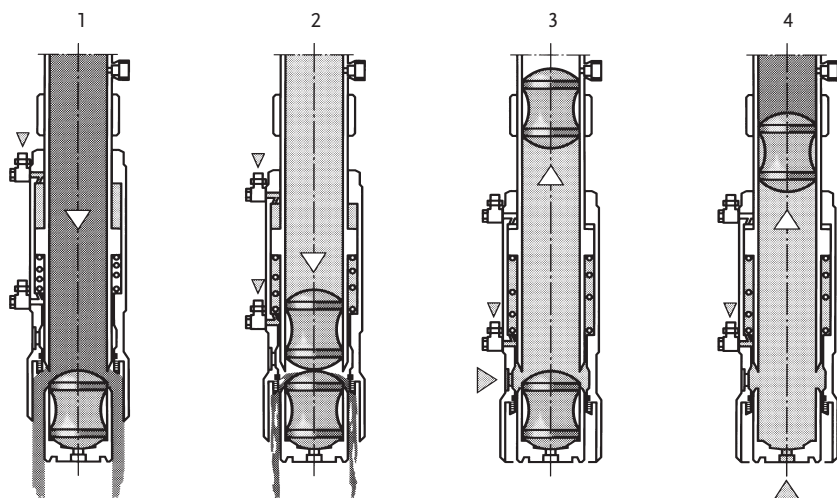
4.4.3

Piggable Loading Facilities

A piggable loading facility is always installed at the end of a piggable pipe or a piggable swivel arm. It permits the pigging of pipes through the loading facility. Thus, when filling tank trucks or rail cars the entire product which is in the pipe can be pushed into the vehicle or, in response to an overfilling indicator, all the product in the pipe can be driven back into the tank. Different products of a product family can be filled successively by the same loading facility without problems.

Example: Loading Lance.

The loading lance (Fig. 4.21) is a piggable loading facility, which is attached to the end of a piggable pipe or at a piggable swivel arm. It consists of an interior pipe and an outer sliding sleeve that can move up and down. The sleeve can be moved pneumatically into the positions open/closed/throttle and thus serves as a flow-control device, particularly at the end of product feeding. If the air supply fails a built-in spring closes the loading lance automatically. The loading lance can be equipped with pig sensors, air connections, and a level-control switch.



 product
 propellant

Loading lance with pig inside is open, product flows past the pig into the tank truck or rail tanker.

The second pig is pushed by air or another propellant into the loading lance and forces the product through the loading lance into the tank truck. The loading lance is in throttle position to control the outflowing product.

The loading lance is closed, the propellant in the product line is depressurized. The second pig is separated from the first pig and returned to its original position.

Should the overfill protection system be actuated, the loading lance closes automatically. The first pig will be pushed forward by a propellant and forces the liquid in the pipeline back into the storage tank. An overfilling of product is avoided.

Fig. 4–21. Loading lance (I.S.T., Hamburg, Germany)

4.4.4

Drum-loading Valves

Besides tank trucks and rail cars finished products of a production plant are also filled into drums, and containers of different sizes. In multiproduct plants, to avoid mixing, a separate filling valve must be used for each product or a piggable drum-loading valve is required. Piggable loading valves are always installed at the end of a piggable product pipe.

Example: Drum-Loading Valve.

The drum-loading valve shown in Fig. 4–22 can be used to fill several products into drums successively from an upstream manifold system. The drum-loading valve consists of a pig receiving and launching station and is equipped with a mechanical

pig sensor, and connections for propellant and pressure relief. At the outlet of the station the drum loading valve itself is coupled; it is easily exchangeable. The entire station can be driven up and down pneumatically to allow bottom bunghole and bottom level filling. The valve is suitable for filling drums of most sizes with a fixed lid and bunghole and also open drums.

If the drums are on automatic balances, then at the end of a drum-loading procedure the valve can be switched automatically to throttled fine flow and be closed completely and drip-free after reaching the preselected amount.

Drum-loading valves are frequently integrated into automatic drum-filling units. Filling of 60 drums per hour is possible (e.g., drum-loading unit from Feige, Germany).

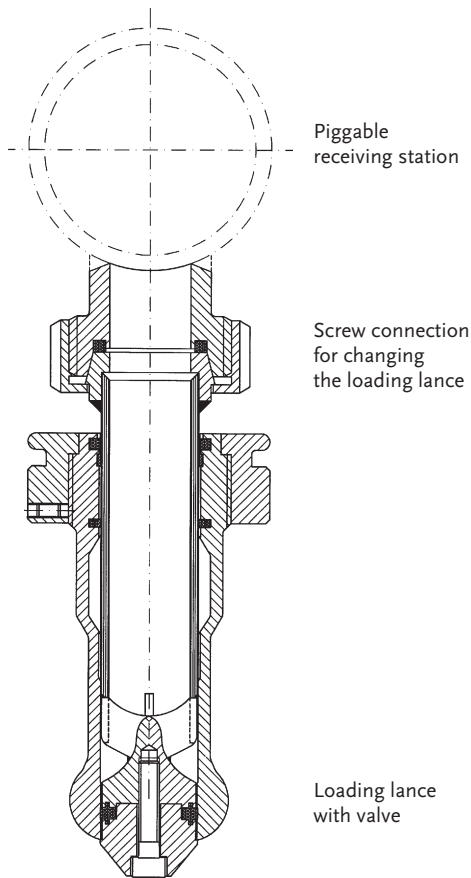


Fig. 4-22. Drum-loading valve (I.S.T., Hamburg, Germany)

4.5

Pressure Drop in Piggable Valves

In principle the pressure drop in piggable valves can be calculated as for a nonpiggable valve. The total pressure drop in a piggable system depends on the kind of conveyed liquid and the individual pressure drops of the pipes, pipe bends, and valves. Flow measurements on valves showed that the pressure drop could be calculated sufficiently accurately with Equation (4.1) (see also Chap. 12),

$$\Delta p = 0.5 \cdot \xi \cdot \rho \cdot v^2 \quad (4.1)$$

Δp :	Pressure drop	[Pa]
ξ :	Resistance constant	[-]
ρ :	Density	[kg/m ³]
v :	Flow speed	[m/s]

The resistance constant ξ for a 3" pipe (DN 80) lies between 4.5 and 6.5, depending on the type of valve. For larger nominal sizes smaller ξ values can be expected, and vice versa. Fig. 4.23 shows the pressure drop of a T-wing valve, (3" DN 80) transporting heating oil.

To obtain accurate ξ values it is necessary to carry out tests on the respective nominal size and type of valve. For the calculation of a pigging unit normally the approximate values for the valves, indicated by the manufacturer are sufficient. The general procedure for the estimation of pressure drops is described in Chap. 12. The resistance constant of DIN valves and 90 degree valves lie within the range of $\xi = 3.5$ –6.0; for a bellow-type valve (3" DN 80) $\xi = 4.9$.

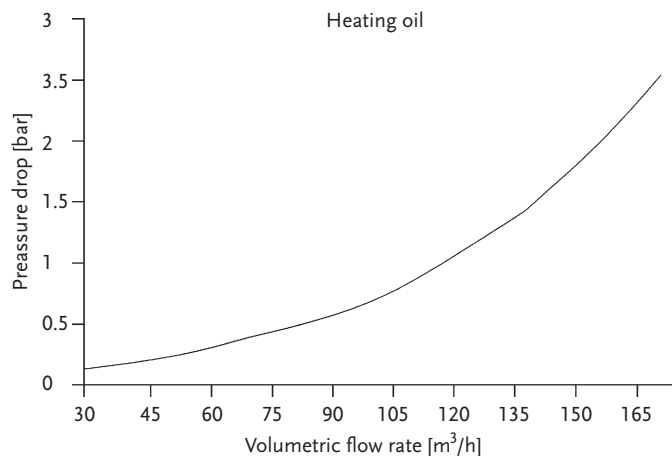


Fig. 4-23. Pressure drop at a 3" (DN 80) T-ring valve (I.S.T., Hamburg, Germany)

4.6

Stress on Pig Traps

Pig traps (see Section 4.3.3) in the form of round metal rods stop the pig and let the pushed-out product pass unhindered. The rod can be fixed at one or both ends. The kinetic energy of impinging pigs must not lead to permanent deformation of the rod.

For a pig trap fixed at one end (Fig. 4–24)

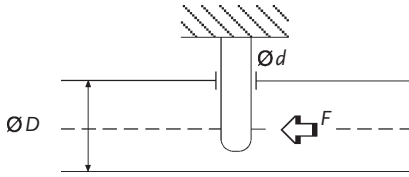


Fig. 4–24. Schematic of a pig stop, fixed at one end.

Solving the differential equation of the modulus line shows that the rod bends in the middle of the pipe over a deformation path f (Eq. 4–2).

$$f = \frac{F \cdot D^3}{24 \cdot E \cdot I_y} \quad \text{with the geometrical moment of inertia} \quad I_y = \frac{\pi \cdot d^4}{64} \quad (4.2)$$

The permissible impact force F_{tol} is determined by the requirement that the flexural yield strength σ_{bF} of the pig trap material (Fig. 4–25) must not be exceeded, since the material should behave linear-elastic (Eq. 4–3)

$$\sigma_b = \frac{M_b}{W_b} = \frac{F_{tol} \cdot D \cdot 32}{2 \cdot \pi \cdot d^3} \quad (4.3)$$

σ_b : Existing bending stress

M_b : Bending moment

W_b : Section modulus

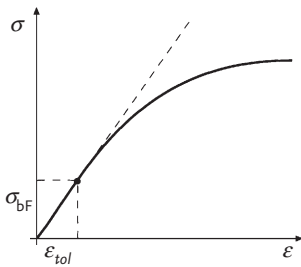


Fig. 4–25. Stress–strain diagram of the pig trap material.

The permissible speed c_{tol} of the pig is obtained by application of the law of energy conservation. The kinetic energy is equal to the sum of the work of elastic deformation of the trap and the work of elastic deformation of the pig.

Figure 4–26 applies to a solid cast pig. It is assumed that frictional heat is negligible and the material behaves linear-elastic. The stored energy of the rod can be determined by integration of the force-displacement curve.

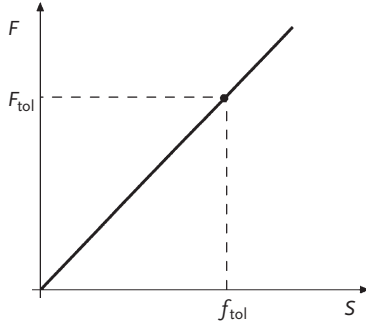


Fig. 4–26. Force–displacement curve of the pig trap material.

Plastics under compressive load behave similarly (Eq. 4–4).

$$F_{\text{tol}_p} = \frac{\pi \cdot D^2}{4} \cdot \sigma_{\text{tol}_p} = \frac{\pi \cdot D^2}{4} \sigma_{\text{bF}_p} \quad (4.4)$$

The permissible elastic strain s_1 is assumed to be 50 % of the distance s between pig head and core magnet (Fig. 4–27); hence Equation (4–5) follow.

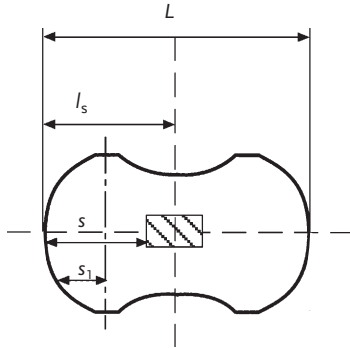


Fig. 4–27. Fundamental dimensions of a pig with core magnet.

$$\int_0^{s_1} F \cdot ds = \frac{1}{2} \cdot F_{\text{tol}_p} \cdot s_1 \quad (4.5)$$

Solving the law of energy conservation in terms of c_{tol} given Equation (4–6).

$$\frac{1}{2} \cdot m \cdot c_{\text{tol}}^2 = \frac{1}{2} \cdot f_{\text{tol}} \cdot F_{\text{tol}} + \frac{1}{2} \cdot F_{\text{tol}_p} \cdot s_1 \quad (4.6)$$

$$\rightarrow c_{\text{zul}} = \sqrt{\frac{\sigma_{\text{bF}}^2 \cdot D \cdot \pi \cdot d^2}{96 \cdot E \cdot m} + \frac{1}{2} \cdot s_1 \cdot \frac{\pi \cdot D^2}{4} \cdot \sigma_{\text{bF}_p} \cdot \frac{2}{m}}$$

Table 4–2 lists some material parameters for bending stress, and Tab. 4–3 maximum pig speeds without permanent deformation of the trap.

Table 4–2. Material parameters for bending stress.

Material	Flexural yield strength	Elastic modulus
SS rod of pig trap	$\sigma_{bF} = 498 \text{ N mm}^{-2}$	$E = 199\,000 \text{ N mm}^{-2}$
CS rod of pig trap	$\sigma_{bF} = 332 \text{ N mm}^{-2}$	$E = 205\,000 \text{ N mm}^{-2}$
Pig: thermoplastic	$\sigma_{bF_P} = 1.5 \text{ N mm}^{-2}$	

For a pig trap fixed at both ends (Fig. 4–28), the deflection f center of the pipe is given by Equation (4–7).

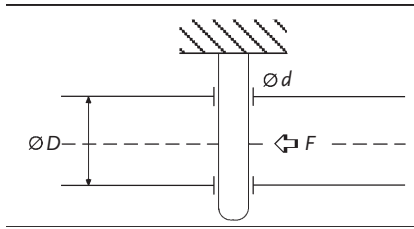


Fig. 4–28. Schematic of a pig stop, fixed at both ends.

$$f = \frac{F \cdot D^3}{1536 \cdot E \cdot I_y} \quad (4.7)$$

Here the pig trap resists the 64-fold load up to the flexural yield strength relative to a pig trap clamped on one side (Eq. 4–2).

Table 4–3. Permissible speed for pigs without lasting deformation pig trap.

DN [inch]	D [mm]	d [mm]	m [kg]	L [mm]	I_s [mm]	s [mm]	s_1 [mm]	c_{tol} one-sided	c_{tol} two-sided
50/2"	55.1	20	0.35	71	35.5	15.5	7.8	8.7	15.4
80/3"	82.5	20	0.43	103	51.5	24	12	15.1	20.6
100/4"	107.1	20	0.74	126	63	28	14	16.1	20.2
150/6"	158.3	30	1.79	185	92.5	50	25	20.4	24.9

d : pig trap diameter

m : mass of the pig

c_{tol} : permissible pig speed

The above results permit only qualitative statements due to the unknown deformability. They show that with increasing nominal size of the pig its energy storage capacity increases superproportionally. The kinetic energy is thus predominantly taken up by the pig material, and this reduces the load on the trap.

Although the trap clamped on both sides is clearly stiffer, the permissible speed at larger nominal size is determined by the compressibility of the pig material. Since speeds in pipes can reach up to 80 m/s, it is recommended to increase the diameter of the pig traps. An absolute value of the diameter cannot be stated, since experimental values of the deformability s_1 of pigs are not available.

5

Pipework

5.1

Requirements for Piggable Pipes

An industrial pigging unit consists not only of a pigging line, but also of a number of nonpiggable pipes (propellant lines, product supply lines etc.). The planning, selection, and mounting of these conventional pipes is assumed to be familiar to the reader. In the following sections the characteristics of piggable pipes are described [1]. As the direct partner of the pig the piggable pipe has the largest contribution of all system components to the quality of cleaning. The quality of the pipe determines the quality of the cleaning by the pig.

Before beginning with the specification of the pipe the requirements on the total pigging unit must be clarified. Depending on the required degree of cleanliness these can be low (coarse-cleaning pigging unit) or very high (fine-cleaning pigging unit).

The tasks of a pigging unit can range from occasional mechanical cleaning to emptying a pipeline with minimal residual product. With a product change contamination of the new product by the old is limited to a few ppm. The task spectrum of industrial pigging units is discussed in Chap. 10.

While occasional coarse mechanical cleaning with a brush pig or spherical foamed-plastic pig can also be carried out in a normal pipe, not designed for pigging, the avoidance of product mixing by fine cleaning is only possible in a pipe that adheres to the rules discussed below. Thus, there is no single specification for piggable pipes; instead, the recommendations in the following sections are to be followed to a lesser or greater extent, depending on the application and product. The piggability is thus always a question of the requirements [2].

It is also a question of economy: pipes with smaller tolerances and their careful welding and installation are expensive; therefore, the specification of the requirements must be discussed thoroughly.

In the piggable pipe no components that reduce the cross section may be incorporated, e.g., orifices, sieves, filters, blinds, etc. A piggable pipe must not exhibit any changes in diameter (increases are also not acceptable). The only part of a pigging unit whose cross section changes somewhat is the pig loading and unloading station

(see Section 4.3.1). Here the pig (oversize) can be easily inserted. The station is closed, and the pig is then pressed into the pipe through a conical pipe section.

5.2

Materials for Piggable Pipes

Pipes for industrial pigging units are manufactured from stainless steel for most applications. Stainless steels are especially suitable for pigging lines that handle a whole group products. Usually, the magnetic pig indicators used with industrial pigging units work only with paramagnetic steels (see Chap. 8.1.2).

The materials with the DIN numbers 1.4541 (AISI 321) and 1.4571 (AISI 316 Ti), used to a large extent in the German chemical industry, are preferred at present also for pigging lines. These materials are, however, prone to titanium carbide precipitations, which make the smoothing of longitudinal welding seams more difficult. Furthermore, they cannot be readily ground and polished.

For these reasons, analogous to the U.S. steel grades AISI 304L and AISI 316L, use of the steels with the DIN material numbers 1.4307 and 1.4404 began, which exhibit similar chemical resistance and mechanical/technological properties. A contrast to the titanium-stabilized steels are the extra low carbon (ELC) steels (see Table 5–1).

Manufacturers and operators of industrial pigging units by no means agree on the required kind of pickling and/or passivation. Most manufacturers pickle by immersion, i.e., inside and outside. Some suppliers regard this as a reason for higher pig wear. However, this only occurs if the surface is roughened and due to excessive pickling time and/or unfavorable composition of the pickling bath. With careful pickling this can be avoided. Erosion pickling always leads to a rough surface. Even when erosion pickling is prescribed to avoid medium-initiated stress corrosion cracking, it should be used in pigging lines only in special cases (i.e., extreme stress corrosion cracking). The better solution would be the use of a more resistant material.

If pipes made of unalloyed carbon steel can be used for an industrial pigging unit, then pipes in accordance with DIN 1626 (welded pipes of unalloyed steel [3]) or to DIN 1629 (seamless pipes of unalloyed steel [3]) are suitable. The materials are St 37–2 and/or St 42–2. Since they exhibit ferromagnetic properties, pigs with magnets cannot be detected.

Steel pipes standardized according to DIN 2391 (seamless precision steel pipes [3]) and/or DIN 2393 (welded precision steel pipes [3]) are unsuitable as pressure lines for products and hence as pigging lines. Although they are designated precision steel pipes, they are not submitted to pressure and leakage tests. They are used only for steel structures.

Other materials for piggable lines belong to the class of special materials and are accordingly rarely used. In individual cases short pigging lines made of highly corrosion resistant nickel-base alloys (Hastelloy, Incoloy) are used in the chemical indus-

Table 5-1. Comparison of austenitic stainless steels alloying constituents and strength properties

Material number	Material standard, material designation in parentheses	Mass fraction in %					Other elements	0.2 % Proof stress (N/mm ²) – transverse	1 % Proof stress (N/mm ²) – transverse	Tensile strength (N/mm ²)	Resis- tance to intercrys- talline corrosion	Density (g/cm ³)	Remarks
		C ≤	Si ≤	Mn ≤	Cr	Mo	Ni						
1.4541	DIN EN 10028-7 (X 6 CrNiTi 18-10)	0.08	1.0	2.0	17.0	–	9.0	Ti ≥ 5 × % C	220	250	520	yes	7.95
					19.0		12.0				720		
1.4306	DIN EN 10028-7 (X 2 CrNi 19-11)	0.03	1.0	2.0	18.0	–	10.0	–	220	250	520	yes	7.95
					20.0		12.0				670		–
1.4307	DIN EN 10028-7 (X 2 CrNi 18-9)	0.03	1.0	2.0	17.5	–	8.0	–	220	250	520	yes	7.95
					19.5		10.0				670		–
304L	ASTm A 240	0.03	0.75	2.0	18.0	–	8.0	–	170	–	485	yes	7.95 ^a
					20.0		12.0						
1.4571	DIN EN 10028-7 (X 6 CrNiMo 17-12-2)	0.03	1.0	2.0	16.5	2.0	10.5	Ti ≥ 5 × % C	240	270	540	yes	7.95
					18.5	2.5	13.5				690		–
1.4404	DIN EN 10028-7 (X 2 CrNiMo 17-12-2)	0.03	1.0	2.0	16.5	2.0	10.0	–	240	270	530	yes	7.95
					18.5	2.5	13.0				680		–
316L	ASTM A 240	0.03	0.75	2.0	16.0	2.0	10.0	–	170	–	485	yes	7.95 ^a
					18.0	3.0	14.0						

a) Regarding the mechanical properties, there is no distinction between cold- and hot-rolled materials in ASTM

try. In the presence of hydrogen chloride these materials have service lives several times longer than those of austenitic CrNi steels.

Nonmetallic pigging lines have so far only been used for coarse cleaning. Plastic pipes are standardized as pressure pipes and as sewage pipes. Pressure pipes, partly for pressure up to 16 and 25 bar, are available in the materials listed in Tab. 2–5.

Table 5–2. Plastic for pressure pipes

Material	Abbreviation	Standard
Polyvinyl chloride	PVC-U, PVC-C	DIN 8062
Polyethylene	HDPE, LDPE, VPE	DIN 8072, 8074, 16893
Polypropylene	PP	DIN 8077
Acrylonitrile-butadiene-styrene	ABS	DIN 16891
Acrylonitrile-styrene-acrylate	ASA	DIN 16891
Polybutene	PB	DIN 16969
Glass-fiber-reinforced epoxy resin	EP-GF	DIN 16870
Glass-fiber-reinforced polyester resin	UP-GF	DIN 16868

Manufacturers of semifinished plastic products have different recipes, which can exhibit different fabrication and performance properties due to the use of lubricants, stabilizers, and modifiers, but are marketed under the same type designation, and this can lead to problems. Optimal plant reliability is ensured only if mixed constructions of different recipes are avoided. This applies also to welding additives, which must be of the same type.

In individual cases, for laboratory or miniplant applications as well as for test and demonstration purposes, piggable glass pipes are used.

5.3

Piping Elements

5.3.1

Pipes

Welded or Seamless Pipes

Straight pipelines in the nominal size range 1" to 10" are available in both seamlessly drawn and longitudinally welded forms. Generally, pipes of both types are applicable in pigging units. Longitudinally welded and seamless pipes are two different "philosophies". Experience with pigging units using both types exists. In each case, the most economical finishing method should be selected.

Seamless (DIN 2452 [3]) and welded high-grade steel pipes (DIN 2463 [3]) were manufactured in Germany according to different standards but with the same standardized dimensions. In European standards these were combined in a common standard: DIN EN ISO 1127 [3].

Seamless pipe only appears to have an advantage over welded pipe. In fact, the longitudinal weld produced in press or fusion welding devices is remarkably symmetrical and without seam dip. During finishing process the interior seam is smoothed, and the seam quality is $v=1.0$. Stress-relief annealing and further treatment by cold drawing are possible further processing steps, depending on the manufacturer. Pig wear is symmetrically distributed around the periphery, since the position of the longitudinal welds in the individual pipes is also statistically distributed.

An advantage of welded pipe over seamless pipe is the larger range of possible diameters, since the production technique is substantially more flexible.

When welding the circumferential welding seam of longitudinally welded pipe sections the question arises whether to permit longitudinal weld on longitudinal weld or to have a deliberate twist about a center angle. The former method creates a cross-seam which should be avoided according to conventional pressure vessel engineering guidelines for larger wall thickness, but has the advantage of a symmetrical pipe-to-pipe transition. A more uniform pig travel can be achieved by using longitudinal weld on longitudinal weld.

Inner Surface

A further benefit of welded pipe is the possibility of using cold-rolled sheet as starting material. Thus, very smooth surfaces are achieved with a surface roughness $R_a = 0.8 \mu\text{m}$, and $1.6 \mu\text{m}$ in the region of the welding seam (see Fig. 5-1). Hot-rolled metal sheet and the inner surface of seamless pipe have a roughness height of on average $4 \mu\text{m}$, i.e., about five times higher than that of cold-rolled sheet. The surface can be further improved by electropolishing, which is particularly important for pigging lines for pharmaceutical and biochemical applications.

For the highest requirements the total pipe section must be calibrated; for standard applications is sufficient to calibrate only the pipe ends. Pipes with very large nominal size ($> 12''$) must also be calibrated completely.

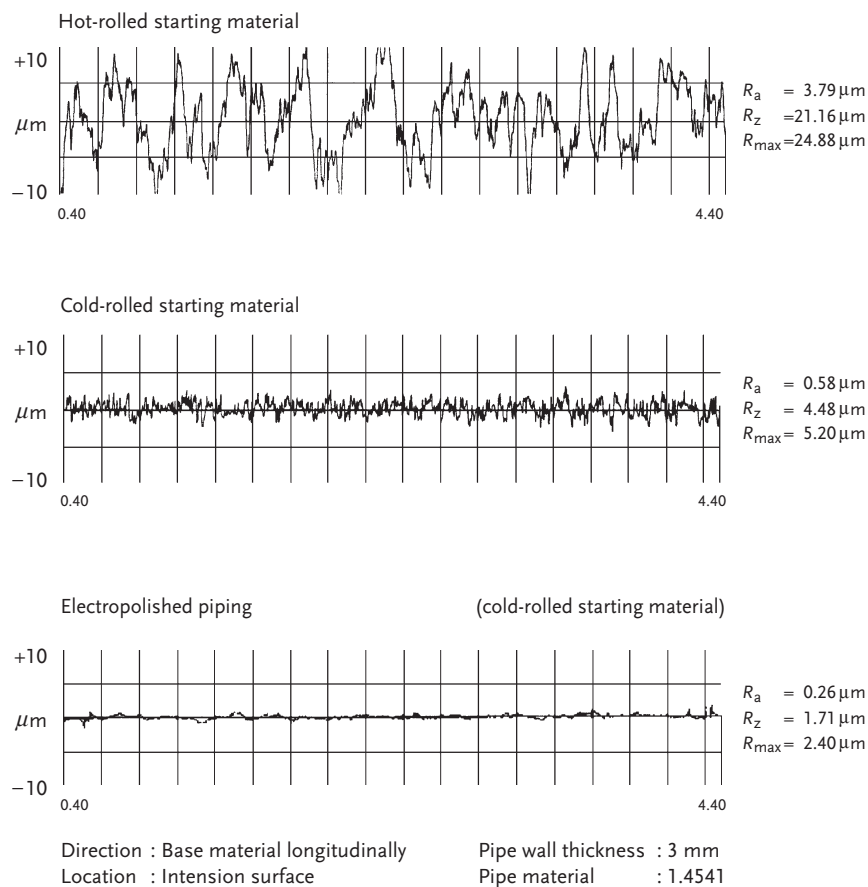


Fig. 5-1. Comparative surface roughness of different metal sheets

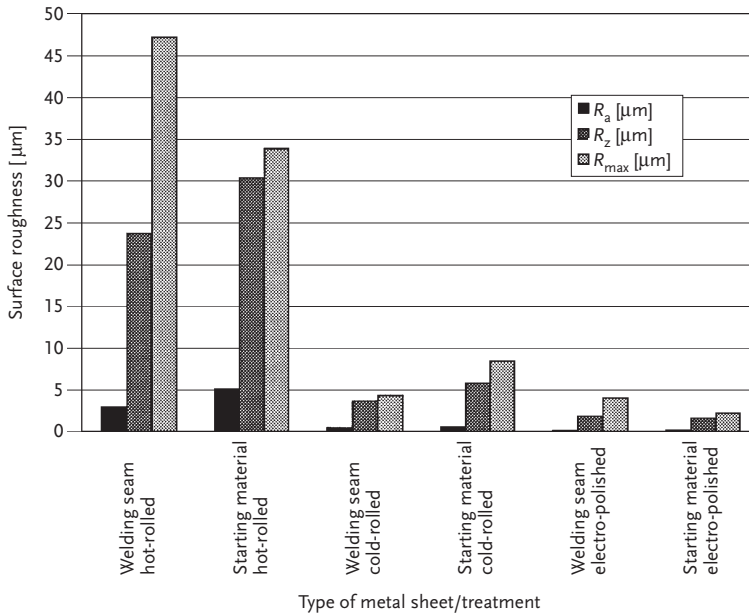


Fig. 5–2. Comparison of the surface roughness of hot-rolled, cold-rolled, and electropolished semi-finished material (courtesy of Butting, Germany)

Standardization of Piggable Pipes

A problem in planning pigging units is that the usual standardization of pipes is in terms of outside diameter and wall thickness, while for pigging the inside diameter is relevant. A large number of possible inner diameters thus results for which suitable valves and pigs are difficult to obtain or not available.

The pipe wall thickness should be larger in pigged pipes than in normal pipes. With a lower pipe wall thickness the deviations from roundness are already larger during manufacturing, and pipe supports can more readily cause deformations. Furthermore large dynamic loads in pipe bends and valves can occur during pigging.

Maximum Deviations of Pipe Dimensions

For a precision industrial pigging unit a standard pipe according to DIN EN ISO 1127 [3] with the dimensions D2 for the outside diameter and T3 for the wall thickness (D2, T3: see above-mentioned standard) is to be considered. For this the following worst-case scenario results:

Calculation of the tolerance (difference between maximum and minimum dimensions of the pipe: 114.3 mm $\times$ 3.6 mm according to DIN EN ISO 1127

Outside diameter: 114.3 mm, wall thickness: 3.6 mm

D3 = $\pm 0.75\%$ = 0.86 mm

T3 = $\pm 10\%$ = 0.36 mm

Smallest inside diameter by using the maximum tolerance: combination of smallest outside diameter and thickest wall

$$D_{\min} = 114.3 - 0.86 - 2 \times 3.6 + 2 \times 0.36 = 105.52 \text{ mm}$$

Largest inside diameter by using the maximum of the tolerance: combination of largest outside diameter and smallest wall

$$D_{\max} = 114.3 + 0.86 - 2 \times 3.6 + 2 \times 0.36 = 108.68 \text{ mm}$$

The actual dimension of this pipe may lie between these two limits. The magnitude of the difference (3.16 mm) means that a pig cannot compensate for it by elastic deformation, and the cleaning effect is accordingly bad. Such standard pipes can be applied when using brush, spherical, or lip pigs; for solid cast pigs with a high degree of cleaning they are unsuitable. This example assumes the maximum tolerance; a decrease is possible if pipe sections from a single batch are used.

A new standard has been developed for pipes with standardized inside diameter for industrial pigging units. The thickness tolerance of the semifinished product then no longer affects the inside diameter, but merely changes the outside diameter.

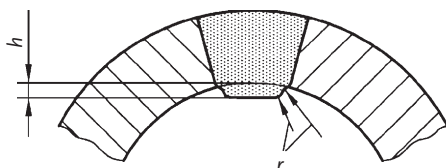
The standard is DIN 2430 – Piping for pigging systems, which consists of three parts: Part 1 : Pipes and pipe bends, Part 2: Piping connections, Part 3: Testing prior to commissioning.

An example of a table dimensions and maximum is shown in Tab. 5–3.

Table 5–3. Excerpt from DIN 2430: dimensions and maximum deviations of industrial pigging lines.

Nominal size	Wall thickness according to EN 10259	Inside diameter	Limit deviations of inside diameter		Excess penetration of inside longitudinal weld h (see Fig. 5–3)
			including ovality	from circumference ^a	
25	2.0 ± 0.09	29.7	± 0.15	± 0.1	< 0.04
50	2.9 ± 0.11	54.5	± 0.25	± 0.1	< 0.04
80	3.2 ± 0.13	82.5	± 0.3	± 0.15	< 0.05
100	3.6 ± 0.13	107.1	± 0.35	± 0.2	< 0.09
150	4.5 ± 0.14	159.3	± 0.75	± 0.25	< 0.25

- a) Calculation: $d_i = \frac{U_a}{\pi} - 2s$
 d_i : inside diameter, U_a external circumference, s actual wall thickness



h : see table above
 r : min 1mm

Fig. 5–3. Excess penetration of the longitudinal welding seam for pigging lines.

5.3.2

Pipe Bends

In principle, for piggable pipes as with conventional pipes, the following methods are possible:

- Use of prebent pipe sections
- Use of straight pipes with welded pipe bends

The former method (pipe bending) requires an accurate and careful preparation of the pipe isometrics as basis of optimal fabrication. A condition for this are the process and instrumentation drawings (P&IDs) and equipment-arrangement and building plans. Already in the planning phase the later course of the pigging line is optimized.

Pipe bends are manufactured by mandrel- or roll-bending machines, which is a very economical method. They are generally used up to DN 150. In addition roll-bending machines are available that achieve bends with radii up to DN 300 with smooth inner curves and free from creases. Otherwise it is advisable to work with a sand-filled pipe (free of wrinkles in the upsetting zone). A possibly decreased utilization degree (permissible bend internal pressure/permissible internal pressure of the straight pipe piece) must be taken into account.

The second method is the welding in of manufactured pipe bends (elbows). For industrial pigging units the mass-produced butt-welding pipe bends according to DIN 2605 (45° and 90°) are used [3]. Longitudinally welded pipe bends are cheaper and have shorter delivery times than seamless pipe bends. These pipe bends can be welded directly to straight sections of the pipeline or provided with weldable neck flanges (e.g., for parts of the plant that are not readily accessible).

Pipe bends are subject to the same requirements as pipes: the maximum permissible diameter tolerance in the curve should not exceed 1 %. The roundness is checked by means of a calibrating mandrel and the pipe reworked if the inside diameter is too large or too small. A shank extension, i.e., a straight intake section without a peripheral welding seam, into the elbow with a length corresponding to at least the nominal size of the pipe should be present. With larger nominal sizes the roundness and/or the uniformity should be examined with a precisely dimensioned sphere.

Bending Radius

Regardless of whether welded pipe bends or prefabricated pipe sections are used the question of the appropriate bending radius of pipe bends in pigging lines arises. The bending radius is indicated frequently as multiple of the nominal diameter. The usual distribution in a chemical plant is ca. 70 % 3D and 30 % 5D bends. Exceptions include pipes for pneumatically conveyed bulk materials, which require larger radii.

The minimum bending radius r for pipe bend in pigging lines is the subject of numerous discussions. Regardless of manufacturers specifications and concessions to the space requirements, however, the choice of bending radius depends on:

- The desired pigging result (sealing effect, cleaning degree, uniform pig travel): the higher the degree of cleaning the larger the bending radius.
- The higher these requirements, the larger the bending radius.
- The elastic behavior of the pig material (hard/soft): the harder the pig material, the larger the bending radius.
- Pig geometry (L/D ratio, pig length): with increasing L/D ratio and increasing pig length L, the bending radius must be made larger.
- The pig type (spherical pig, lip pig, solid cast pig): in this order increasing bending radii are required

Butt-welding pipe bends are offered according to DIN 2505 in the types 2, 3, 5, 10, and 20. Table 5–4 list the different designs and their bending radii (see also Fig. 5–4).

Table 5–4. Design, designation, and bending radii of pipe bends.

Design	Designation	Bending radius r
2	2D	$1.0 d_o$
3	3D	$1.5 d_o$
5	5D	$2.5 d_o$
10	10D	$5.0 d_o$
20	20D	$10.0 d_o$

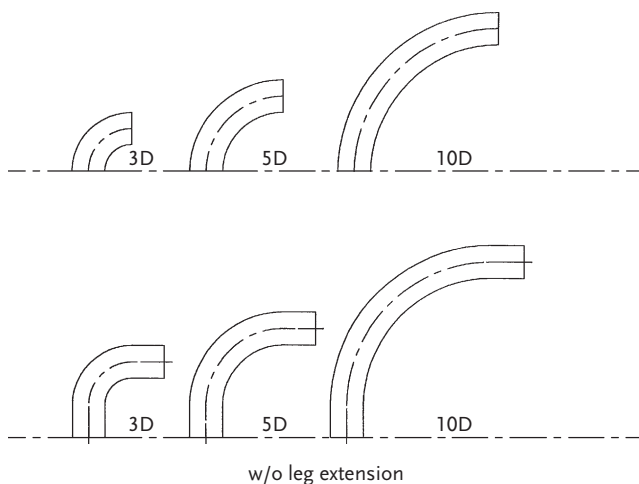


Fig. 5–4. Comparison of different designs of pipe bends.

Elbows with larger radii than type 5 are termed elbows with slim radii.

For the reasons mentioned above the installation of 5D elbows is highly recommended. The bending radius then correspond to the 2.5-fold outside diameter.

Taking into account the spatial and economic boundary conditions, the pig's running behavior, the pigging result, and the service life are optimal when using elbows of this size. In the pigging line with type 5 elbows a lower minimum pig diameter can be used and thus a longer service is guaranteed (see Section 11.3).

Type 3 elbows should be avoided in fine-cleaning applications. They can be used in special cases, under spatially constrained conditions, for example, in loading arms for filling of tanks, rail cars, or ships.

Wall Thickness

For a given nominal pressure pipe bends have a larger wall thickness than pipes. With pigging lines, however, reinforced elbow walls can rarely be used, since with a constant inner diameter a heavier wall would lead to a increased outer diameter. Such bends would be difficult to manufacture.

If pipe bends with different wall thickness to the pipe are used, then a welding joint preparation (to adapt the wall thickness) must be carried out on the welded end of the pipe bend.

In the new DIN standard for piggable pipes the dimensions and maximum deviations of piggable pipe bends are defined and (see Tab. 5–5).

Measurement of the pipe inside diameter at the elbow is very difficult; therefore, the tolerances have to be measured on the basis of the pipe outside diameter.

Table 5–5. Dimensions and maximum deviations of piggable pipe bends (DIN 2430–1).

Nominal size	Bending radius [mm]	Relative limit deviations Δd_{rel} in the bending area [%]*
25	72.5	+0.5 to –1.0
50	135	+0.5 to –1.0
80	205	+0.5 to –1.0
100	270	+0.5 to –1.5
150	390	+0.5 to –2.0

$$* \quad \Delta d_{\text{rel}} = \frac{d_{\text{ob}} - d_{\text{os}}}{d_{\text{os}}} \cdot 100 \%$$

Δd_{rel} relative limit deviation
 d_{ob} outside diameter of bend
 d_{os} outside diameter of straight pipe

5.3.3

Tees

Here only T-pieces without shut-off and pig trapping functions are considered (i.e., fittings, but not valves). Since in pigging lines freedom from dead volume is required such t-pieces are rarely used.

Instead special fittings are installed such as T-ring valves or product branches, possibly with an integrated pig trap and ball valve. These fittings are flanged (see Section 4.3.2).

If a pigging unit can be equipped with branch (see Section 2.3.2) without these special fittings, but with a simple T-piece, the following must be observed:

The outlet must be either two nominal sizes smaller than the pipeline or it must have welded guide bars for pig travel. Another possibility is a short constriction in the outlet, followed by conical widening to the required cross section. The reliability of pig travel depends on the L/D ratio of the pig (see Section 3.2.4).

5.4 Pipe Joints

5.4.1 Flange Connections

The requirements for the entire piggable pipeline discussed in Section 5.1 especially apply to the flange connections. For standard pigging tasks conventional standardized pairs of flanges can be used. With increasing requirements for cleaning performance, flanges must be modified or special flanges must be manufactured.

In principle piggable pipes can be flanged or welded. For long pipelines, welding of the individual pipe sections is recommended, but in some cases, e.g., buildings with out ready access, flange connections are unavoidable. In general however, flange connections are only necessary for the valves. The number of pipe bends, flanges, T-pieces, and valves should be minimized. Today, long straight pipes do not need flanges for removing stuck pigs.

A flange connection consist of a pair of flanges, the gasket between them and the connecting elements. Flanges for conventional pipes are standardized according to nominal sizes and nominal pressures (DIN 2500 [3]). Flanges for piggable pipes are standardized since Sept. 2001 with DIN 2430-2. An exception of the recommended dimensions and tolerable deviations are shown in Table 5–6 and Fig. 5–5.

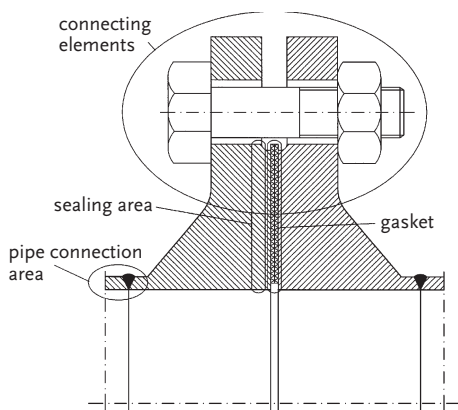


Fig. 5–5. Flange for piggable pipelines

Table 5-6. Dimensions and tolerances for piggable flanges, after DIN 2430-2.

Nominal Diameter	d_1	d_2	d_3^a	d_4^b	h_1 PN 16	h_1 PN 40	h_2	h_3	h_4	h_5	O-Ring
DN 25	29.7 ± 0.1	$33.7 \begin{smallmatrix} 0 \\ -0.2 \end{smallmatrix}$	$43.4 \begin{smallmatrix} 0 \\ -0.2 \end{smallmatrix}$	$53 \begin{smallmatrix} +0.046 \\ 0 \end{smallmatrix}$	$53 \begin{smallmatrix} -0.060 \\ -0.106 \end{smallmatrix}$	36 ± 1.5	38 ± 1.5	6 ± 0.5	$2.7 \begin{smallmatrix} +0.05 \\ 0 \end{smallmatrix}$	$2.2 \begin{smallmatrix} 0 \\ -0.1 \end{smallmatrix}$	47.22×3.53
DN 50	54.5 ± 0.1	$60.3 \begin{smallmatrix} 0 \\ -0.3 \end{smallmatrix}$	$68.4 \begin{smallmatrix} 0 \\ -0.2 \end{smallmatrix}$	$78 \begin{smallmatrix} +0.046 \\ 0 \end{smallmatrix}$	$78 \begin{smallmatrix} -0.060 \\ -0.106 \end{smallmatrix}$	43 ± 1.5	45 ± 1.5	6 ± 0.5	$2.7 \begin{smallmatrix} +0.05 \\ 0 \end{smallmatrix}$	$2.5 \begin{smallmatrix} 0 \\ -0.1 \end{smallmatrix}$	72.62×3.53
DN 80	82.5 ± 0.15	$88.9 \begin{smallmatrix} 0 \\ -0.4 \end{smallmatrix}$	$100.4 \begin{smallmatrix} 0 \\ -0.2 \end{smallmatrix}$	$110 \begin{smallmatrix} +0.054 \\ 0 \end{smallmatrix}$	$110 \begin{smallmatrix} -0.072 \\ -0.126 \end{smallmatrix}$	47 ± 1.5	55 ± 1.5	7 ± 0.5	$2.7 \begin{smallmatrix} +0.05 \\ 0 \end{smallmatrix}$	$2.5 \begin{smallmatrix} 0 \\ -0.1 \end{smallmatrix}$	104.37×3.53
DN 100	107.1 ± 0.15	$114.3 \begin{smallmatrix} 0 \\ -0.4 \end{smallmatrix}$	$125.4 \begin{smallmatrix} 0 \\ -0.2 \end{smallmatrix}$	$135 \begin{smallmatrix} +0.063 \\ 0 \end{smallmatrix}$	$135 \begin{smallmatrix} -0.085 \\ -0.148 \end{smallmatrix}$	49 ± 2	62 ± 2	9 ± 0.5	$2.7 \begin{smallmatrix} +0.05 \\ 0 \end{smallmatrix}$	$2.5 \begin{smallmatrix} 0 \\ -0.1 \end{smallmatrix}$	129.77×3.53
DN 150	159.3 ± 0.2	$168.3 \begin{smallmatrix} 0 \\ -0.4 \end{smallmatrix}$	$184.8 \begin{smallmatrix} 0 \\ -0.2 \end{smallmatrix}$	$199 \begin{smallmatrix} +0.072 \\ 0 \end{smallmatrix}$	$199 \begin{smallmatrix} -0.100 \\ +0.172 \end{smallmatrix}$	52 ± 2	72 ± 2	9 ± 0.5	$4.3 \begin{smallmatrix} +0.05 \\ 0 \end{smallmatrix}$	$2.5 \begin{smallmatrix} 0 \\ -0.1 \end{smallmatrix}$	189.87×5.33

a) corresponding to tolerance group H8

b) corresponding to tolerance group e8

In the following, four flange features (pipe connection area, sealing area, gasket, and connecting elements) and their effects on piggability are described (see Fig. 5–5). A general requirement for flange design in piggable pipelines is avoidance of high temperatures and pressures. The design challenge is the avoidance of cracks and dead spaces.

Pipe Connection Area

For the pipe connection area, a weld-on flange with a conical neck, a welding flange (flat flange), or a threaded flange can be used. For piggable weld-on neck flanges are recommended. The welding seam is readily accessible, easy to inspect, and can be ground manually. In the case of the welding flange, the welding seam at the pipe end flange joint leads to a gap (dead space). A moveable flange can be achieved by means of a welded shoulder.

Sealing Area

In accordance with DIN 2501 [3] the sealing area can be of the types flat, tongue and groove, spigot and recess, and with turned groove. The simple flat flange does not provide for accurate centering of pipes, but it has the advantage that the flange connection can be installed and deinstalled without axial shifting of the counterparts.

Apart from the turned centering shoulder the gasket can be freely accessible or embedded in a gasket chamber. Certain gaskets require a chamber (e.g., O-rings). If over- or an underpressure in the pipe cannot be excluded (e.g., a pressure peak during pig travel), a chambered gasket is advantageous.

For the function and/or cleaning efficiency of the pigging line the radial position of the gasket is crucial, i.e., whether it is near the inside of the flange or further outside. The larger the gasket diameter relative to the pipe inner diameter, the longer the gap between product and seal (dead space). The radial position of the gasket and/or the position of the gasket chamber depends on the desired degree of cleaning. With gaskets that are in direct contact with the product (flat gaskets, sterile gaskets; see Chap. 16) it must be ensured that they do not extend into pipe, even after tightening the screws.

The sealing surface of the flanges should be smoothed. The inside diameter of the flanges must correspond to that of the pipe. The inner edge in the region of the sealing area must be rounded (radius 1.5 or 2 mm), i.e., flanges must generally be reworked to make them suitable for application in a pigging unit. High demands on the pigging unit (pigging result) require centering of flange pairs. These requirements can be fulfilled by flanges with spigot and recess. For less stringent requirements with flat flanges, misalignment of the inside diameters must be avoided.

Gaskets

Flat gaskets (soft gaskets), encased gaskets, and more rarely metal gaskets are suitable for pigging units. Flat gaskets should be as thin as possible. The inside diameter of the gasket must be equal to that of the pipe; under no circumstances may the gasket protrude into the pipe.

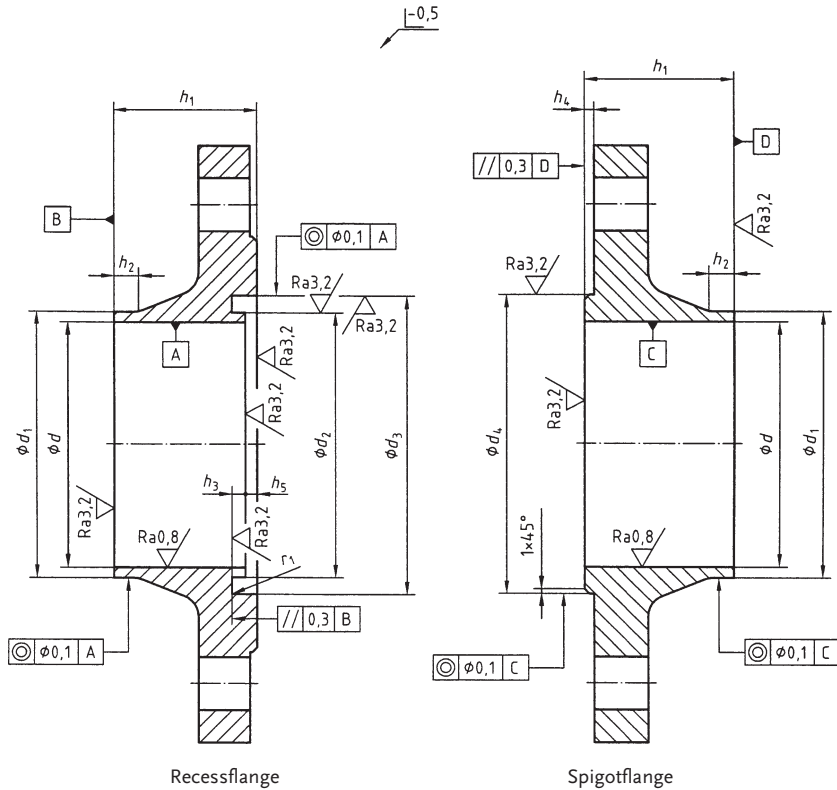


Fig. 5-6. Flange with spigot/recess for pigging units, after DIN 2430-2.

Connecting Elements

Depending on nominal pressure and diameter, piggable flanges are connected with 4, 8, or 12 bolts in the size range M10 to M27, usually according to DIN 931; bolts after DIN 2510 [3] are not required.

The general construction rules for the positioning of the bolts need not to be obeyed with the usual strictness in this case, since no high pressures or temperatures occur. Nevertheless, the bolts should be as close as possible to the inside of the flange and/or the gasket, to avoid warping of the flange face. During mounting the flanges must not be tilted. To avoid inclination of the sealing areas, the screws must be tightened symmetrically, possibly with torque monitoring.

5.4.2

Welded Pipe Joints

This section deals only with aspects of relevance to welded joints in piggable pipes.

General notes: Before welding all pipe ends must be examined with a calibrating mandrel and reworked if necessary. The welding region must be prepared carefully.

The pipe ends are cut to length perpendicular to the pipe axis (flat). Before beginning construction test welding must be performed. It makes a difference whether the circumferential seams can be welded in a workshop under optimum conditions or whether they must be welded on a pipe rack. Two techniques are applied: orbital welding and welding in welding sleeves; the former method is preferred.

Critical parts of piggable pipelines are primarily the junctions between the individual pipe sections. Their permissible ovality of the pipes specified in the general standards can lead to misalignment of the pipes at the junctions, which impairs the function and shortens the service life of the pig. Overhanging pipe ends present increased resistance to the pig, which is radially prestressed. Recesses at the junctions lead to puddle formation and thus to undesired and intolerable formation of residues. Sagging of the welding seam root (seam dip) and the relapse of the root are shown schematically for a circumferential weld seam lying in the vertical plane in Fig. 5–7.

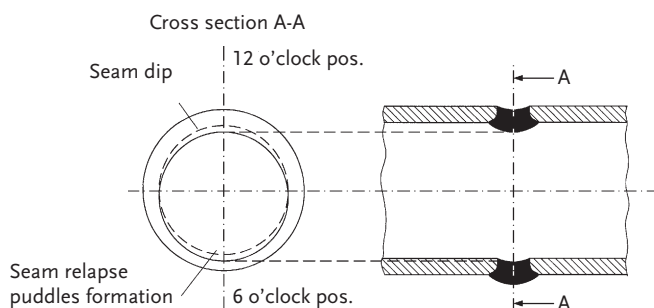


Fig. 5–7. Seam dip and seam relapse

A prerequisite for a pipe to be perfectly piggable at the joints is therefore the removal of the ovality of the pipe ends and their mutual coaxial alignment before welding. This is ensured by mandrels or internal clamping devices. The internal clamping device (Fig. 5–8) grips the parts to be welded with pneumatically or hydraulically actuated wedge-shaped chucking elements in a peripheral distribution. It can be moved along the pipe axis.

The internal clamping devices have the following advantages:

- Quick and simple adjustment and centering
- Removal of ovality
- Tacking of the pipe ends is unnecessary
- Leads the protective gas directly under the circumferential welding seam
- Annealing color-free root
- The axial force exerted on the welding seam supports its shrinking process

Straight pipes from 1" upwards can be clamped with this device, and from 3" upwards it can pass through pipe bends. In prefabricated curved pipes sufficient length of the hauling cable and the energy supply must be ensured (see Fig. 5–8).

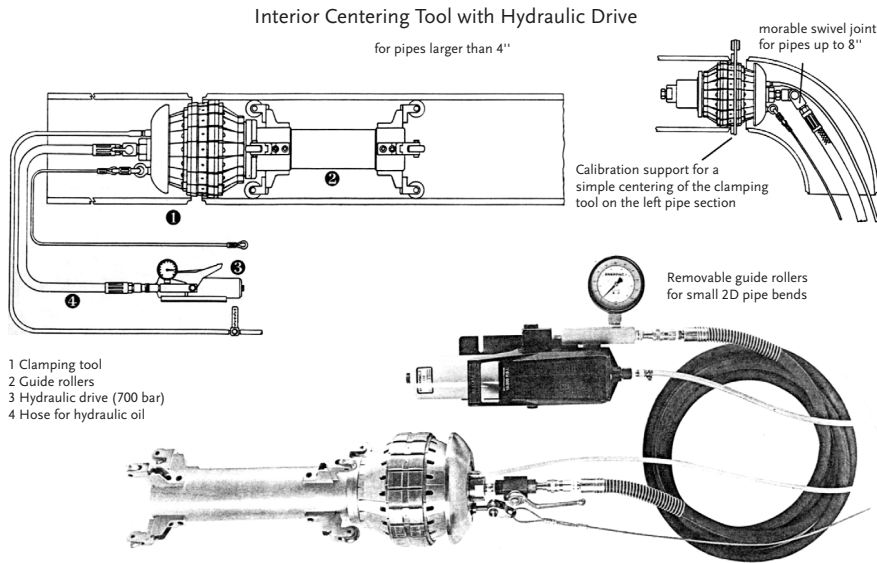


Fig. 5–8. Interior clamping device

The interior clamping device has made a substantial contribution to the piggability of orbitally welded pipes.

To a certain extent, circumferential welding seams can be worked after welding, e.g., by internal grinding. Special internal grinding tools for pipes run at very high speed, so that even at small diameters they reach necessary peripheral speed for the grinding process. Some devices can be driven through and positioned in the welded line, including elbows.

Orbital Welding

Orbital welding is a mechanized tungsten inert gas (TIG) welding process for the connection of individual pipe section. The butt weld is made by a welding clamp. For orbital welding the inner edges of the pipe ends must be deburred. Before welding, the pipe ends are tacked at three peripheral positions (centering) with inert gas internal flushing or fixed with a special clamping device (see above). By carefully setting all parameters a very symmetrical seam can be created. The root dip is only a few tenths of a millimeter, so that a high degree of cleaning of the line can be achieved together with low pig wear.

Advantages of orbital welding:

- Higher (compared with welding sleeves), uniform, and reproducible quality
- No gap formation
- Smooth surface of seam inside and outside
- On the construction site the devices can be used in all welding positions
- Suitable for personnel without welding experience

- The welding seam can be easily checked for internal errors
- Low production cost (in contrast to welding sleeves only one seam is necessary)

Disadvantages of orbital welding:

- Very expensive automatic welding machine
- Very accurate joint preparation required
- Higher sensitivity of the devices to external influences
- Weld defects which occur during welding are only detected after welding is complete
- Test welding required before beginning of welding on the building site or after equipment malfunction

Partial-Seam Welding

Partial-seam welding is a special case of orbital welding. It avoids dipping of the welding seam in the 12-o'clock position and relapse in the 6-o'clock position. In the so-called critical falling-seam range, fusion errors and noninclusion of the seam flanks in the root are avoided. The following description assumes the case of a circumferential welding seam lying in a vertical plane (e.g., construction work on a pipe rack).

This new technique exploits the finding, that upwardly welded seams lead to optimal root formation, i.e., an almost completely flat smooth pipe inner surface without any transition. The welding seam is made of two partial seams S_1 and S_2 (see Fig. 5–9), both of which start from the lowest point B. Seam S_1 is welded from B anticlockwise and upwards to the highest point. To achieve a smooth transition between the first and second partial seams a S_1 is welded a little past the highest point of the seam (11-o'clock position).

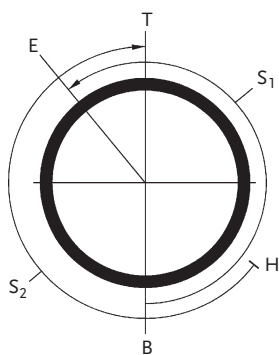


Fig. 5–9. Partial-seam welding

A smooth transition at the lowest point of the seam is achieved by means of a preheating section, which starts around the 4-o'clock position and ends in the initial range of S_2 . Seam S_2 is welded clockwise from B to T, whereby it welds over part of S_1 from E to T. In this over-welding section the welding current is continuously decreased.

This new, patented technique can be carried out with conventional orbital welding devices which use inert gas without welding-rod materials and have a nonmelting electrode made of tungsten.

Welding Sleeves

Welding sleeves (see Figs. 5-10 and 5-11) are short pipe sections, which are pushed over the pipes to be connected and are welded to them by two circumferential fillet welds.

The welding sleeves are custom manufactured, so that the inside diameter of the sleeve and the outside diameter of the pipe fit with a defined amount of play (for easy sliding). Standard commercial pipe sections are unsuitable due to their inaccuracies. The pipe ends are cut to length at right-angles, pushed together, and tacked at three positions with interior inert gas flushing. The sleeve is slid over and welded with fillet welds (seam thickness = pipe wall thickness), whereby the pipe must be flushed inside with inert gas during the entire welding procedure. With long pipes inert-gas savings can be made by using balloon bulkheads.

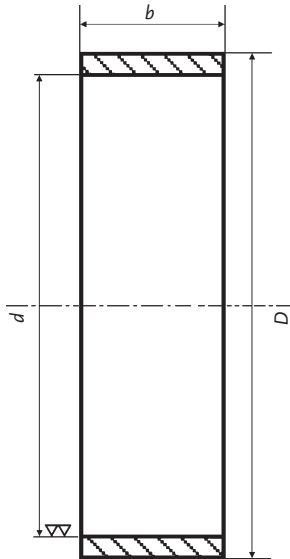


Fig. 5-10. Dimensions of welding sleeves

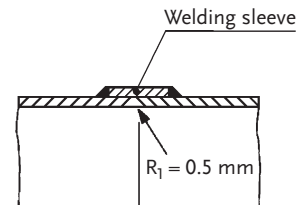


Fig. 5-11. Pipe joint with welding sleeve

Disadvantages of welding sleeves:

- Expensive execution (two welding seams, expensive pipe sleeves, polishing of the tacking positions).
- Examination of the welded joint for internal errors is not possible or is very difficult.
- Contractions in the welding zone
- During internal pickling, the pickling agent penetrates into the gap and can no longer be neutralized (danger of crevice corrosion).
- Skilled welders required.

The main advantage of the pipe welding sleeves is that the high investment costs for the automatic welding machine can be saved.

With other joints (e.g., mechanized circumferential seam welds with stationary torch for pipe-flange joints) the inside of the welding seam must be post-treated mechanically.

For manufacturing of piggable lines it is favorable to execute the welding seams mechanically (orbital technology or with stationary torch). Wherever possible pre-bent pipes are preferred to welded pipe bends.

5.5

Example of a Pipe Specification

Here, two examples of a specification for piggable pipes (6", DN 150) are given.

Specification for a Piggable Pipe acc. DIN 2430

- Piggable pipe DIN 2430 – 150 – k2g – 1.4307.
Designation of a piggable pipe of normal size 150 mm, surface finish k2g, material 1.4307.
- Piggable elbow DIN 2430 – 150 – 90 – k2g – 1.4307.
Designation of a piggable elbow of normal size 150 mm, angle 90°, surface finish k2g, material 1.4307.
- Piggable flange DIN 2430 – 150 – 40 – R – 1.4404.
Designation of a flange of normal size 150 mm, pressure rating 40, with recess, material 1.4404.

Specification for a Piggable Pipe acc. DIN 17457

Straight Pipe

- Inside diameter of 159.3 mm, wall thickness 4.5 mm.
- Material: 1.4541, longitudinally welded, made of cold-rolled strip (17441).
- Tolerance of inside diameter, including ovality: ± 8.8 mm.
- Tolerance of inside diameter from circumference: ± 0.4 mm.

- Thickness tolerance: ± 0.15 mm, max. straightness deviation: 1.0 mm/m.
- Roughness height inside max. $2.5 \mu\text{m}$, excluding welding seam range.
- Design DIN 17457, test class 1, k2.
- External seam polished, interior seam pressed, root dip < 0.45 mm.
- Unplaned, sawn ends, production length 12 m.
- Certificate of acceptance test: EN 10204/3.1B.

Pipe Bends

- Material: 4541, made of welded pipe, as described above.
- Type 5D, bending radius 400 ± 30 mm.
- Inside diameter: in bending plane $159.3^{+1.5\%}$ mm, 90° to the bending plane $159.3_{-1.5\%} + 0.5\%$ mm.
- Root dip < 0.3 mm.
- Wall thickness attenuation in the outside bend up to ca. 30 %.
- Cold-bent, free of creases, with two-side shank extension of 150 mm.
- Pipe ends calibrated according to DIN 2559/1.
- After bending: heat-treated, pickled.
- Certificate of acceptance test: EN 10204/3.1B.

Welded Joints

- Partially mechanized welding process with orbital technology (pTIG).
- Root protection with forming chamber, O_2 measurement in the seam region.
- Connection of the pipe sections by I-joints without welding filler.
- Surface of the welding seam inside the pipe must be piggable, i.e., no sharp-edged seam regions.
- No oxide formation in the seam region.
- Free of annealing color (straw yellow is permissible according to DIN).
- Maximum seam overhang smaller than for welding test specimen.

Quality Assurance

- Approval at the manufacturer by measurement of all pipe sections.
- Mechanical internal cleaning of all pipe sections before processing.
- Visual inspection of the pipe inside surface.
- Inspection of all welds by video from the inside.
- X-rays of the welding seams at the flanges.

5.6

Construction of Piggable Pipes

For the construction of piggable pipelines the usual general construction guidelines apply. During transport and installation it must be ensured that no damage (e.g., dents) occurs.

Supports, hangers, and holding devices should be used more frequently than with conventional pipelines and selected carefully. An increased number of supports ensure a better sit of the pipeline and prevent hammering of the pipe during pig travel. During pig travel changes in speed, passage through an elbow, and stopping at a pig trap result in substantial dynamic forces and/or changes in impulse. On the other hand, the pipeline must not be deformed by the holding device. Placing flexible tapes in the holding device is suitable for fulfilling this requirement.

The number of circumferential welding seams must be minimized. It is therefore recommended to use prebent pipe bends and longer pipe sections.

Apart from the standard length of 6 m some suppliers also offer 12 m pipe sections. However, the mandrels of pipe bending machines are often designed for 6 m length, and many automated warehouses are also restricted to this length. Construction welding is described in Section 5.4.2.

5.7

Piggable Hoses

Hoses are used to connect vessels in a highly flexible manner and/or for distribution to particular pipes. In filling and emptying of mobile transport containers, hoses are often unavoidable. With respect to the additional requirement for piggability, solutions involving fixed installations together with the special valves described in Section 4.4 (loading lances, piggable loading arms, swivel joints, and piggable manifolds) are preferable. In this case the unit is also automatable.

Expansion joints, e.g., to compensate for piston stroke, oscillations, or stretching in connection with a motor or a machine do not exist in pigging units.

A complete hose line consists of the actual hose and the necessary coupling elements at both ends. Both the hose and the coupling elements must be piggable. In particular the transition between the hose and the coupling element should be checked in this regard. Piggable hoses should be of heavy-duty design (reinforcing mesh and/or braiding), since pressure jumps and impulse changes must be expected during pigging.

Metal and Plastic Hoses

Pure metal hoses are fabricated due to the demand for flexibility only in corrugated form (spiral and/or parallel corrugation). Thus, variable inside diameters and dead spaces are created; they are not piggable.

However composite structures are a different case, e.g., metal hoses with a plastic inliner. The liner is pulled over the sealing area of the connecting element, generally the flange face. Here a relatively large radius is necessary (see Fig. 5–12). Beside plastics (PTFE) elastomer linings are also available. Here the same materials can be used as for the pigs: NBR, Viton, silicone, etc.).

With pure plastic hoses absolutely smooth inside surfaces are possible. Only with correct manufacturing and selection of suitable coupling elements is their piggability guaranteed.

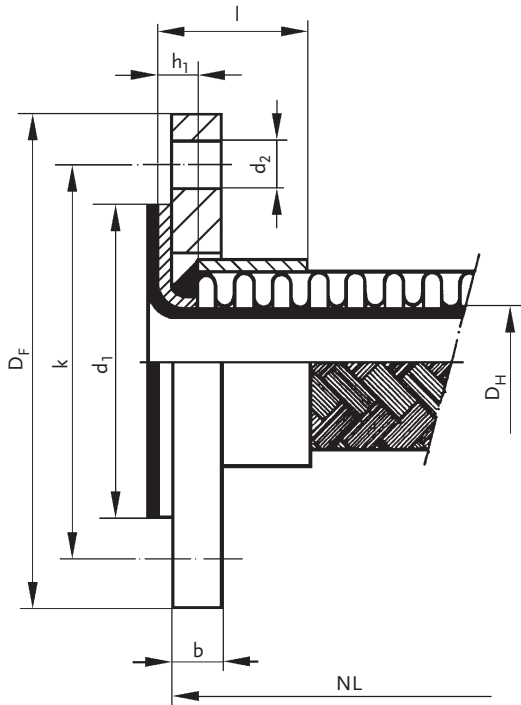


Fig. 5–12. Stainless steel hose with inliner

Available nominal sizes are up to 4". They are predominantly available in standard lengths up to 6 m. Individual suppliers are willing to manufacture hoses with a desired inside diameter. This is possible, however, only to a limited extent. The inliner can be manufactured more easily with a given inside diameter than the external hose. The distance between inliner and hose must not be too large, since a supporting effect must be maintained.

Connecting Elements and Couplings

Suitable elements are:

- Weld-on flange and/or welding neck with flange.
- Weld-on flared flange.
- Milk pipe joint (male thread with connector nut DIN 11851 [3]).
- Pipe ends prepared for welding.
- Quick-release connecting elements (hose connectors).

The couplings often used with hoses, e.g., tank car coupling in accordance with DIN 28450 [3], (e.g. Kamlok couplings) as well as the leakage-free dry couplings (disconnection with discharge protection) are not piggable.

Piggable hoses are rarely used. A piggable hose has lower flexibility and thus a larger bending radius than a standard hose. Above all hoses of larger nominal size are substantially more difficult to handle, and therefore their use is not advisable.

6

Additional Equipment

6.1

Pressure-Relief Vessel

If an industrial pigging unit is operated with compressed air as propellant, a pressure-relief vessel is necessary for the safe disposal of the exhaust air, which is partially saturated with product. This vessel:

- Relieves
- Reduces pressure peaks
- Slows down the compressed-air flow velocity
- Collects condensable product residues
- Leads the exhaust air to waste-gas purification or to an incinerator
- Releases the cleaned exhaust air to the atmosphere.

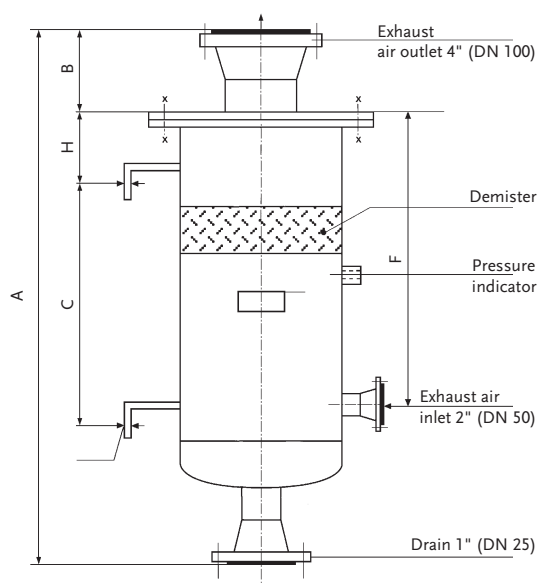


Fig. 6-1. Pressure-relief vessel

The vessel (Fig. 6–1) is a pressure vessel (inner pressure 4 bar g) with a volume of 30, 60, or 100 L with at least three nozzles (compressed-air inlet, compressed-air outlet, condensate outlet). Often a demister is incorporated. The pressure-relief vessel is subject only to a one-off examination, since it operates open to the atmosphere and thus is not considered to be a pressure vessel.

Since throttling is usually carried out on the exhaust-air side, the pressure-relief vessel is positioned after the orifice plate. To monitor the condensate level a sight glass or an alarm is practical; if necessary, the container can be also heated. The condensate can be disposed of by a return to the suction side of the pump or emptied into a container.

6.2

Propellant Tank

If the pig is driven with a liquid propellant, (e.g., water or a solvent), then a propellant tank is required for its supply.

Functions of the driving medium tank:

- Storage of sufficient propellant
- Trapping of returning propellant contaminated with product and mixing with that still in the tank
- Batching tank for a special propellant matched to the product (pure liquid or mixture)
- Investigation of pig wear

The propellant tank must be able to hold sufficient propellant to propel the pig for the entire pigging procedure. Since it is a hydraulically filled system, it is relatively easy to calculate the total tank volume by considering a few criteria. When the pig is in the most remote receiving station, the total pigging line is filled with propellant. If the pig is to be returned to the initial position, the propellant lines must also be completely filled. The tank must therefore be able to hold at least the sum of these two volumes. Additionally a certain minimum liquid level in the tank must be maintained. Running dry of the propellant pump must be avoided under all circumstances. In the vessel a vortex can form when propellant is pumped out. This can be avoided by incorporating a vortex breaker. Finally, unavoidable losses of propellant must be considered: residual inner-wall wetting after pigging, evaporation, and losses during filtration of the propellant lead to a constant loss of propellant. These losses must be regularly compensated and taken into account in dimensioning the propellant tank.

Empirical values for the tank volume are 1.5 to 3 times the volume of the pigging line.

Contamination of the propellant by product residues can be regarded as a measure of pig wear. In such cases the contents of the propellant tank can be periodically renewed. The product contained in the contaminated propellant can be recycled. Only in unfavorable cases must it be disposed of by incineration.

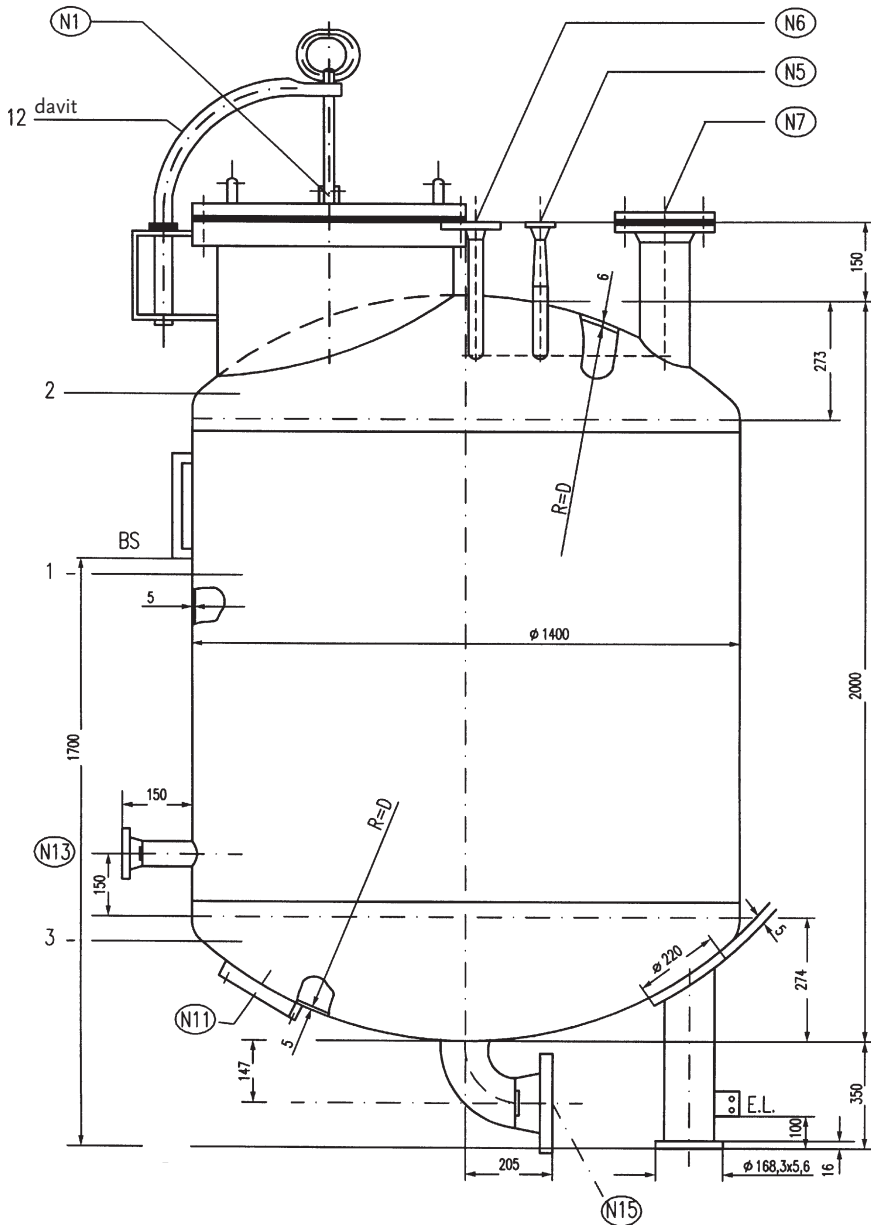


Fig. 6-2. Propellant vessel

Fig. 6-2 shows a typical propellant vessel. It is executed as pressure vessel (1 bar g) with a volume of 2700 L made of stainless steel 1.4541. The vessel stands on four tubular feet and has a manhole at the top. Propellant return is connected to N 6 and N 5 serves for filling and the refilling with propellant. N 7 is a reserve nozzle.

zle, for example, for a pressure gauge. The inlet to the propellant pump is via N 15, which can also be used also for emptying. N 11 and N 13 can be used for the level indicators. N 1 is a manhole with a tilting device (davit) for the cover.

If necessary, small amounts of solvents, cleaning agents, (e.g. tensides), or disinfectants can be added to the propellant. For tandem cleaning with a cleaning agent or solvent between two pigs travelling the same direction, an additional, smaller cleaning-agent tank may be necessary for the propellant tank. Generally this tank resembles the propellant tank in design.

6.3

Filters

In the case of products, small amounts of which already discolor the propellant or make it cloudy, and these which tend to form solid particles (polymer particles or coagulates), workup of the propellant is necessary. In the simplest case, this is performed by a filter incorporated in the propellant return before the propellant tank (see Fig. 6–3).

Product contamination of the propellant can lead to increased tendency to foaming, which unfavorably affects the running behavior of the pigs. Contamination is caused in particular by worn pigs toward end of their service life.

For the pressure filtration of liquids, bag and/or cartridge filters are suitable. The propellant flows through the filter from inside to out, and the solid contaminant is held back on the inside.

Exchangeable filters can be used to avoid downtimes. Filtration of the propellant lengthens the intervals between propellant renewal and decreases pig wear.

6.4

Pumps

Principally, pigging units contain two kinds of pumps: product pumps and propellant pumps.

The product pump, (several pumps for several products) is situated in the proximity of the product volume to be conveyed. The discharge line of the pump is usually identical to the pigging line. In exceptional cases the product pump can be bypassed by a piggable pipe. The performance of the product pump is calculated according to the usual methods (nominal size, flow, pressure drop). The pump type is selected according to product-specific and spatial aspects and is not further described here.

The propellant pump is situated between the propellant tank and the pig launching station; the discharge line is identical to the pigging line. Performance is calculated for an optimal pig speed of ca. 1 m/s. For aqueous propellants a centrifugal

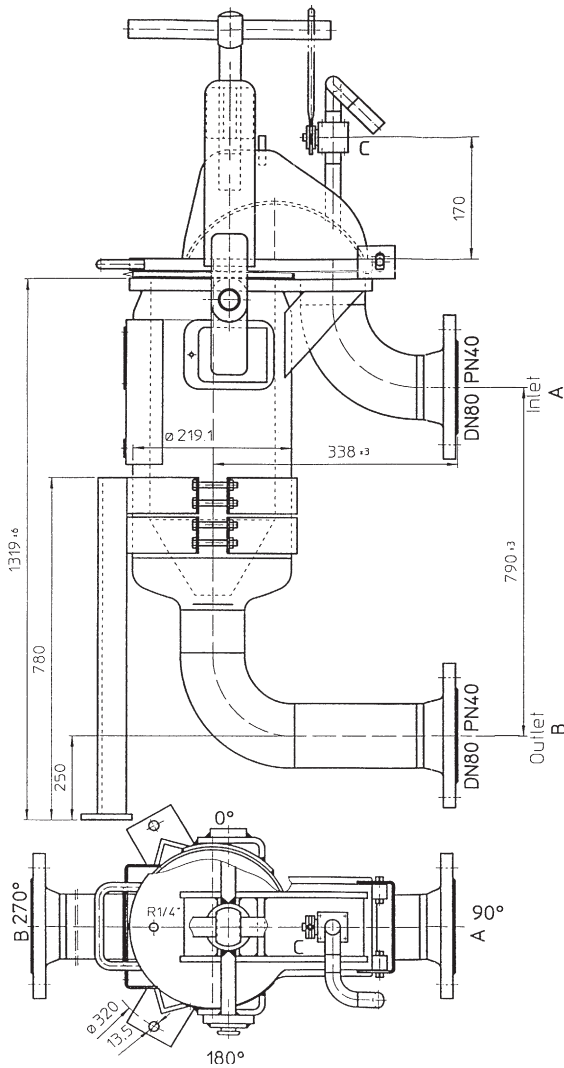


Fig. 6-3. Propellant filter (ISP, Frechen, Germany)

pump is used. With very viscous products displacement pumps (e.g., screw pumps) are necessary. With displacement pumps the pressure side must be protected against over-pressure.

7

Propellants

Pigs are not generally moved by their own drive unit, but are set in motion by a propellant. Since kinetic energy is transferred from the driving medium to the pig, the nature of the transfer is of crucial importance for the kind of movement. The duration of transfer and the potential energy play important roles. Hence, pigs, driven by a gas behave differently from liquid-propelled pigs. Due to their compressibility gaseous propellants lead to uneven pig movement. With liquid propellants ideal plug flow develops behind the pig and leads to homogenous pig movement.

A pig can also be driven by the product itself. This is necessary and usual for certain steps in industrial pigging units. Also in long-distance pipelines, transport of the pig is often performed by the product itself. Often, product pumping need not be interrupted for pig insertion and removal.

Most inspection pigs for open channels (e.g., sewers with open raceways) are driven or pulled by friction wheels. These pigs have no sealing components (lips, cups) and are thus not snug-fitting. A propellant is not required in this case.

7.1

Gaseous Propellants

With gaseous propellants the pressure is not supplied by a pump, but is transferred from an installed pipe system or a compressor unit with accumulator.

To achieve homogenous pig movement, internals can be used for the generation of defined driving-air volumes. A simple component for this purpose is an exhaust-air throttle installed in the pressure-relief air line (between pig receiving station and pressure-relief vessel) e.g., an orifice. However it must be ensured that sufficiently large air volumes can still flow.

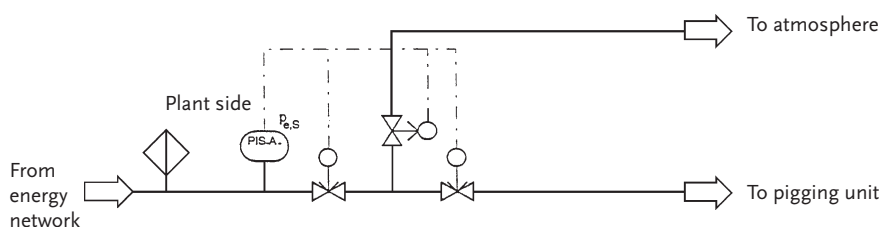
The most common gaseous propellants for industrial pigging units are compressed air and nitrogen, whereby the former accounts for about 90%. If a compressed-air network is present in the plant, this is the most economical way of driving an industrial pigging unit. Table 7–1 lists typical data for compressed-air and nitrogen networks for operating pigging units.

Table 7–1. Characteristics of compressed-air and nitrogen networks

Network	Min. pressure, bar	Reg. pressure, bar	Max. pressure, bar	Temperature, °C	Safety device pressure, bar	Nominal pressure, PN
Compressed air	3.7	4.0	5.0	10 to 50	5	10
Nitrogen	7	8.5	10	0 to 50	10	10

Compressed air is available almost everywhere in an industrial plant, and except in the cases in which safety reasons (Chap. 19) speak against it, can be used a propellant. Usually it is sufficient to ensure a plant air pressure of 4 bar.

Since during pig travel no complete mechanical isolation of the medium from the network and the product exists, contamination cannot be excluded. The required network-protection device consists of a double shut-off with intermediate pressure relief (block and bleed) and automatic switching (Fig. 7–1). The secured working pressure on the consumer side must not exceed 80 % of the network pressure. Breathing-air and control-air networks must not be used for pigging.

**Fig. 7–1.** Network-protection device for compressed air or nitrogen

Nitrogen is used as propellant when combustible liquids are pigged. Nitrogen must be used if the difference between the product flash point T_f and operating temperature T_{op} is less than 5 K (see Chap. 19):

$$T_f - T_{op} \leq 5 \text{ K}$$

The use of nitrogen as driving medium is not unproblematic because of the possible danger of suffocation (displacement of oxygen from the room air) and should be clarified in individual cases (see Chap. 19).

If the pig is accelerated by a pressure buildup, the pressure cushion relaxes due to volumetric expansion, but the pressure does not break down anywhere near as fast as with a liquid under pressure. Consequently the pig is strongly accelerated and driven forwards, until the expansion of the propellant can no longer accelerate it.

From this state of maximum speed onwards the pig becomes slower, and, depending on the pressure reserve of the propellant, can also come to a complete standstill, until a pressure builds up which is large enough to accelerate the pig

again. Thus, the pig moves jerkily forward (stick/slip behavior). This behavior is undesirable, since the cleaning effect is strongly speed dependent (Chap. 10), and so a consistent degree of cleaning cannot be ensured.

7.1.1

Speed Behavior of Gas-Driven Pigs

The maximum speeds calculated for the stick/slip effect are determined by the design of the pigging unit. For reasons of industrial and occupational safety, open-ended pigging units are only used for trial runs. However, due to the absence of back-pressure open pigging units have higher maximum speeds than closed units. Depending on pipe nominal size the difference can be up to 25 %.

Therefore, the causes of the stick/slip behavior are first tested for the more critical case of an open-ended pigging unit. For this purpose, a study was made on the dependence between speed and distance travelled by pigs in pipes.

The test pigging unit had the following characteristics:

- Nominal size 4"
- Open-ended
- Solid cast pig weighing 0.74 kg
- Maximum propellant pressure 4 bar g

The results depend on the case of a test pipe with an open end.

The basic model for the calculations assumes the following conditions:

- The pig is held by frictional forces and starts moving only when sufficient pressure has built up to overcome the static friction.
- When the pig moves, it is driven only by the pressure cushion, without any additional propellant from the supply line contributing to the acceleration. If additional propellant flowed from the supply line, further stick/slip movements would result. A mass balance shows that the pig moves more quickly than the propellant can flow.
- Speeds were calculated and verified for straight-line movement without tube bends.

Depending on the sliding pressure which must be applied by the propellant to overcome the static friction and factors such as the nominal size of the pipeline, the pig mass, and the volume available for storage of pressure energy in the propellant the speed of the pig along its path can be calculated.

The model calculates the speed from the principle of the conservation of energy by means of a force balance on the pig. By solving a differential equation, the time dependence of the distance–speed curve can be determined, as shown in Fig. 7–2 for the above example.

This clearly reveals the stick/slip behavior observed in practice: After a relatively short distance the pig already achieves maximum speed and then quickly comes to a standstill again. By means of a differential treatment, the acceleration can be calculated from the speed–distance temporal dependence (Fig. 7–3).

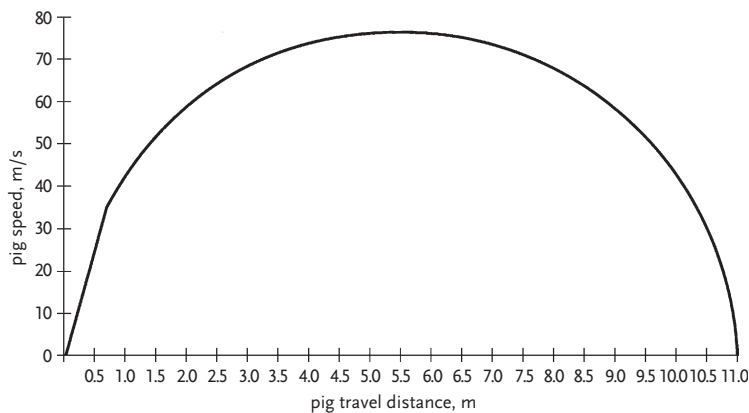


Fig. 7-2. Speed/path diagram for 4", 4 bar g, open-ended

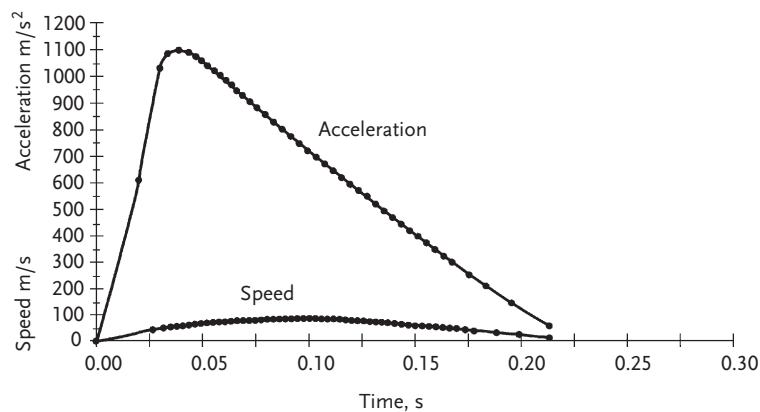


Fig. 7-3. Acceleration-distance plot for 4" pipe, 4 bar g, open-ended

For comparison, rifle bullets reach about 5000 m/s^2 , which also means a high kinetic energy. Since kinetic energy depends quadratically on speed, the attainable maximum speed was investigated as a function of the pressure of the driving medium and the nominal size.

Table 7.2 lists maximum speeds under the test conditions described above, whereby the pipe diameter is changed and corresponds with the mass of the pig.

Table 7-2. Maximum speed (in m/s) for stick/slip behavior

Driving pressure, bar*	Pipe nominal size		
	2" (DN 50)	3" (DN 80)	4" (DN 100)
4	57	73	76
5	110	142	147
6	161	207	215

* Gauge pressure

Such high speeds, as occur for example at 6 bar g, would destroy the pig in a short time due to high wear and the mechanical stress on entering the receiving station. The degree of cleaning also deteriorates, since the thickness of the residual film increases with increasing speed (see Chap. 10), and there are also risks due to the high kinetic energy.

7.1.2

Remedial Actions

The problem is solved in practice first by limiting the pressure of the propellant to 4 bar. Since the stick/slip effect negatively affects the cleaning process, one attempts to achieve uniform speed of pig travel. This is realized by installation of a throttle on the exhaust-gas side, which generates a constant back-pressure that damps the acceleration of the pig and leads to more uniform travel. Under no circumstance may the air supply be throttled, since a sufficiently high propellant flow rate must always be present. Since the magnitude of the back-pressure depends, among others on the extent of the pigging system and the pig material, experience and testing are necessary for setting the optimal value.

It has proved reasonable to set the back-pressure so that the pig speed does not exceed 7 m/s, which also reduces wear. Preferably, however, 2 m/s should not be exceeded. In contrast to liquid-propelled units, which exhibit substantially quieter running, here an additional exhaust-air system is required for throttling and to let out the throttled air and the following propellant. In some cases, depending on the product, the exhaust air can contain combustible substances, whose hazard potential must be taken into account (see Chap. 19).

7.2

Liquid Propellants

7.2.1

Properties of Liquid Propellants

Apart from special liquid propellants the product can also be regarded as liquid propellant. The following liquid propellant are commonly used:

- Water (also with additives, inhibitors, or fully demineralized)
- Product
- Cleaning agents
- Solvents

Compared with gaseous propellants the use of liquids propellants requires increased expenditure for installation and maintenance. A separate liquid-propellant circuit is required, consisting of a storage vessel, a pumping station, suitable stop valves, and propellant pipes. If a propellant return pipe is dispensed with, then a propellant tank is often required at each end of the pigging line. The liquid used can be for example, water or a suitable cleaning agent and/or solvent. Mixtures are also possible. The liquid propellant becomes enriched with product and must be regenerated or disposed of. The advantages compared with gaseous propellants are:

- Higher cleaning efficiency in the pigging line
- More uniform pig travel
- Lower probability of pig malfunctions
- Reduced pig wear.

When using product as propellants it must be ensured that the product pump has a similar performance to the propellant pump and thus generates similar pig speeds. Viscosity differences between propellant and product must be taken into account. The statement that every pumpable medium is also piggable applies in principle to both the product being pushed by the pig and to the product driving the pig.

In an industrial pigging unit the use of gaseous and liquid propellants for different procedures is possible and is often realized. Alternate use of liquid and gaseous propellants with their respective advantages and disadvantages is an important task in the design of more complex industrial pigging units. In addition, an appropriate combination of different transport mechanisms can lower capital outlays. In principle each combination is permitted and only the driving mode “gas against gas” is to be avoided.

For example, the pig can be driven by the liquid product, which is conveyed by the product pump. The product stream drives the pig ahead of itself. After the product has been pushed out of the pipe (cleaning step), back-pigging can be carried out by driving the pig with compressed air.

7.2.2

Dimensioning of Liquid-Propelled Pigging Units

One of the key points in dimensioning liquid-propelled pigging units is the design of the pump for the propellant in accordance with the pressure drop. In the simplest case the propellant is water, but the pig can also be driven by a following product, for example if materials with similar characteristics (product family) are conveyed in the unit and the quality of cleaning permits this.

If the pressure drop can be calculated, dimensioning of the pump is straightforward, since the pump power is directly proportional to the pressure drop (Eq. 7-1)

$$P = \Delta p \cdot \dot{V} \quad (7-1)$$

Liquids are practically incompressible at pressures up to ca. 80 bar. Therefore, they store no energy and transfer kinetic energy uniformly to the pig, even when the pig material is compressible (e.g., foam pig). If the pig is accelerated by pressure build up behind it, the driving pressure cushion relaxes so quickly that the acceleration decays almost immediately.

Due to the uniform transfer of energy mentioned above, liquids do not have unwanted effects on the pumping behavior. For this reason, here we deal mainly with dimensioning of the elements for pressure transmission, both on the propellant side, and on the product side. The discussion is limited to industrial pigging units.

Dimensioning preferably follows the order:

- Data collection
- Choice of pig size
- Choice of nominal size
- Choice of the exact inside diameter of the pipeline
- Dimensioning of the product pump
- Dimensioning of the propellant pump
- Driving medium vessel

Data collection initially involves collecting information and basic data for clarifying the requirements to be met by the planned pigging unit. The purpose of the pig run must be analyzed accurately (see Chap. 1 and Section 2.2). Pipe routing (differences in height, isometrics), nominal size, performance, and pressure drops must be known. The pigging system and the sequence table should also be available. With several different products their compatibility must be examined among themselves and with the pig and pipe materials. The selection of the propellant can take place with the help of these data. Then a data collection is available as a source of information for all further dimensioning steps.

The choice of the nominal size and the dimensioning of the product pump and/or its drive unit is based on the throughput of the devices connected to the pigging line, e.g., the filling stations. Here the pressure drops of the pipes and valves must be considered.

The dimensioning of the propellant pump is best carried out by analysis of the sequence table. For each work procedure and/or operational condition the way in which the pump is stressed must be considered.

8

Control System

8.1

Components of the Control System

Experience has shown that operation of a pigging line requires more complex process control than a conventional system with different pipelines for different products. In many cases a sequence of actions is necessary for the sequential steps of a pig run, which are actuated either manually or run automatically. Therefore, different realization stages in the process instrumentation result depending on the requirements.

Today control of the sequence is normally realized by a programmable logic controller (PLC) or a near-process component (NPC) of a distributed control system (DCS). The DCS should have its strengths in the realization of sequences of functions; for pigging, the pure control-engineering aspect is generally of lesser importance. The degree of automation determines the application of a PLC or a DCS in the pigging technology.

The complex technology involved in automation of a pigging unit requires a suitable multilevel process-control system.

Near-Process Components (NPC)

In an NPC various automation functions are integrated, such as control and monitoring of a process in a production plant. Today, the sequences of a stepped control must be realized by a PLC. Conventional wired-programmed control is also realizable, but with increasing demands on the automation or with the need for greater flexibility (frequent changes, space requirement, maintenance) PLCs have clear advantages.

Field Bus System

To run a process optimally, it is necessary that the units which monitor and control the process can communicate among themselves. Field bus systems are a current topic in process control engineering and are increasingly being used in the chemical industry for the automation of processes. In a field bus system the field devices (actuators and sensors) are connected directly to local digital in- and output (I/O) cards remote from the control system (ET 200, Siemens). Inputs and outputs of the

cards communicate via a bus with the control system. Many manufacturers already offer in situ modules which permit connection of the field devices, even for units in explosion-hazard regions. A bus coupler is the connecting element between the in- and output modules and the control system.

The advantages of a field bus system lies in the cost reduction of over 50 % and the low wiring expenditure. In addition, since fewer interconnections and I/O modules are required, planning costs are lower, documentation is simplified, and system performance is improved. The benefits for the user are savings at all levels, space savings, and the expandability of the bus system.

Monitoring and Operating Components (MOC)

An MOC is a central unit to which several operator workplaces can be connected. Automation of the field level in the control system permits an operation by, e.g., push-button input, e.g., on a display in an in situ control post or via a control room. Here feedback signals on operating conditions or position indications of actuators can be visualized. In the case of a larger number of possible inputs, feedback signals, or extensive sequences in the PNC, this visualization results in increased costs due to additional and more expensive planning. At the same time, operation by the operating crew may become more complicated, which in turn can lead to operating errors.

The use of a display-oriented prompt facility (e.g., light pen input in a menu-based system) is very helpful in such cases. Such a concept can be realized by means of a standard process control for the automation of processing plants and a system bus from an appropriate vendor. In simple terms, a system bus is a highway for the transport of data, to which the PNCs, which are responsible for the actual control task, and the MOC for monitoring and control are connected.

8.1.1

Sensors

Pigging technology requires field devices which are compatible with this technology. Constrictions of the pipe, for example, for instruments that operate with cross-section contraction (e.g., volumetric flow meters), are not permitted. Therefore, all necessary measuring instruments, especially for filling trucks, rail tanks, and ships, are installed outside of the pigging unit.

Flow Measurement

Flow measurements in piggable lines can be accomplished in individual cases with a magnetically inductive flowmeter (MIF) provided the circumstances and diameter permit application in the pigging line. At the same time the product properties must permit the application of the particular MIF (e.g., electrical conductivity $> 5 \mu\text{S/cm}$).

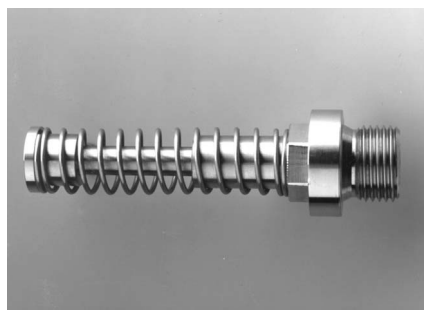
More recent developments in instrumentation such as the Coriolis mass flowmeter allow this mass flowmeter, which is very suitable for liquids, to be used directly in piggable pipelines. Ultrasonic flowmeters, attached to the outside of the

pipe, can also be used. In this case fading out of the signal during passage of the pig is necessary to avoid false measurements. However, the in-line solutions do not fulfill in all cases the increased requirements for measurements of volume in filling stations.

Pressure Measurement

Pressure measurements allow the state of pig motion to be determined (e.g., driven by propellant, relaxation of pipeline, examination of the state of the pig). In many cases suitable measuring systems can be attached to the pigging line without generation of dead volumes or hindrance of pig travel.

For the operator of an industrial pigging unit the precise position of pig is of fundamental importance. In an automated pigging unit contactless detectors are suitable. If the pigging unit is not automated, a mechanical indicator, such as a spring-loaded feeler (Fig. 8–1), can indicate the presence of a pig in a particular position (e.g., in a pig station). The position of the mechanical indicator can be evaluated over a proximity switch.



Mechanical pig indicator out of operation



Mechanical pig indicator in operation

Fig. 8–1. Mechanical pig indicator (I.S.T., Hamburg, Germany)

Pig Detection

Magnetic detection of pigs is most frequently used. During pig fabrication permanent magnets of defined magnetic field strength are incorporated (see Section 8.1.2).

Magnetic detection is inexpensive and well established. Nevertheless, problems often occur in the start-up of a plant, since the fine tuning of the magnetic field detectors is laborious. During operation readjustments are often necessary. At the same time, it must always be guaranteed that the pigs delivered by the manufacturer exhibit the same magnetic field. To avoid spurious measurements, the pipe and valve materials must not be magnetizable.

If a pig did not depart as intended from its end position and can no longer be detected by fixed magnetic detector, then handheld detectors are required to find it. The working principle is the same as for magnetic field detectors (see. Fig. 8–2).

Pig detection by telemetry methods is especially suitable for large pigs in crude oil pipelines. Here a radio signal sent by the pig indicates its exact location. Pigs detection by radioactivity is also possible but is rarely used because of requirements for radiation protection.

8.1.2

Permanent Magnets and Magnet Sensors

For the automatic control of the pig in an industrial pigging units it must be determined with certainty whether the pig has reached a given position in the station or on its travel. For this purpose a permanent magnet of sufficient strength is incorporated in the pig, the magnetic field of which can be detected by magnetic sensors. Because of the importance of this technology in industrial pigging units it is dealt with in greater detail here μ .

The relationship between magnetic flux density (or induction) B and field strength H (Eq. 8-1)

$$B = \mu_0 \mu_r H \quad (8-1)$$

relates the effect of the magnetic field B with its cause H .

The permeability of vacuum μ_0 is a fundamental physical constant:

$$\mu_0 = 1.2566 \cdot 10^{-6} \text{ V s A}^{-1} \text{ m}^{-1} (\text{H m}^{-1}).$$

The relative permeability μ_r is a proportionality factor. It indicates the factor by which the magnetic flux density B increases when empty space containing the field is filled with the material in question. A distinction is made between:

Ferromagnetic materials: $\mu \gg 1$

Paramagnetic materials: $\mu > 1$

Diamagnetic materials: $\mu < 1$

The unit of magnetic flux density is T (Tesla, $1 \text{ T} = 1 \text{ V s m}^{-2}$). The unit of magnetic field strength is A m^{-1} .

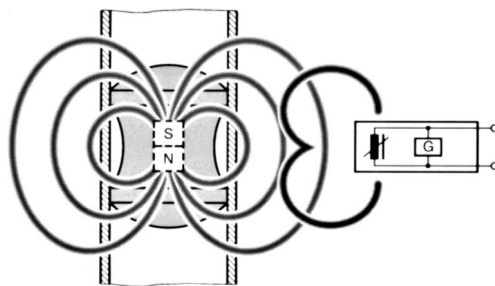


Fig. 8-2. Principle of a magnetic pig indicator

Dependence on Distance

Assuming a symmetrical field, the flux density B is inversely proportional to the distance r (Eq. 8-2).

$$B = \mu_0 \mu_r H / 2\pi r \quad (8-2)$$

Magnetic lines of flux are subject to refraction at boundary surfaces, like rays of light. With ferromagnetic materials this refraction is very strongly pronounced. If a ferritic steel pipe is brought into a magnetic field, then lines of flux entering the steel nearly all run through the pipe, so that its interior is practically field-free (magnetic screening effect). In the reverse case, a magnetic field within the pipe is shielded from the outside.

Permanent magnets consist of materials whose atoms have magnetic properties and are aligned in the field direction and retain this aligned position, provided it is not opposed by strong external fields. Therefore, materials for continuous magnets must have high remanence (strong magnetic field) and a high coercivity (low influenceability by external fields), i.e., a large area enclosed by the hysteresis curve.

Materials for permanent magnets are: hard ferrites (HF magnets), rare earth element magnets (RE magnets), samariumcobalt, and neodymiumironboron.

For insertion into the pig body the magnets are welded or glued into high-grade steel capsules since the magnetic materials are highly sensitive to corrosion and can discolor the product.

Magnet Sensors

Magnet sensors (pig indicators) are proximity switches which react to the field of a permanent magnet even through ferrous metals. The switching gaps are larger than with inductive sensors. The response characteristic depends on the orientation of the permanent magnet. The approach of a magnet amplifies the external magnetic field. Thus, the reversible permeability of the core of the coil becomes smaller. Since the solenoid coil inductance L depends on this permeability, it also drops. Thus the current I rises with constant voltage V : the power input of a magnetic sensor rises with the approach of a magnet.

The usual shape is cylindrical, with a diameter of ca. 10 to 16 mm and provided with male thread for accurate positioning (Fig. 8-3). Sensors are installed radially to the pipe (Fig. 8-4). By means of the thread and two thin bolts they can be moved steplessly along an oblong hole and thus be adjusted.

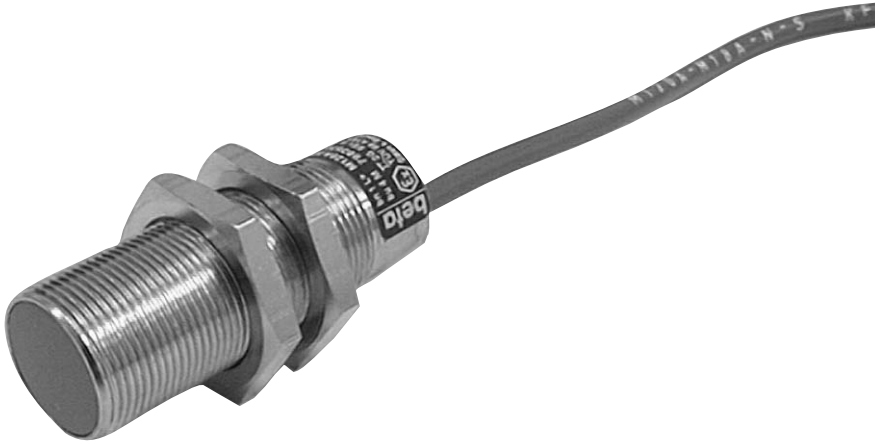


Fig. 8-3. Magnet sensor (Beta Sensorik, Küps, Germany)

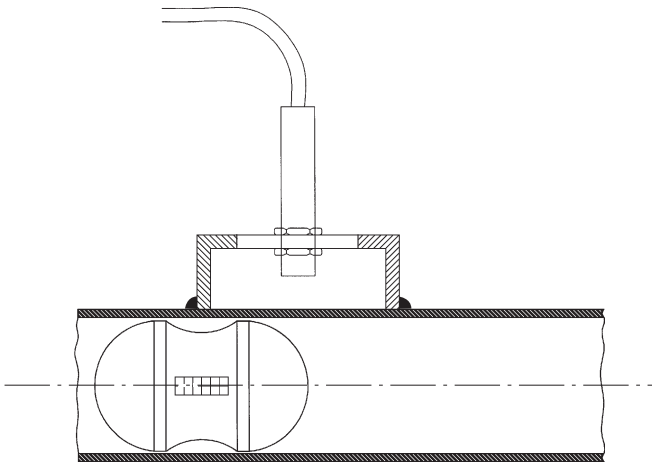


Fig. 8-4. Magnet sensor and running pig

Example:

Switching gap s : 0 to 60 mm (0.5 Da) i.e., applicable up to 4"

Switching frequency f : 400 to 1000 Hz; $T = f^{-1}$: Time of response for detection (T = duration of one oscillation)

Sensitivity: 1 mT

Sampling rate for application in a process control system (DCS) (pulse stretching possible): f^*

Pig speed: $v = 1$ m/s

Axial extension (length) of the field (for field strength 1 mT) at a radial distance of $0.5 D_a \cdot L_{\text{field}}$

For a given sampling rate f and range of the magnetic field L_{field} a maximum speed for which the pig can still be detected is given by Equation (8–3).

$$V_{\text{det, max}} = L_{\text{field}} \cdot f^* \quad (8-3)$$

8.1.3

Actuators

The valves described in Chap. 4, if not operated manually, are driven by actuators. Electric motors or pneumatic drives can be used.

The selection of the drive units must be coordinated with the data of the valve such as torque, break-off moment, angle of rotation, etc., and the energy supply, e.g., control air, direct or alternating current. Pneumatically driven valves with flaps for the connection of T-pieces, are suitable for branches and pig traps. The change of position can take place by actuation of an electrically driven single solenoid valve in the air line to the actuator. By choice of a suitable drive unit a piggable three-way switch can also be automatically controlled.

Automation of a pig launching or receiving station can be achieved with stop valves, e.g., as shown in Fig. 8–5.

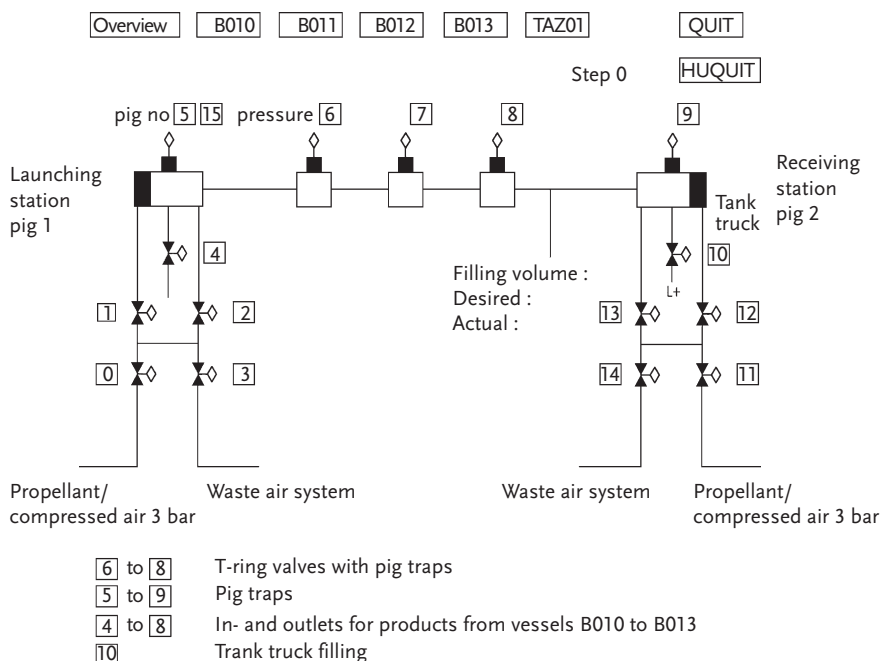


Fig. 8–5. Industrial pigging unit, as depicted in the monitor.

In the hard copy of a screen of a DCS (see Fig. 8–5) a two-pig system is depicted, which is available to the personnel for the process of filling a tank truck. The pig launching (5) and receiving station (9) with pig traps and T-ring valves (6–8) are evident.

The valves 0 to 3 and 11 to 14 are provided with control drives and serve for the supply of the propellant (compressed air) and/or relaxation of the pigging unit to an exhaust-air system (safety positions of the valves and pig indicators are not shown). The fittings are opened and/or closed in such a way that the transport of the two pigs can be accomplished according to requirements. Opening or closing of a valve is indicated by a color change. In the example shown product from any tank B 010 to B 013 can be brought to the filling facility and then be pigged back into the tank.

8.2

Operating Modes of the Sequence Control

8.2.1

Manual Operation

In the simplest case initiation of pig travel takes place by manual local actuation of manual valves by the production personnel.

8.2.2

Enhanced Manual Operation

In enhanced manual operation, the respective control signals for individual actions are entered via an interface to the automation system. This can be push-button selection in a conventional control room, keyboard entry to an input screen, or a light pen input, e.g., to the screen of a monitoring and operating component (MOC) of a process control system. This is the most inexpensive approach to automation, and can also be used to return a fully automated system to the initial state after malfunction and abortion of automatic operation.

8.2.3

Touch-Controlled Operation

The individual steps of the sequence are selected separately in response to a user prompt. The individual steps are followed by a plausibility check or an inquiry as to further switching conditions. This mode is suitable, e.g., for checking sequence or for the ending a prior disturbed sequence control.

8.2.4

Automatic Operation

In automatic operation the sequence takes place automatically. After fulfilment of all switching conditions the system proceeds to the next step of the sequence control. In automatic operation at any time “stop” should be possible, with transition to enhanced manual operation, touch-controlled operation, or complete abortion of the selected automatic operating mode. The operating conditions should be indicated to the operator by an MOC (Fig. 8–6) or conventionally (e.g. flow sheet visualization at an instrument panel).

With all modes of operation, the filling procedure is started locally and supervised by local personnel.

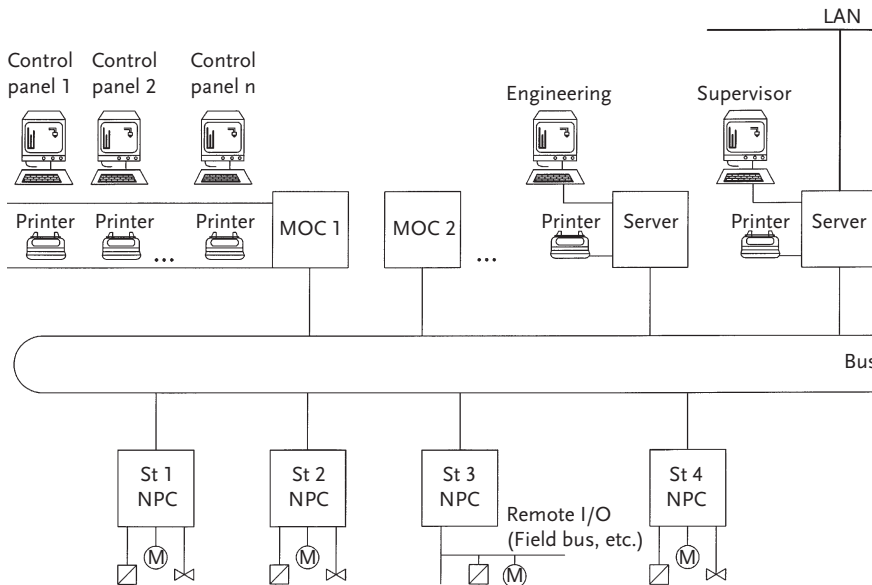


Fig. 8–6. Example of a structure of a pigging unit

8.3

Examples of Sequence Control

8.3.1

Sequence Control of a One-Pig System

As a simplified example of the design of the sequence control of a piggable pipeline the tank truck filling facility depicted in Fig. 8–7 is described. The simplified operating diagram (Fig. 8–8a-e) shows the individual steps. The filling procedure is started, e.g., by pushing a button at the local control center of the filling station.

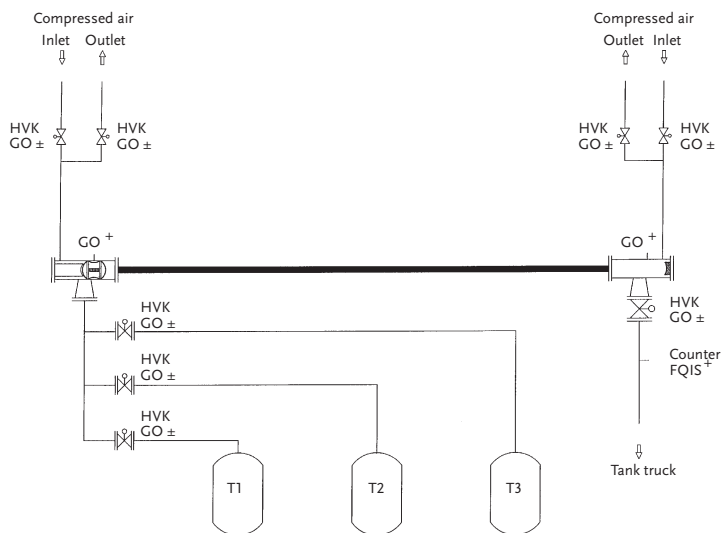


Fig. 8-7. Schematic of a one-pig system

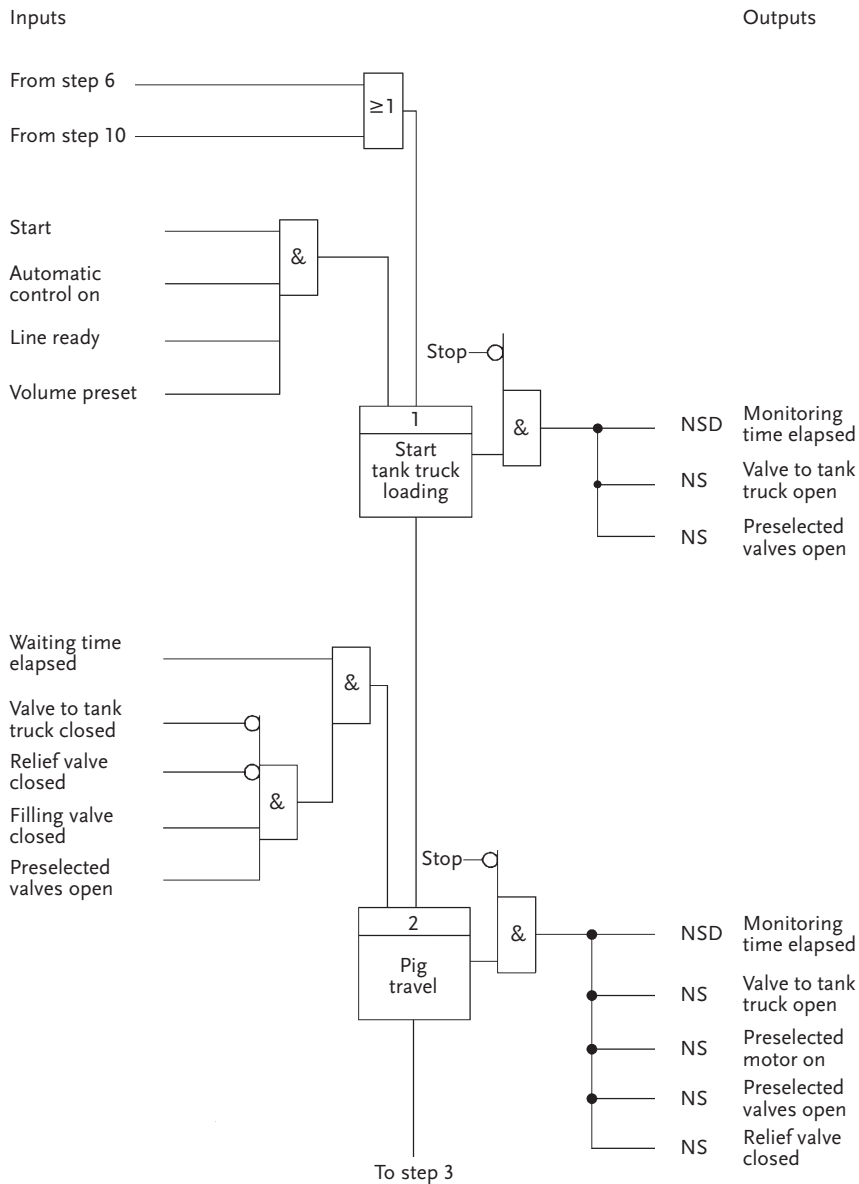
The tank truck can be filled from different storage vessels, e.g., T 1 to T 3. The choice of a certain tank results in a corresponding path, which is set up manually or automatically. When this path is established, the initial position for the chosen filling is achieved. Hence, the subsequent sequence control can be activated and be started, and filling of the tank truck can begin. The example selected here is depicted in Fig. 8-8a-e in the form of a simplified operating diagram. The monitoring and waiting times necessary for successful and synchronized processing of the sequence are not given in detail.

After reaching the initial position the sequence can be activated in step 1 by actuation of the “start” button. In step 2 the pig in the launching station is propelled with the product through the pigging line to the receiving station at the filling point. The pumps and valves required for this are addressed by the sequence control. The arrival of the pig in the receiving station is the key condition for switching to step 3. In step 3 the path to the tank car opens, i.e., the filling flap on the tank truck opens, so that the product can be driven into the tank car via a meter.

Step 4 is the actual filling process with measurement of volume in the filling device. The volume measurement, carried out here with an elliptical-area meter, lies outside of the piggable line in a short pipe to the filling device, which can run dry.

The signal “amount reached” (step 5) leads to the cessation of product flow, closing of the filling flap, and attainment of the initial position in step 6. The piggable pipeline is still filled with product, and the pig is in the receiving station.

In step 7 back-pigging is prepared, which starts in step 8 of the sequence. In step 9 the pig travels to the launching station and the product remaining in the pipe is driven via a bypass at the pump back into the initially selected storage vessel. In step 10 the selected operating mode “fill tank truck” is then logged out and the system is ready for the next filling procedure.

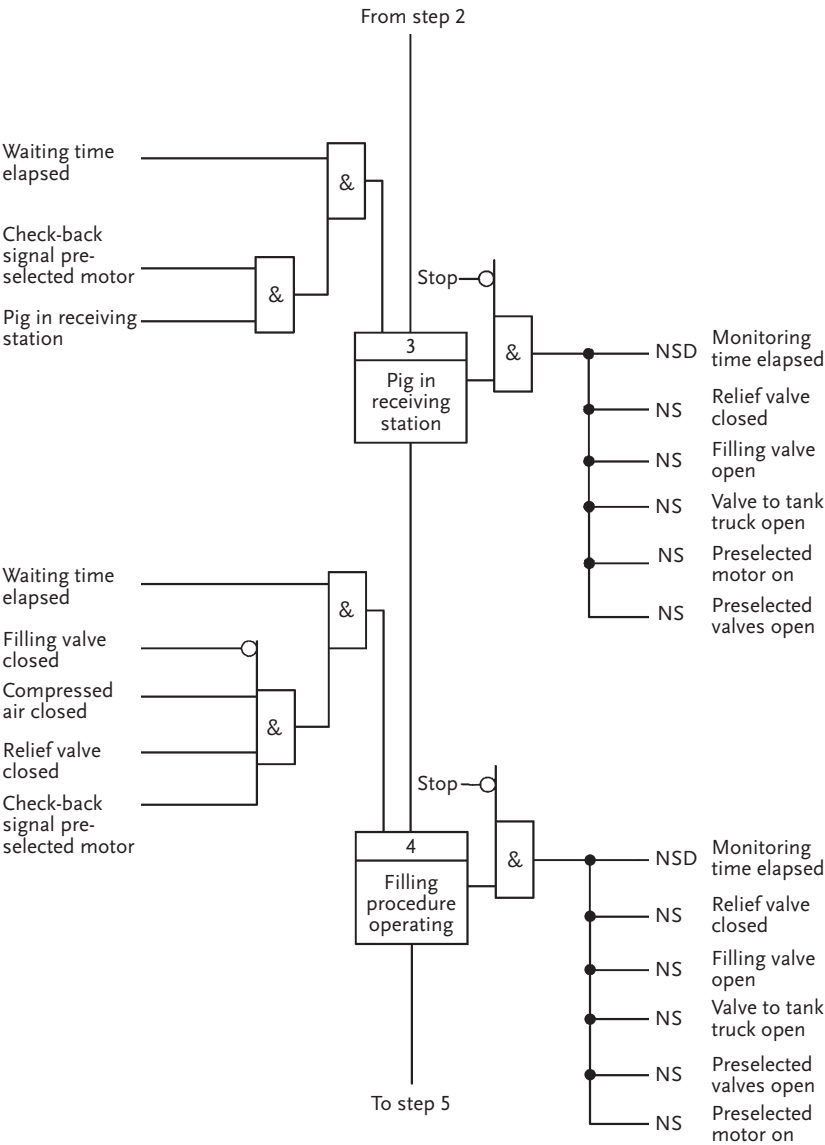


a

Fig. 8-8a-e. Simplified logic diagram for a one-pig system

Inputs

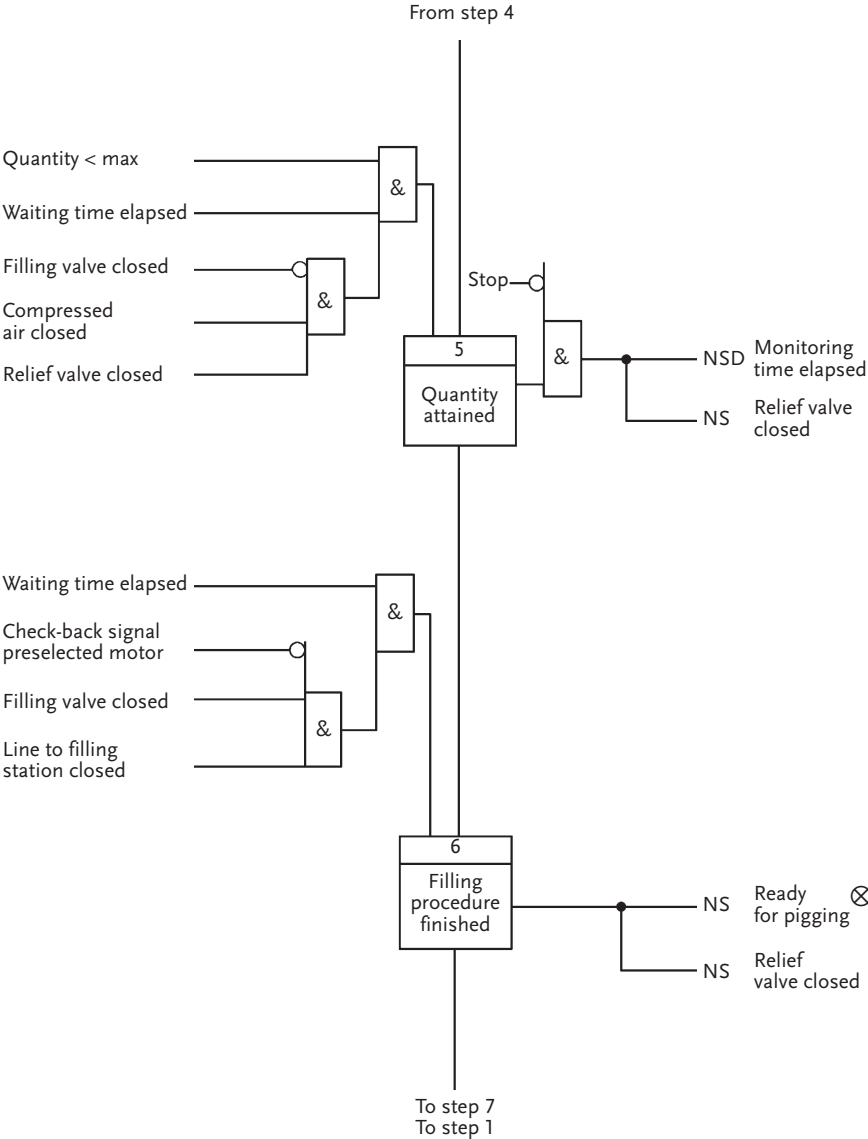
Outputs



b

Inputs

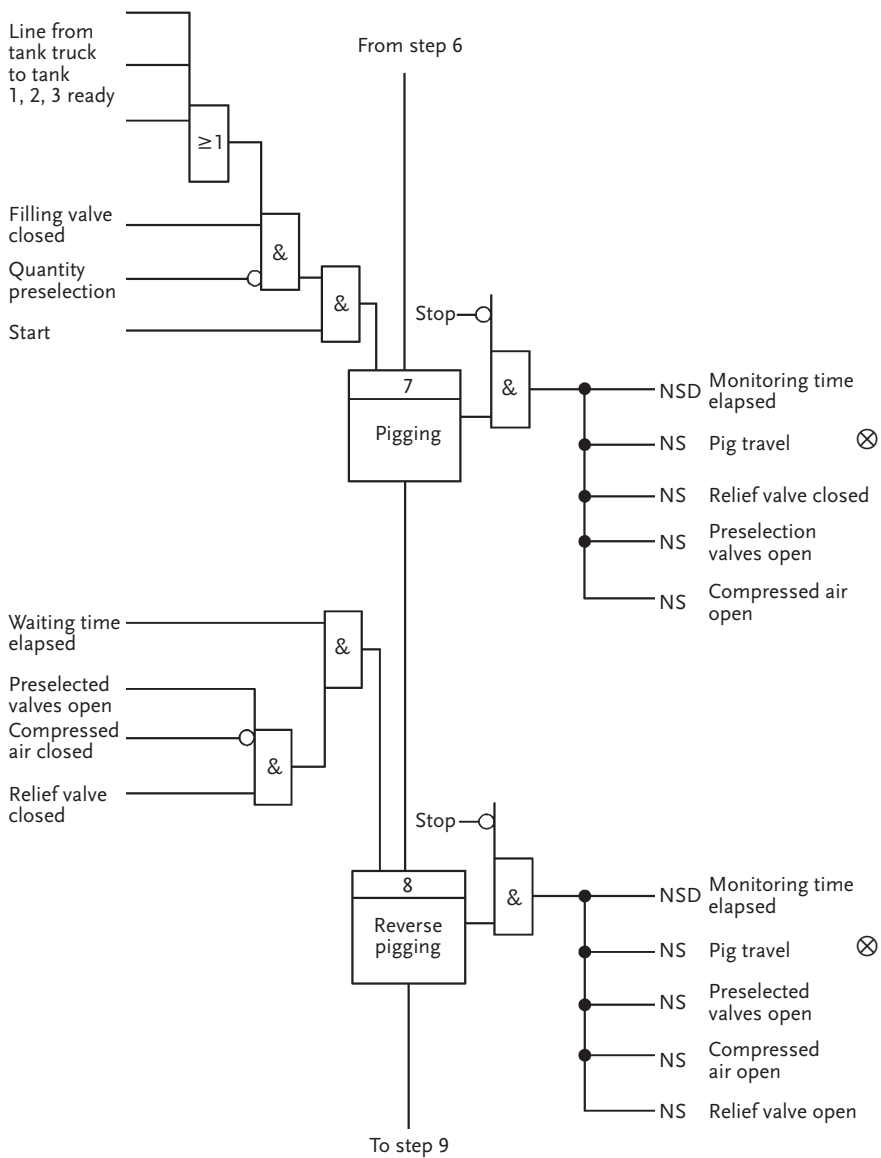
Outputs



c

Inputs

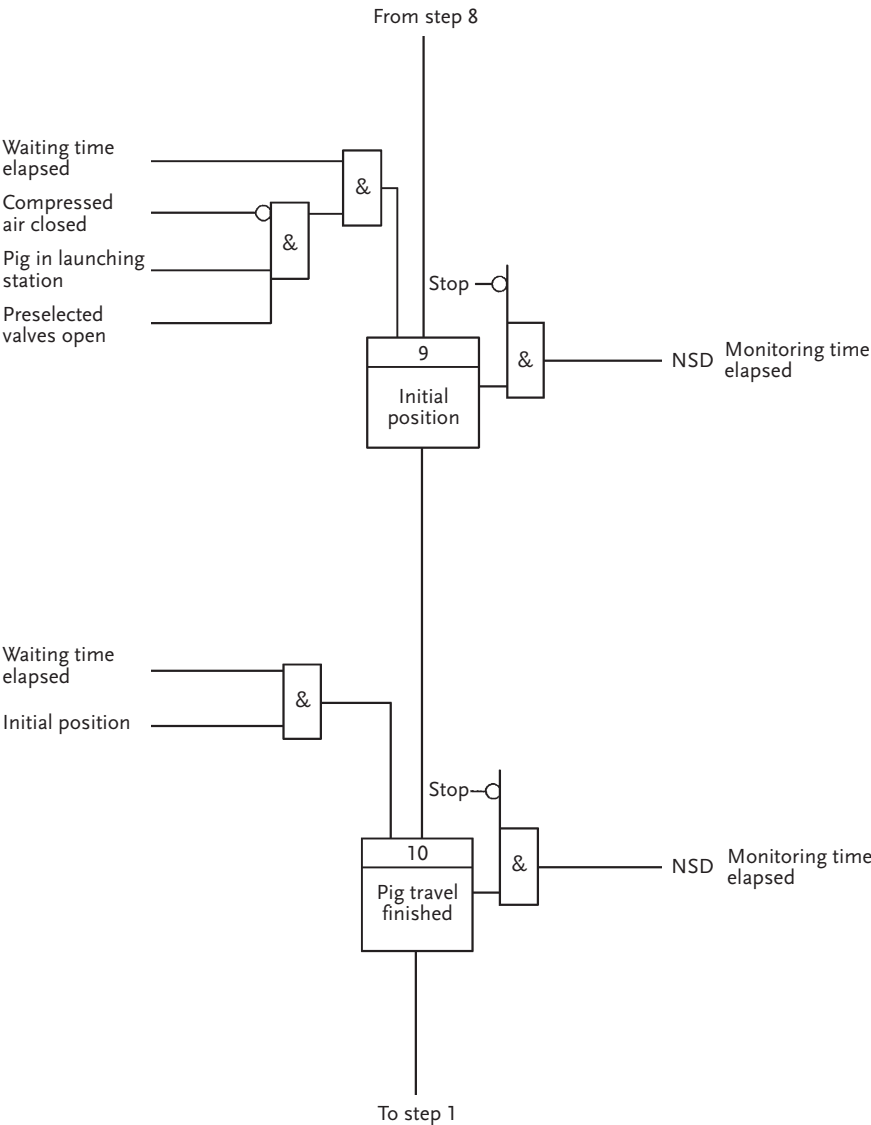
Outputs



d

Inputs

Outputs



e

8.3.2

Sequence Control of a Two-Pig-System

The sequence control of a piggable pipe with a two-pig system is discussed here for the simplified example shown in Fig. 8–9.

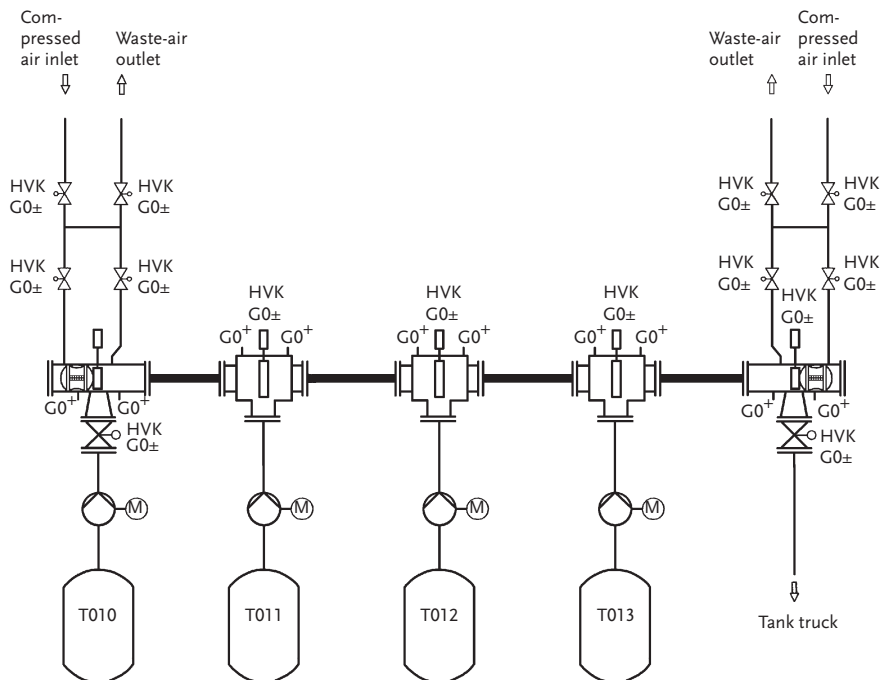


Fig. 8–9. Schematic of a two-pig-system

Tank trucks are to be filled from four storage tanks (T 010 to T 013) selected from the control room. The pigging path is selected manually or by automated operation in the process control system. Then, the selected filling procedure can be started. Automatic operation follows the sequence shown in simplified form in Fig. 8–10 a–e.

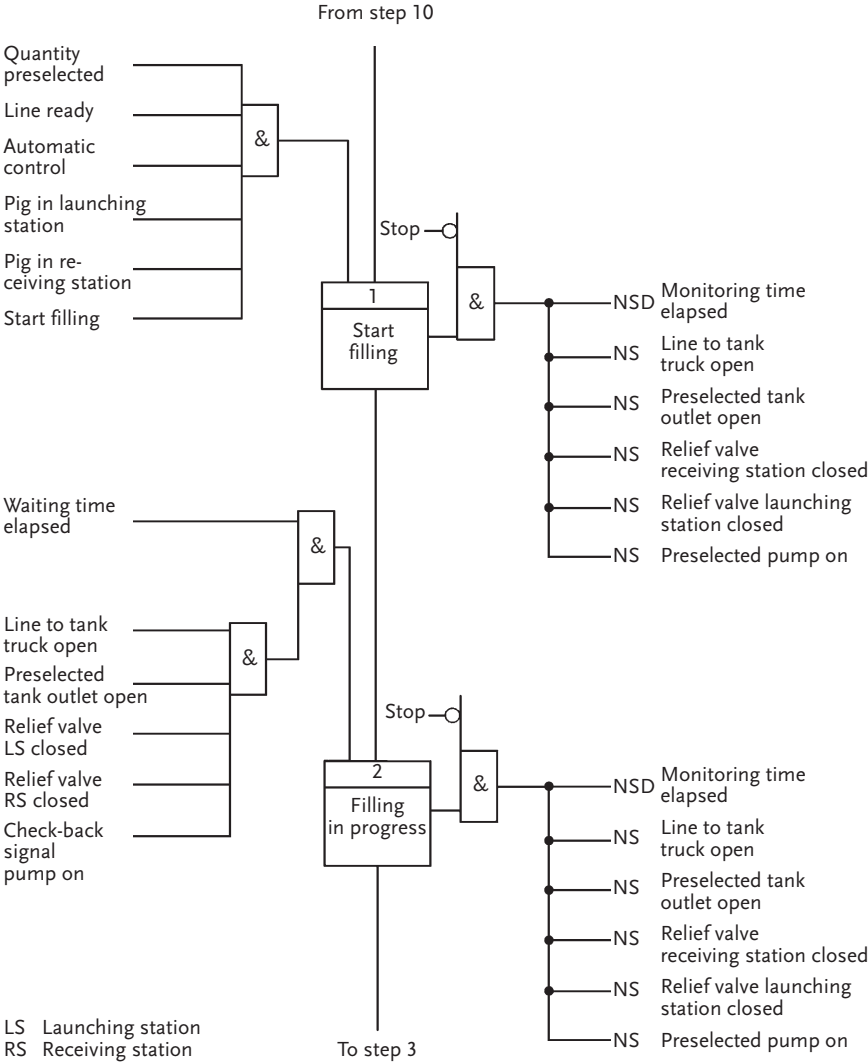
In the initial position the launching and receiving stations each contain one pig. The path from the tank to the filling location and the filling volume have been preselected. In step 1 the sequence is activated by pressing the start button. In step 2 the feed pump is switched on, and product pumping starts. In step 3 the preselected volume is reached, and in step 4 the loading procedure is terminated. The pump is switched off, the inlet valve to the tank truck is closed, and the readiness for pig travel is indicated. In step 5 pigging is initiated automatically. The pigs are driven to the source tank. In the step 6 the two pigs are at the T-valve of the source tank, the residual product has been pushed back into the source tank, and the T-valve closed.

In step 7 the two pigs are driven to the launching station by the propellant. After pig detection in the station, in step 8 the front pig is sent to the receiving station, by

opening the appropriate valves for the propellant. In step 9 one pig is in each of the launching and receiving stations, the system is pressure-relieved, and thus the initial position has been reached again. In step 10 the pigging procedure is terminated.

Inputs

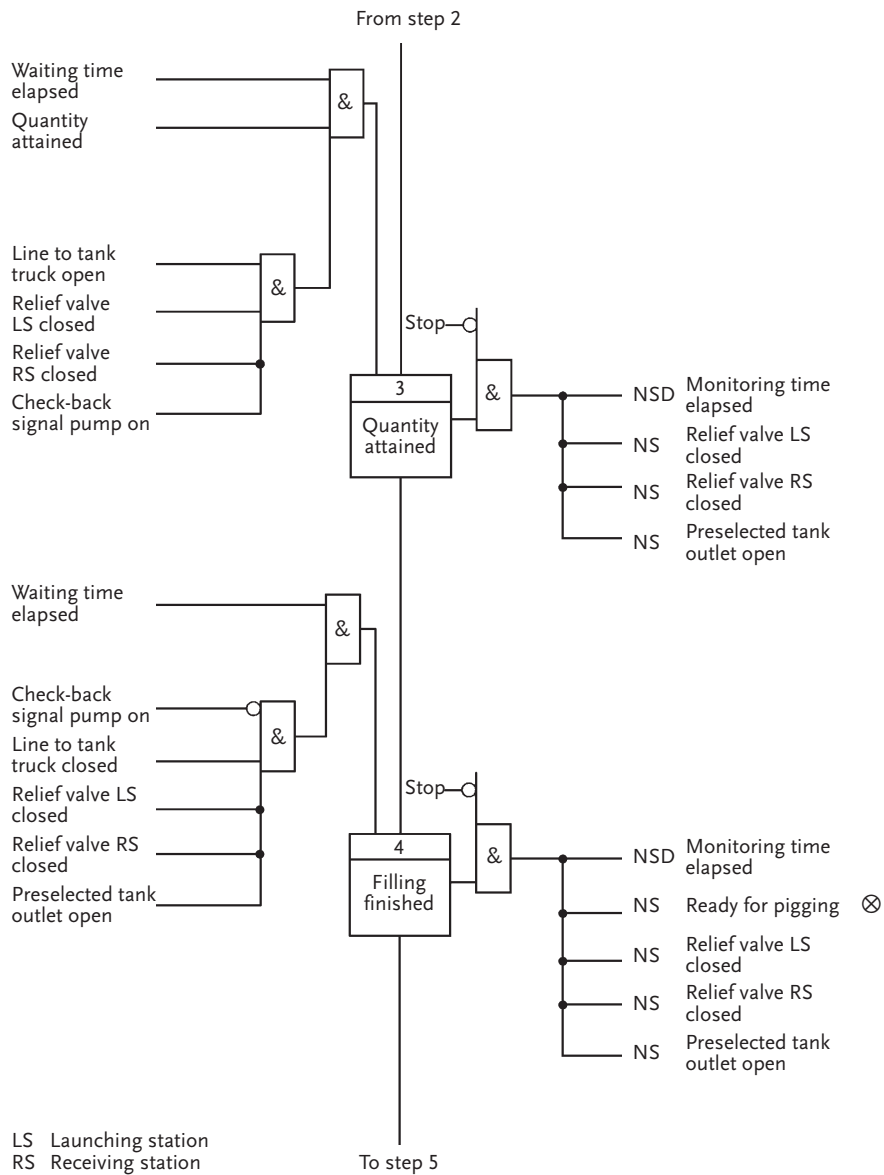
Outputs



a
Fig. 8-10a-e. Simplified logic diagram for a two-pig system

Inputs

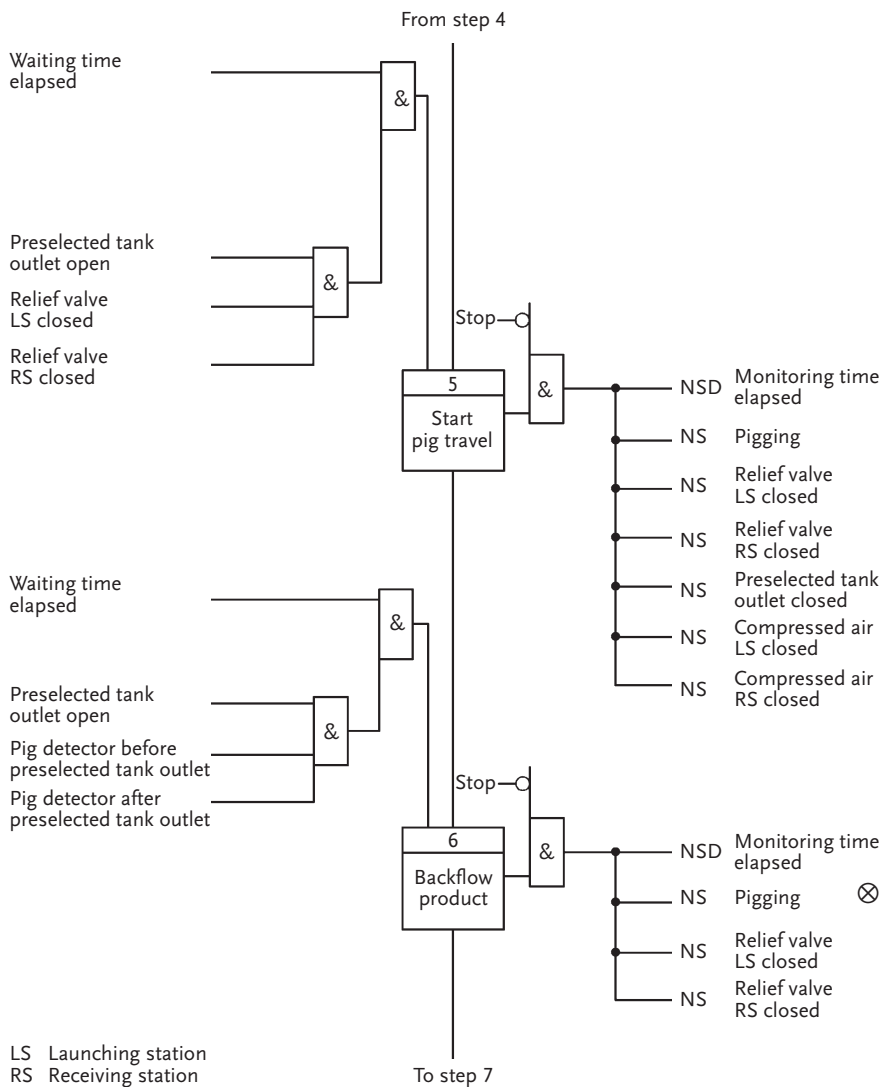
Outputs



b

Inputs

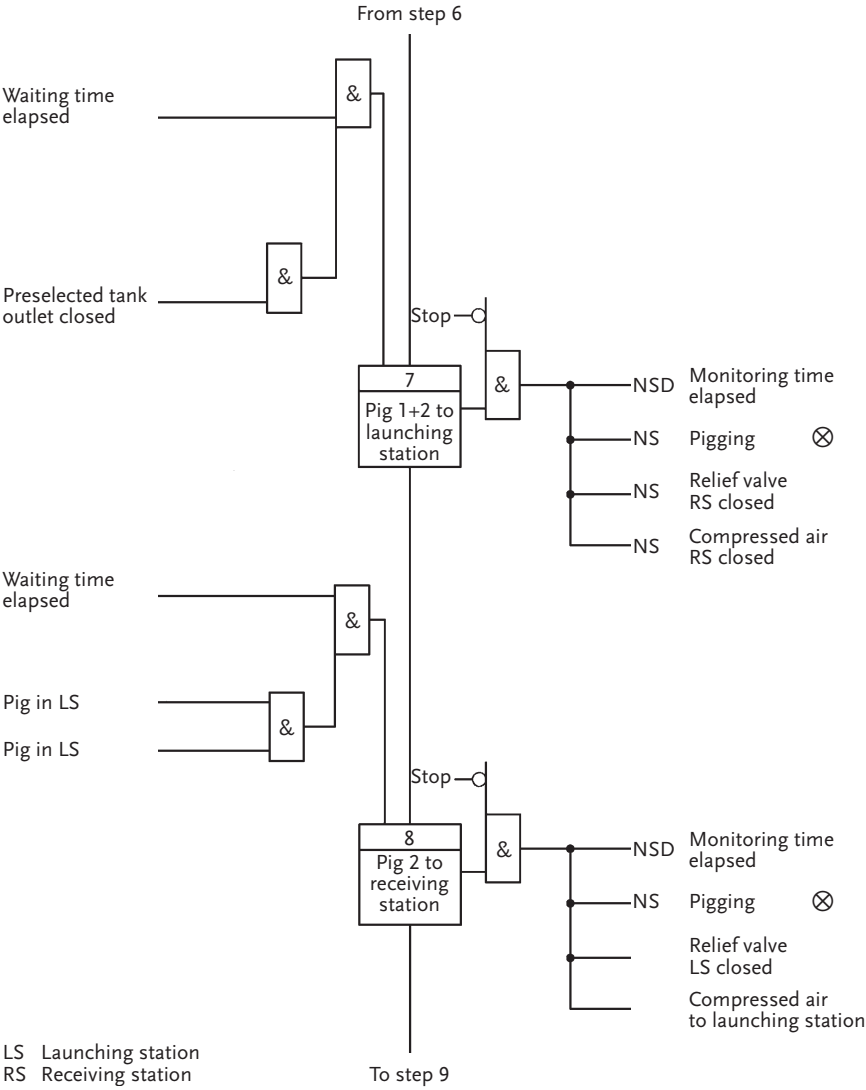
Outputs



c

Inputs

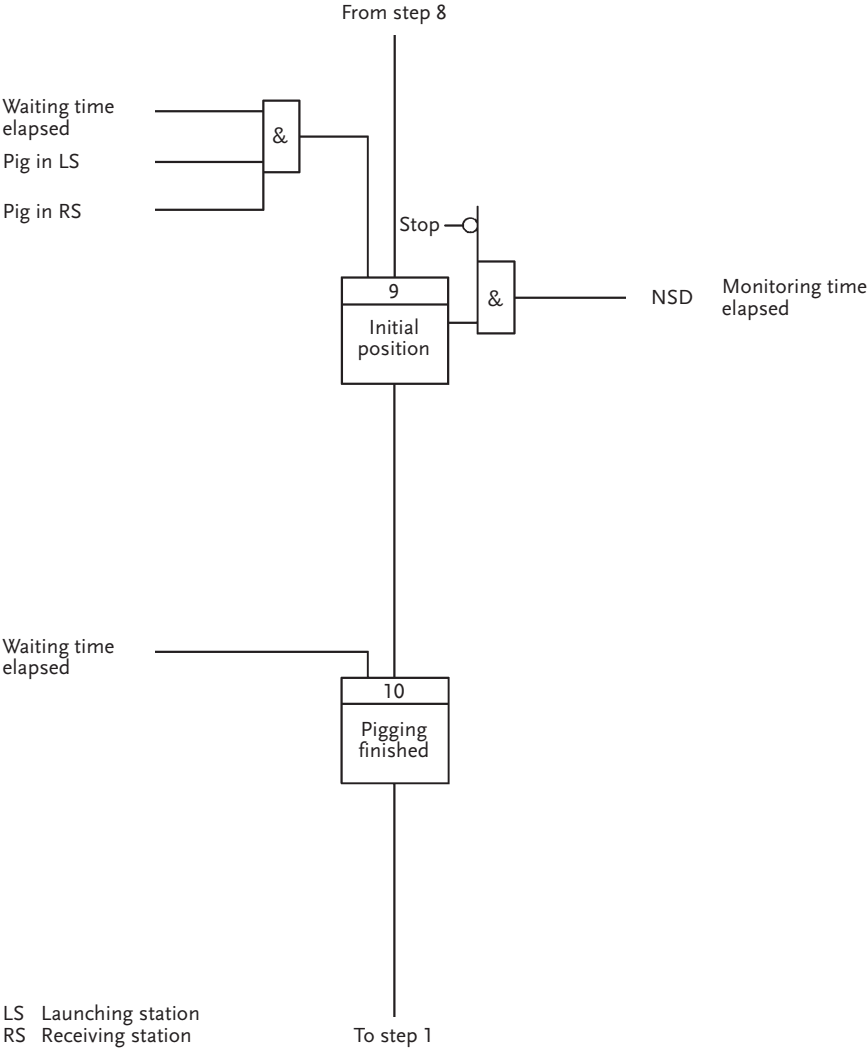
Outputs



d

Inputs

Outputs



e

8.3.3

Sequence Control of a Cleaning Procedure

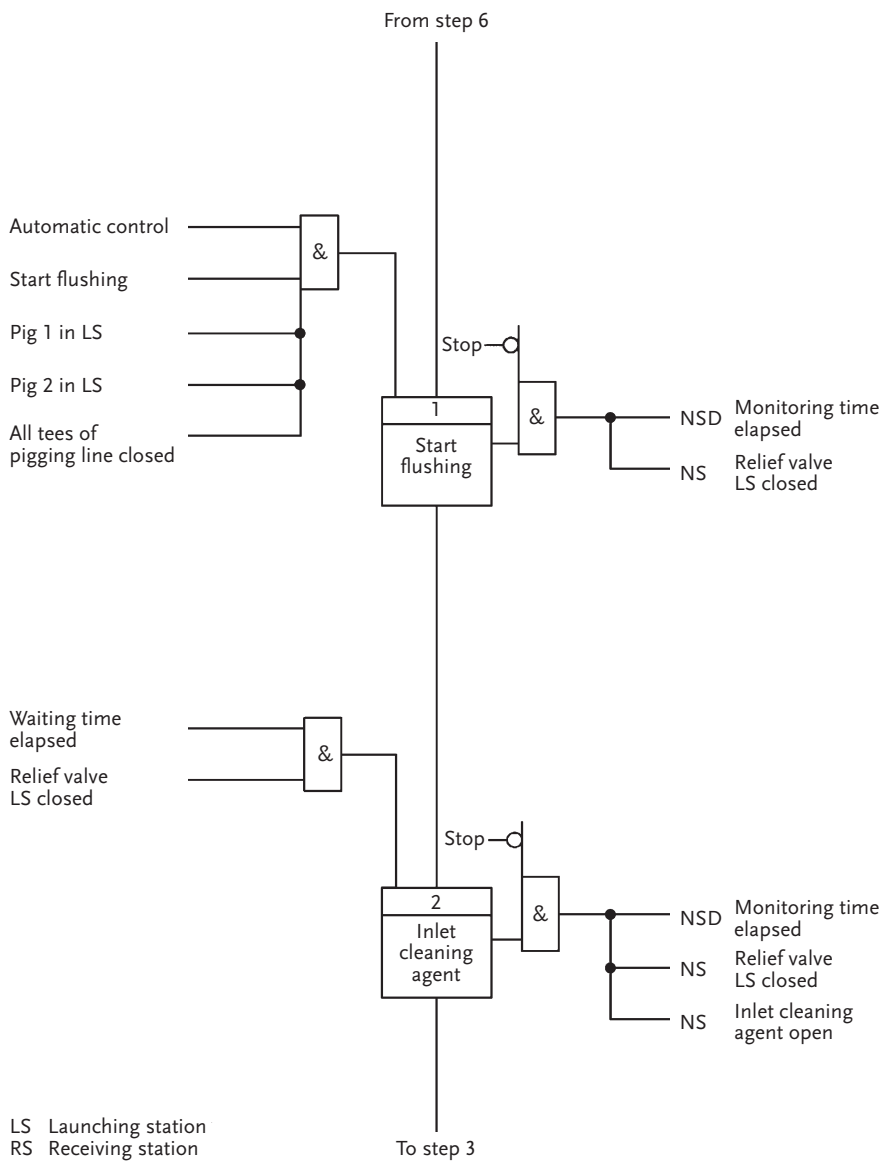
Cleaning procedures are preferably accomplished with a TPS, since the amount of cleaning agent can be minimized by enclosing it between two pigs. The simplified operating diagram in Fig. 8–11 a–c shows the sequence of a cleaning procedure.

In the initial position the inlet valves are closed, the relief valves are open, the piggable pipeline is thus pressureless, and both pigs are in the launching station. All outlets at the pigging line are closed. The command “start cleaning” initiates the sequence control for the cleaning procedure. The relief valve at the launching station is closed in step 1. In step 2 the inlet valve for the cleaning agent, which is located at the launching station between the two pigs, is opened. The rear pig 2 is pressed into the end position of the launching station. Pig 1 is pushed by the cleaning agent into the pipe, until the pig indicator on the pipe closes the inlet valve. The desired amount of cleaning agent is now enclosed between the two pigs. The valve for the propellant (e.g., air) is opened in step 3, and the cleaning tandem moves toward the receiving station. The arrival of the pig 1 in the receiving station initiates step 4, which closes the valve for the propellant and opens the relief valve. Now the valve for the propellant at the receiving station is opened, and the cleaning tandem is returned to the launching station. In step 5 pig 2 is back at the launching station.

Now the entire rinsing procedure can be repeated as often as necessary for the required degree of cleaning. In this example only one cleaning procedure is accomplished (there and back of the tandem), after which the cleaning agent must be removed. By opening the cleaning agent outlet valve parallel to the inlet valve, the cleaning agent can be removed from the pigging line, preferably into a collecting tank. When pig 1 is also back again at the launching station, in step 6 the pigging line is relieved, and the sequence control is in the initial position again.

Inputs

Outputs

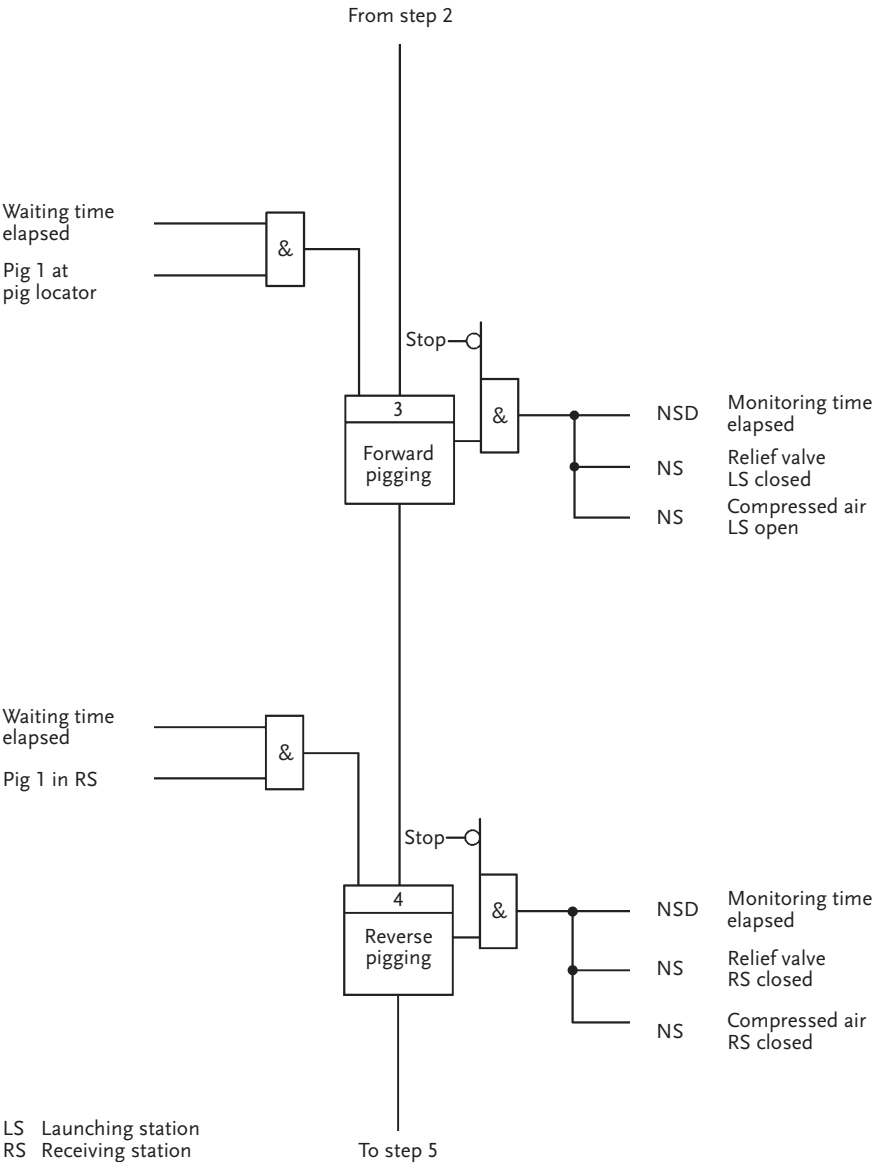


a

Fig. 8-11a-c. Simplified logic diagram for a cleaning procedure

Inputs

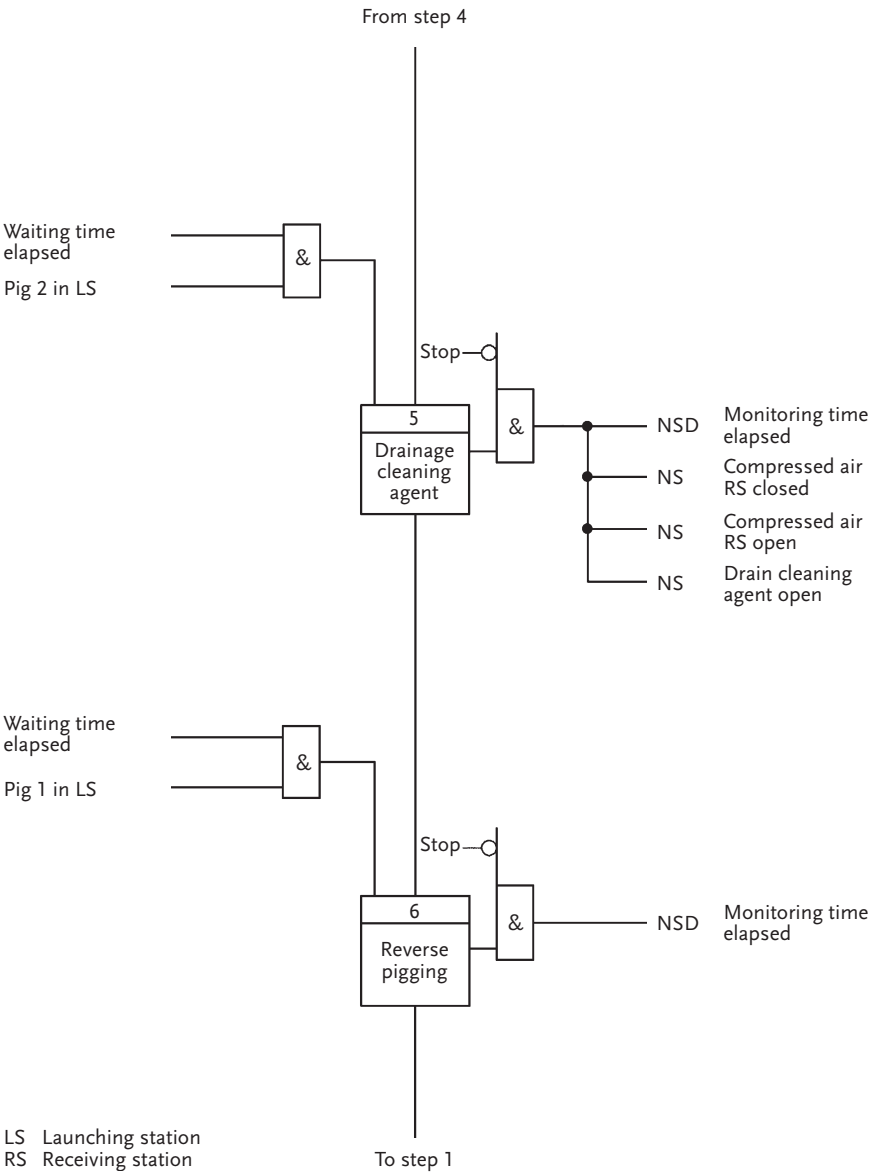
Outputs



b

Inputs

Outputs



c

III

Applications

9

Decision Criteria for Pigging

If one is interested in the application of pigging technology the question arises whether it is technically feasible and economically viable.

The following sections discuss these questions in more detail and offer aids to decision making with a view to future competitiveness.

9.1

General Criteria

The first step in the examination for alternatives to conventional technologies is always determined by a fundamental question: Does new technology bring a decisive improvement? Or, in somewhat wider terms: will new technology provide a long-term advantage over competitors? The new technology is evaluated with regard to the criteria economy and reliability.

Often, however, these terms prove to be insufficiently precise for recognizing the benefits of a new technology. Furthermore, an objective evaluation must also uncover possible weak points. For this reason a prospective user should consider the two following sections of an evaluation.

9.1.1

Product – Infrastructure – Technology

Industrial pigging units offer the following benefits in relation to the single product lines (conventional system):

- Lack of space or static problems due to the weight of pipes on piperacks play no role since several pipelines are replaced by a single one. Thus smaller nominal sizes and more economical pipelines can be realized.
- Pipes remain free of deposits and incrustations, so that the high installation expenditure for heat tracing and insulation can be omitted, provided environmental influences, e.g., exposure to the sun need not be considered.
- Risks due to aging or demixing processes in problematic products which tend to polymerize or decompose are eliminated due to short retention times (also with frost-sensitive products).

- With a large product range and a frequent product change the necessary cleaning procedures and amounts of cleaning agent, as well as the associated preparation and operating periods, are reduced to a low level.
- Valuable products or raw materials with low production quantities can be conveyed, filled, and recovered with substantially lower losses.
- Loading facilities for viscous products can be supplied bubble-free.
- Automated and largely maintenance-free operation almost completely eliminates operating errors and reduces personnel expenditure.
- Wastewater costs due to cleaning agents are reduced or completely eliminated; this is especially an economic advantage if fees for organic carbon must be paid.
- The kind of installation of the pipeline, e.g., with a slope, does not play a role, i.e., the pipe need not be self-emptying.

If checking the above criteria reveals a potential for a change in technology, the next important question is the reliable technical realization.

9.1.2

Physical and Chemical Properties of the Products

If a pigging unit is intended only for one product, it must be determined whether the physical and chemical properties of the product permit pigging. In a pigging unit for several products this examination is necessary for all products. In particular, these products must belong to a product family, i.e., they must have similar properties.

Besides viscosity, melting point, and boiling point, the physical properties also include the rheological properties, i.e., velocity and shear-stress-dependent phenomena which affect the gliding and lubricating properties of the fluid. The liquid product must be able to form a load-carrying lubrication film between the running pig and the solid pipe inner wall, the liquid in this close gap being very strongly sheared.

Above all the chemical product properties must be examined as to whether a possible hazard or change of the product exists due to the reactivity of the products among themselves. Reactivity also includes the polymerization behavior, hardening, and adhesion of products, and especially the behavior in thin layers (inner wall wetting, thin film effects), on cold or hot metal parts, and in small dead volumes of valves.

The products must not influence the metal components and the plastic of gaskets and pigs by corrosion or otherwise, e.g., swelling or erosion. In such cases, however, a suitable material combination and system design can be remedial measures, for example, using a different pig material when the product is changed.

With a large variety of products or unknown product properties it can be useful to construct a simple test plant with manual control to obtain information on fundamental operating conditions. Such pigging test facilities supply information about the resistance behavior of materials, amount of residual liquid in the line, the wear characteristics of pigs (service life), and the interaction of propellant and valves.

In addition, laboratory tests determine the swelling behavior of pig materials by weighing and the color numbers of the products, which provide information on product contamination and resistance of the pig material.

The examination and evaluation of the above topics should make it possible to determine whether pigging technology represents a technically practical alternative. The next step is to clarify the question of economy. Section 9.2 evaluates three examples with consideration of operating and investment costs and amortization time.

Conventional piping and pigging technology are compared with the associated specific costs. The examples were selected in such a way that as a broad a range of applications as possible is covered. Naturally, it is possible to interpolate the given costs. However, the degree of automation is not included, because these costs depend too strongly on the requirements of the operator.

9.2

Economic Criteria

If both pigging technology and conventional pipeline are technically feasible, the economic evaluation is the next criterion to be examined. This includes the one-off investment and the operating costs. In the comparison between conventional systems and pigging systems, the costs for the energy supply were not considered, since these are negligible in relation to the other expenditures. It was also assumed that infrastructure for the propellant, electrical connections, and drive air for pneumatic units are already present. For realistic comparison of conventional technology and pigging technology, three different applications were selected:

- A long pipeline, in which application of pigging would allow cleaning procedures to be dispensed with.
- A long pipeline, in which application of pigging would allow insulation and electrical tracing to be dispensed with.
- Replacement of ten dedicated pipes for ten products by one piggable pipeline.

First the investment costs are calculated, assuming a service life of ten years. The specific costs used apply to average conditions in 2001. Planning costs are not considered. Likewise savings in steel structures, fixtures, and the resulting space saving cannot be evaluated. Construction of a new plant was assumed. An alternative that is more expensive in terms of investment costs is economical if it leads to savings in operating costs, which in the third year of operational amount to at least 25 % of the excess investment costs. This means an amortization period of at most four years. Equation for the pay-out calculation:

$$P = \frac{\Delta OC_{12}}{\Delta IC_{12}} \cdot 100 \% > 25 \%$$

ΔOC_{12} : Difference operating cost

ΔIC_{12} : Difference invest costs

Index 1: conventional pipeline

Index 2: pigging unit

9.2.1

Long Pipeline without Cleaning Procedures*Description:*

For operational reasons a product cannot remain in the pipeline for a longer period of time. It is not possible to empty the product-filled pipe by gas pressure for product reasons (viscosity). The following alternatives are to be compared:

Conventional pipeline:

3", PN 10, 100 m long with siphons, stainless steel, not insulated, not traced.

Pigging unit:

Piggable pipeline 3", PN 10, 100 m length, (88.9 mm diameter, 3.2 mm wall thickness), longitudinal welding, open-pig system (OPS), enhanced manual operation (see Section 8.2.2), propellant is air.

Investment costs:

Since only a single piggable pipeline is considered here, a simple type of sequence control was selected, but which has the possibility of extension to automated control engineering (see Table 9–1). The higher costs for construction and materials result mainly from the more complex welding (seam dips with limited tolerance).

Table 9–1. Comparison of investment costs for the example long pipeline without cleaning procedures.

Investment costs, conventional piping system	
Pipe material (20 €/m)	20 k €
Erection (mainly pipe rack work, welded, 35 €/m)	35 k €
Valves, flanges	10 k €
Total	65 k €
Investment costs, pigging system	
Pipe material (25 €/m)	25 k €
Erection (mainly pipe rack work, welded, 40 €/m)	40 k €
Valves, flanges, pressure relief vessel 0.5 m ³	20 k €
Higher expenditures for control equipment (waste air, propellant)	20 k €
Total	105 k €

Annual Operating Costs

With the conventional mode of operation the cleaning agent is pushed out of the pipe by compressed air. It is assumed due to the loading of the wastewater with organic compounds, costs will arise for its disposal (see Table 9–2).

Table 9–2. Comparison of annual operating cost for the example long pipeline without cleaning procedures.

Operating costs, conventional piping system	
Cleaning agent (DM water)	1.50 €/m ³
Loss of product	500 €/m ³
Frequency of cleaning procedure	1 per week, 50 per year
Wastewater disposal	0.5 €/m ³
TOC treatment and COD fees	1.00 €/m ³
Fractional product losses during rinsing	10 %
Pipe content	5 m ³
Filling with cleaning agent and cleaning once	15 €
Loss of product	250 €
Disposal of lost product and cleaning agent (10.5m ³)	15 €
Total	280 € × 50 = 14 000 €

Remarks: emptying of the pipe filled with DM water by compressed air

Operating costs, pigging system	
Total pig travel	50 km/year
Pig service lifetime	20 km
3 pigs, 250 € each	750 €
Higher expenditure for maintenance of more complex system	2500 €
Total	3250 €

* Remark: one pig run is sufficient, no rinsing

Total cost comparison		
	Investment costs	Operating costs per year
Conventional piping system	65 k €	14 k €
Pigging system	105 k €	3.5 k €

Evaluation of the comparison:

Although the pigging unit causes 40 k€ higher investment costs, a reduction of around 75 % in the operating costs results.

The pay out calculation (P) shows that an amortization is possible after four years at the latest.

$$P = 11.5 \text{ k€} / 40 \text{ k€} \times 100 \% = 26 \%$$

With longer lines amortization is possible after less than two years due to the superproportionally higher operating costs of the conventional system.

Example: pipe length 2000m, $P = 3 \%$.

Interestingly, a shorter pipeline (length 500m), also has a slightly higher P of 28 %, because the operating costs of the pigging unit do not change greatly with the length of the pipeline, and the investment costs of the conventional pipeline do not decrease proportionally. With increasing length, the pay out calculation for single pipelines clearly shifts in favor of the pigging system.

9.2.2

Omission of Tracing*Description:*

For operational reasons a product may remain in the pipeline for a longer period; in this case, however, the pipe must be insulated and traced. Application of a pig would allow insulation and electrical heating (tracing) to be dispensed with. The following alternatives are to be compared:

Conventional pipeline:

3", PN 10, length 1000 m, stainless steel, with insulation and tracing

Pigging unit:

Piggable pipe 3", PN 10, (dimensions 88.9×3.2 mm), length 100 m, longitudinal welding, open one-pig system (OPS), enhanced manual operation (see Section 8.2.2), propellant is air.

Investment costs:

Since a single piggable pipe is involved here, a simple type of sequence control was selected, but which has the possibility of extension to automated control engineering. The higher costs for erection and materials result mainly from the more complex welding method (seam dip with limited tolerance).

The open system was extended to a closed system within which the pig returns after completion of the pigging procedure to the initial position.

Special requirements of the electrical connections and electronics for application in explosion-hazard areas are not taken into account in the procurement of the electrical tracing system.

Table 9–3. Comparison of investment costs, for the example on pipeline without insulation and electrical tracing.

Invest costs, conventional pigging system	
Pipe material (20 €/m)	20 k €
Erection (mainly pipe rack work, welded, 35 €/m)	35 k €
Valves, flanges	10 k €
Electrical line heating (material and work, 50 €/m)	50 k €
Insulation (material and work, 65 €/m)	65 k €
Total	180k €

Investment cost pigging system	
Pipe material (25 €/m)	25k €
Erection (40 €/m)	40 k €
Valves, flanges	30 k €
Higher expenditure for control equipment (venting, propellant)	20 k €
Total	115k €

Operating cost per year:

Tracing allows the product to remain in the pipeline: there are no costs for cleaning agents and disposal. The operating mode of the closed system with pig return doubles the annual distance travelled by the pig and thus leads to higher pig wear.

Table 9–4. Comparison of annual operating costs for the example long pipeline without insulation and electrical tracing.

Operating costs, conventional piping system	
Electrical heating (tracing) 20 W/m ² , 1000 m, 3000 h/a, 0.05 €/kWh	3000 €
Higher expenditure for maintenance of electrical tracing	750 €
Total	3750 €

Operating costs, pigging system	
Number of pig runs	1/week, 50/year
Total pig run length (forward and reverse run)	100 km/year
Pig service lifetime	20 km
5 pigs, 250 € each	1250 €
Higher expenditures for maintenance of more complex system	2500 €
Total	3750 €

Total cost comparison

	Investment costs	Annual operating costs
Conventional piping system	180k €	4k €
Pigging system	105k €	4k €

Evaluation of the Comparison:

Due to the very cost-intensive tracing the investment costs of the conventional pipeline are more than 50 % higher than the costs of the pigging unit. The operating costs for longer pipelines are higher, but are negligible compared with the investment costs. Investment costs that are lower by ca. 56 k € confirm this “classical” field of application for pigging lines. An additional safety aspect is provided by pigging technology for products that tend to decompose or polymerize.

9.2.3

Multiproduct Pipe*Description:*

A tank truck loading facility is to be supplied from a tank farm via a piperack, over a distance of 400 m. Of the ten products, five can remain in the pipeline after pumping, and the remaining pipelines must be insulated and traced. It is to be checked whether a piggable pipeline would be more economical.

Conventional pipelines:

Ten pipes 3", PN 10, 400 m long, stainless steel, five of which are insulated (mineral wool and cover sheet) and electrically traced.

Pigging unit:

Piggable pipe 3", PN 10, (dimensions 88.9×3.2 mm), length 80 m, longitudinal welding, one-pig system (OPS), enhanced manual operation (see Section 8.2.2), propellant air, conventional pipes between the individual tanks and the manifold.

Investment costs:

Since a single piggable pipe is involved, a simple type of the sequence control was selected but which has the possibility of extension to automated control engineering. The higher costs for erection and materials result mainly from the more complex welding method (seam dip with limited tolerance). A closed pig system was selected. Special requirements of the electrical system and electronics for application in explosion-hazard areas are not considered in the procurement of the electrical tracing.

Table 9–5. Comparison of investment costs for the example “substitution of 10 dedicated pipelines”.

Investment costs, conventional piping system	
Pipe material (20 €/m)	80 k €
Erection (mainly pipe rack work, welded, 35 €/m)	140 k €
Valves, flanges (30 €/m)	120 k €
Electrical line heating (material and work, 50 €/m)	100 k €
Insulation (material and work, 65 €/m)	130 k €
Total	570 k €

Investment costs, Pigging system	
Pipe material (25 €/m)	10 k €
Erection (40 €/m)	16 k €
Piggable valves	75 k €
Nonpiggable valves	20 k €
Higher expenditure for control equipment (venting, propellant)	25 k €
Total	146 k €

Annual Operating Costs

Since the product can remain in the five electrically traced pipelines, there are no costs for cleaning agents and disposal.

The operating mode of the closed pig system with pig return doubles the annual pigging distance and thus leads to higher pig wear.

Table 9–6. Comparison of annual operating costs for the example with “substitution of ten dedicated pipelines”

Operating costs, conventional piping system*	
Electrical line heating (tracing) 20 W/m ² , 2000 m, 3000 h/a, 0.05 €/KWh	6000 €
Higher expenditure for maintenance of electrical tracing	1500 €
Total	7500 €

* Remark: Under the assumption that a pipe not in use can remain filled with product, and no cleaning procedures are necessary, there are no operating costs other than tracing costs.

Operating costs, pigging system*

Number of pig runs	2/day, 500/year
Total pig run length	400 km/year
Pig service lifetime	20 km
20 pigs, 250 € each	5000 €
Higher expenditures for maintenance of a more complex system	5000 €
Total	10000 €

* Remark: One pig run is sufficient, no cleaning.

Total cost comparison

	Investment costs	Operating costs per year
Conventional piping system	570 k €	6 k €
Pigging system	146 k €	10 k €

Evaluation of the comparison:

Insulation and tracing constitute the major part of the investment costs of the conventional system. In comparison the higher operating costs for the pigging unit are not critical.

This task is well suited for the application of a pigging unit. The application of conventional pipelines would result in fourfold investment costs.

9.2.4

Evaluation of the Examples

The aforementioned examples assumed a few pig travels per day. If more frequent pig travels are required, then manual control becomes laborious and labor-intensive. However, the application of a more complex control system, e.g., an operating and tracking system or integration into a process control system, will lead to substantially higher investment costs.

The extension of the control with integration into an existing process control system in a system on the order of magnitude of the example “substitution of ten individual pipes” can increase investment cost by up to 20 %. For planning a new plant these values, must be projected with adjustment for inflation on the basis of the current costs.

9.3

Quality Criteria

According to ISO 9000 certified suppliers must carry out regular quality audits to prove their performance. It concerns not only the quality of the products themselves but also the documented path by which this desired quality is achieved. Reproducible cleaning and pumping processes can represent a crucial part of the certification process. Conventional pipeline technology causes a series of problems, which can threaten product quality or allow it to be achieved only with relatively high expenditure. For example certain products undergo changes during long retention times in the pipeline and no longer achieve the required final quality, or a product must be stabilized by tracing. In these cases a piggable pipe can lead to reproducible quality, if the products do not affect each other from pig run to pig run. If even in the case of product families small amounts of residues lead to degradation of quality, intermediate cleaning must be used. The economy in such cases must be checked for each individual case. Plants in sterile chemistry, the food industry, and cosmetic applications must meet special requirements, and the authorities specify maximum residue levels in the pipelines. For evaluation of the degree of cleaning, see Chap. 10.

Piggable valves, due to their small production volume, are subjected to a thorough final inspection and due to the nearly pocket-free design, operate reliably. Sequence control by a process control system offers the possibility of automated sequences, which provide for a largely consistent cleaning procedure. Since the service lives of the pigs, which are subject to wear, are known sufficiently accurately, the quality of cleaning can be ensured by regular pig substitution. Thus the attainable product quality with frequent product changes can be determined on the basis of a few measurable parameters, without having to constantly examine the outgoing products themselves.

In addition by using an industrial pigging unit a company can react substantially more flexibly to requests from customers, without having to make large technical investments.

9.4

Environmental Criteria

Wastewater reduction and avoidance of residues have become important cost factors for most companies. Here pigging technology can make a significant contribution, by recovering residual substance from the line and, where cleaning procedures are essential, reducing the wastewater load. Thus the energy balance of the production plant improves at the same time, since consumed resources can be used more intensively.

Planning and erection of the pipeline take place according the usual technical rules and company standards, which ensure a uniformly high safety standard. Modern orbital welding technology permits high-quality installation. Sufficient experiences is available in the installation and the operation of pipelines, so that leakage

can be almost excluded, since, for freedom from dead spaces the number of flange connections is minimized.

A plant with a multiplicity of lines increases the probability of a leakage. It requires a larger fortified area with suitable water-retainment and disposal facilities and possibly a monitoring system (see Chap. 18).

Emissions occur during forward pigging to the tank and during pressure relief of the exhaust air line. Depending on product properties, amount (safety data sheet), and duration of the emission, it may be necessary to subject the exhaust gases to cleaning or incineration. Since, however, usually short time intervals and/or low concentrations are involved, handling the exhaust gas usually represents no problem. If exhaust air treatment is required this can be achieved by today's technology without large expenditure.

10

Cleaning Degree after Pigging

10.1

Qualitative Classification

This following chapter deals primarily with industrial pigging units in which solid cast pigs are used.

Since in most cases in which pigs are used for pipe cleaning, not only the simple removal of product adhering to the pipe inner wall and puddles collected by gravity, but also the quality of the cleaning process is important, it is necessary to discuss this topic. In particular, if directly after pig cleaning, a product from another product family can be fed, or intermediate cleaning is required, the contamination of the product is of interest. In the most descriptive case this could be white paint after black paint.

The planned plant can be classified according to cleaning degree and schedule density. The cleaning degree is designated A (lowest) to F (highest) (see Table 10–1). Calculation of the cleaning degree only makes sense for residues that are no longer visible. Therefore this chapter is concerned with the details of the cleaning degree F.

10.2

Precalculation for the Cleaning Degree

Calculation of the cleaning degree depends on so many parameters that it is not possible to make scientifically accurate statements. In the following the construction of the calculation model is presented and the sources of the numerical values used in the examples are given, with support by measurements and tests where possible.

Subsequent consideration of errors reveals the effect of neglected parameter fluctuations. With the help of this chapter it should be possible, despite the afore mentioned inaccuracies, to determine the order of magnitude of the attainable cleaning degree of a system in advance.

Note that the quality of cleaning can be substantially increased by the use of small amounts of solvent contained between two pigs. In some production areas, e.g., pharmaceuticals and foods, this is even essential, for example, when legal degrees of cleanliness (validation) must be met.

Table 10–1. Classification of Pigging Systems to Cleaning Degree and Operation Frequency

Cleaning Degree		1	2	3	4	5	6	7	8	9					
		Operation Frequency*													
		1/a	5/a	1/m	2/m	1/w	3/w	1/d	3/d	1/h					
A	Remove large solid particles														
B	Coarse mechanical cleaning, brushing, removing of deposits and incrustations								x						
C	Mechanical cleaning, scraping					Industrial Pigging Systems									
D	Emptying of a pipe, small residual amount														
E	Complete emptying, drying														
F	Complete emptying within ppm range														

* 1/a: annual, 1/m: monthly, 1/w: weekly, 1/d: daily

x Example: B8 system, coarse mechanical cleaning procedure, 3 × daily

The goal of the cleaning validation is to prove that after a pig run in accordance with a defined process on product contacted surfaces (inner surfaces of the pipes and valves) that certain limits on substance residues are not exceeded. This is best done by specification of a maximum concentration of the residue in the following product (see Section 10.3.5). This concentration is used as measure of the cleaning degree and is calculated from the ratio of the residue to total quantity of the following product in the completely filled system. The limits depend on product and application and, for the strictest requirements of the food industry can be as low as a concentration of 10 ppm. Requirements in the chemical industry lie within the range between 500 and 2000 ppm when pigging is performed for quality reasons.

It can be assumed that the pig, being a snug-fitting body, cannot clean any microscopic recesses and bumps or the unavoidable dead volumes in valves. Furthermore the lubricating film on the pipe inner wall that is essential for pig movement remains as a residual film of finite thickness. The residue is completely taken up by and homogeneously distributed in the following product, so that the same concentration is present everywhere. This mass of residual liquid relative to the total mass of following product driven through the completely cleaned unit is the residual concentration. Since the sum of the residual films at fittings and pipelines is strongly construction-dependent, data is only available from the manufacturer or determined from material samples. To be able to calculate the total mass of residual liquid with-

out practical tests, a model is to be developed for determining the individual contributions to these residues and to clarify their effect on the total result.

10.3

Concept

In the following sections a pigging unit is examined with respect to which components contain residual liquid after a pig run and thus contribute to contamination of the following product. Individual approaches are introduced for estimating the amounts in the plant components, and values for the individual parameters are given wherever the components could be specified. The statements always only apply to selected components, and the parameters for other components must be determined from new.

10.3.1

Inner Surface Roughness of Pipes and Valves

Standard longitudinally welded high-grade steel pipes from hot-rolled sheet have an average roughness depth of $R_z = 20 \mu\text{m}$. Piggable pipes made from cold-rolled sheet, suitable for Viton or silicone pigs, have $R_z = 3 \mu\text{m}$. Additional electropolishing can achieve average roughness depths of $0.5 \mu\text{m}$ (all values from the company Butting; see Figs. 5–1 and 5–2 in Section 5.3.1).

Since R_z represents an average value, it cannot be assumed that the crevices are uniformly distributed over the inner pipe surface. Therefore, a factor f is defined which describes the fraction of these cavities of the total pipe inner surface. These crevices can collect product by capillary forces, which is not cleaned by the pig. The factor f ($0 < f < 1$) is calculated as the ratio of the area of all crevices to the total inner surface area of the pipe.

Most valves will be made from the same semi-finished materials as the pipes or are manufactured with the same roughness depths, so that this treatment is valid for these components, too. For this reason the following discussion is limited to welded valves. The roughness depth of a pipe inner wall is an average value, which is generally measured mechanically. The average roughness R_z according to DIN 4768, part 1 is the arithmetic mean of the single roughness depths of five neighboring measuring sections and is given in μm . However, this says nothing about the distribution and the fraction of the total inner surface. This can be revealed by scanning electron microscopy (SEM) images which, at a magnification of 1500:1, shows how and where residual liquid is retained. Thereby is it of importance whether the pipe was subjected to pickling. The attack of acid on a stainless steel may extract alloying constituents which are concentrated by crystallization at the grain boundaries. Thus the roughness depth is increased, and the cleaning effect strongly decreased, so that larger amounts of residual liquid are retained than with unpickled or electropolished pipes. To keep the calculation conservative, a pipe inner wall

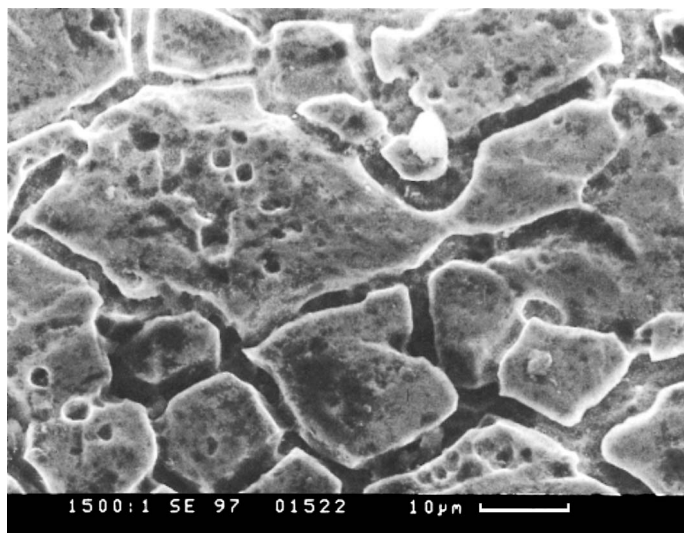


Fig. 10–1. SEM image of a pipe inner surface ($\times 1500$)

made of austenitic cold-drawn sheet was considered, which was subsequently pickled.

The SEM image shows a plateau surface here, pervaded with a network of crevices, some of which are interconnected. The depth is on the same order of magnitude as the width of the crevices, whereby the roughness of the plateau can be neglected. From the scale of the magnification the maximum roughness depth $R_{\max}$ is about $5\mu\text{m}$, so that an average roughness depth of $3\mu\text{m}$ can be assumed, which corresponds to cold-rolled semi-finished product. If the area is measured in a raster-like mode then the surface fraction of the crevices in the total inner surface area can be determined. From this sample of material a surface fraction of $f=0.15$ could be determined with an average roughness depth of $R_z=3\mu\text{m}$. If the tubing interior surface was not pickled, the plateau/crevice structure does not occur, and only the recesses are the drawing grooves of the production process. The fraction f for the unpickled pipe represents the portion of the drawing grooves and is on average $f=0.1$ as can be determined from SEM images. The value of R_z as a measure of the depth of these scoring is ca. $15\mu\text{m}$. If the pipe is electropolished, as is required for industrial pigging units in the food and cosmetics industries f drops to an average of 0.05 with a depth of less than $0.25\mu\text{m}$. The volume which is retained in the recesses is calculated by using Equation (10–1) where L is the length of the piggable pipe and d_i is the inside diameter.

$$V_1 = \pi \cdot d_i \cdot L \cdot f \cdot R_z \quad (10-1)$$

10.3.2

Welding Seams

Due to the force of gravity, welding seams have a more or less pronounced dip (see Section 5.4.2). This dip, together with welding bead due to fabrication, results in a bump on the circumferential welding seam, from which adhering product cannot readily be cleaned.

During the finishing process the interior seam is smoothed, so the longitudinal weld need not be considered. Thus the seam root becomes flat for pipes up to nominal size 125 and wall thickness up to 4 mm. The maximum roughness height in the circumferential welding seam region is $1.6\text{ }\mu\text{m}$.

The fraction of the welding seam dip relative to the total inside circumference of the pipe is expressed by the factor g_1 ($0 < g_1 < 1$). On both sides of the dip a ring of liquid is formed with approximately the same width and height (Fig. 10–2).

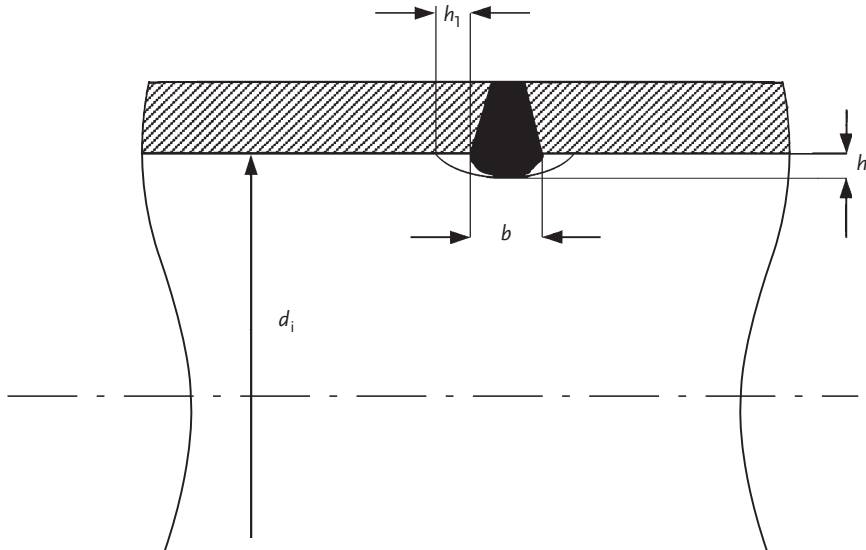


Fig. 10–2. Liquid rings on a welding seam

Depending on the welding technique, the welding seams have different surface qualities and typical dimensions. These are primarily the seam dip h_1 and its fraction of the circumference g_1 . With pipes with nominal sizes of 6" (DN 150) and wall thickness starting from 4 mm, which are TIG welded, the maximum root dip $h_1 = 0.5\text{ mm}$. This dip can, if wished, be removed by internal polishing but serves as a conservative reference value here.

The peripheral fraction of the dip was determined by visual inspection to be $g_1 = 0.2$. The volume of the two liquid rings is determined by Equation (10–2).

$$V_2 = h_1^2 \cdot \pi \cdot d_i \cdot g_1 \quad (10-2)$$

Since the welding seam itself exhibits pendentives (Fig. 10-3) on the total periphery due to its scale structure, this portion must also be considered. This is taken into account by the factor g_2 , which is on average 0.5.

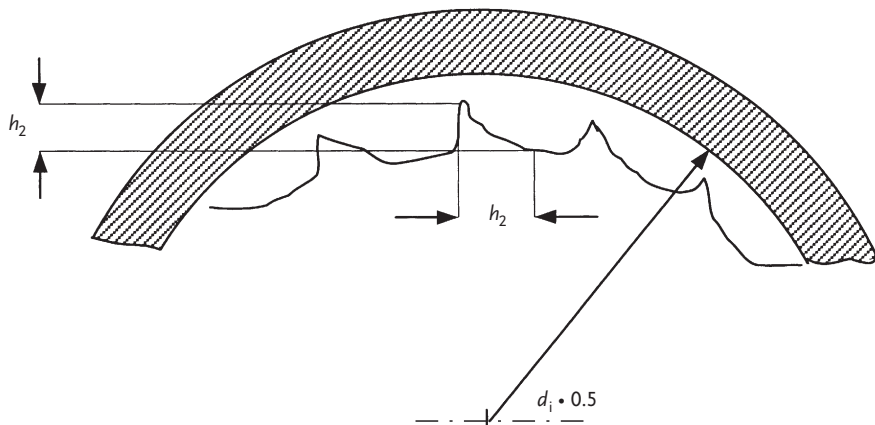


Fig. 10-3. Pendentives on a welding seam

The maximum height of the pendentives with TIG welding was determined to be $h_2 = 100 \mu\text{m}$, and the width b of the welding seam to be 5 mm.

These values serve as reference points for the calculation and are relatively conservative. The application of other welding methods, in particular with smaller nominal sizes, can reduce these values significantly. In relation to the residual film thickness on the pipe inner surface the volume in the plateau crevices, and dead volumes, this volume is of minor consequence.

On the assumption that the pendentives are of equal height and width, the volume of the pendentive is calculated by Equation (10-3).

$$V_3 = \frac{1}{2} \cdot \pi \cdot d_i \cdot b \cdot g_2 \cdot h_2^2 \quad (10-3)$$

10.3.3

Flange Connections

Due to the gasket flanges have two edges that have a disadvantageous effect on the degree of cleaning and the service life of the pigs. Product is retained in the flange gap and cannot be removed by a pig. The depth of the gap depends on the nominal size and the type of gasket. With nominal sizes for which unchambered gaskets or O-rings are generally used, the sealing rings have a thickness of 3 mm. On bolting together the flange, this thickness is reduced by approximately one-third, so that a gap of $s = 2 \text{ mm}$ remains between the flange faces. The actual value is dependent on

the construction of the flange faces and the position of the gasket, but $s=2$ mm is assumed as a worst case here. The distance from the pipe inner edge to the gasket h_3 is dependent on the nominal size and is greater than 2 mm.

The gap volume between the pair of flanges and gasket is completely filled by capillary forces with liquid that cannot be removed by a pig. If solvent is not used to remove this, it inevitably comes into contact with the following product. However, contact and mixing due to friction, owing to the geometrical constraints of the flange gap, take place not in the total volume, but only in an outer zone. The thickness of this layer is assumed to be on the same order of magnitude as the laminar lower layer of the pipe flow, which is typically much less than 1 mm. Therefore, a conservative value of h_3 is three times this layer thickness. The concentration calculation in Section 10.4 will show that the effect of the flange gap volumes is low, similar to the amount of liquid in the welding seams. Furthermore, one seeks to avoid flange connections in pigging units.

The volume of the gap is given by Equation (10–4)

$$V_4 = \pi \cdot d_1 \cdot s \cdot h_3 \quad (10-4)$$

10.3.4

Dead Spaces

Fittings at the end of a piggable pipe have, for reasons of mechanical switching or construction design, protruding edges or recesses, which can fill with product and are not cleanable by the pig. Some suppliers offer fittings with particularly low dead volumes at extra cost. However, when designing a pigging unit many dead spaces can be avoided by skilful combination of different types of fitting, for example, by accurate positioning of pig traps, or launching and receiving stations whose shape corresponds to the pig geometry.

However, some valves cannot be constructed completely free of dead space especially when moving parts and connections for the propellant are present. Although the volumes adhering in these parts can be neglected in relation to the amount in the adhering liquid films in the surface roughness of the total unit, as is shown in Section 10.4, it may also be necessary to eliminate these quantities. This can be achieved by means of a pig travel with a small amount of solvent. The dead volume V_{dead} is defined as the amount of liquid which remains in a valve after a pig travel. It is strongly dependent on the construction. Therefore, only reference values for the fittings considered here can be given. For an accurate calculation the precise position of the pig must be determined, and for each operating condition checked whether and in which orders of magnitude product is retained in crevices, depressions, and gaps.

Exemplarily, valves of the vendor I.S.T., Hamburg, Germany, are quoted here and were available for the following investigations:

Receiving and Launching Stations

Here the position of the pig and the sequence control of the pig travel are decisive. The station shown in Fig. 4–4 has a T-shaped downwards branch, which depending on the distance of the next fitting and the function of the connected pipeline may be filled or only moistened. The sequence control is to be selected such that this volume does not become a dead volume.

The station also has two openings for pig indicators which are flush fitting with the pipe inner wall, but have an annular gap of $s_1 = 1$ mm to the wall and a diameter of $d_1 = 20$ mm. If the pig is positioned in such a way that the downward T-piece need not be considered, as in the example below, then the dead volume is twice the annular gap volume. As with flanges, it is assumed that mixing of the following product with the dead volume occurs over a depth h_3 comparable to the threefold thickness of the lower laminar layer of the pipe flow (Eq. 10–5).

$$V_{\text{dead LS/RS}} = 2 \cdot \pi \cdot d_1 \cdot s_1 \cdot h_3 \quad (10-5)$$

T-Ring Valve

The T-ring valve (Fig. 4–6) is a special fitting which was conceived to minimize the dead volume at branches. Like the launching and receiving stations it has two downward openings for pig indicators, each with a diameter of $d_1 = 20$ mm. The T-ring valve has two construction-specific ring gaps due to the reciprocal guidance of the T-ring. Like the pig indicators these gaps have a width $s_1 = 1$ mm. Thus, the dead volume is given by Equation (10–6).

$$V_{\text{dead TRV}} = 2 \cdot \pi \cdot d_1 \cdot s_1 \cdot h_3 + 2 \cdot \pi \cdot d_1 \cdot s_1 \cdot h_3 \quad (10-6)$$

Loading Lance

Loading lances from the company I.S.T (Fig. 4–21) are piggable up to the end of the opening. They are designed in such a way that by the use of two pigs and an appropriate arrangement of the propellant connections only the last few centimeters of the outlet remain uncleared in the outer sleeve. The thickness of the film there is viscosity-dependent. The example treated below assumes water-like liquids, so that a value of $s_2 = 250$ μm can be given for the residual film thickness. The length of the wet area is on the order of magnitude of the inside diameter of the pipeline d_i and is present both on the outside of the main pipe and on the inside of the sleeve, so that the dead volume is given by Equation (10–7).

$$V_{\text{dead LL}} = 2 \cdot \pi \cdot d_i^2 \cdot s_2 \quad (10-7)$$

10.3.5

Residual Film of the Pigged Pipe*Pig Surface*

Due to the prestress necessary for the cleaning effect pigs are fabricated from flexible materials (see Section 3.2.1). These elastomers are predominantly foamed directly in the mold and thus have a certain fraction of pores near the surface. However, in of polyurethane these are usually not open-celled, i.e., they are not interconnected. Abrasion on the pipe wall causes continuous wear of the surface and opens new pores. Figure 10–5 shows an SEM image of the wear layer, i.e., the surface that has contact with the pipe wall (sealing layer).

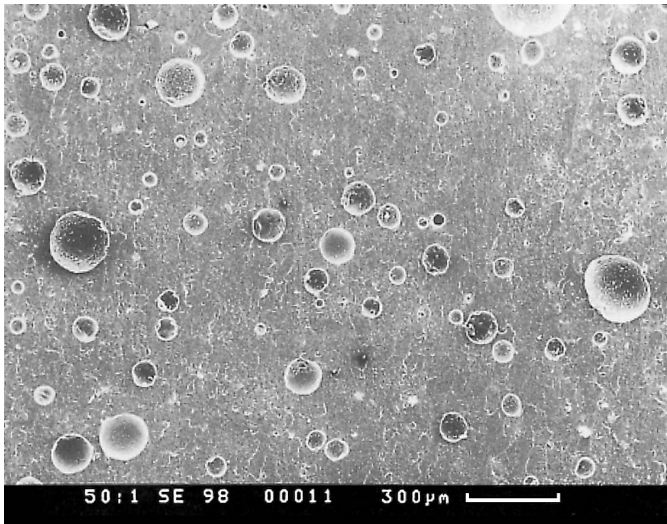


Fig. 10–4. Wear surface of a new polyurethane pig ($\times 50$)

Figure 10–4 shows a new pig made of the same material. Both images were recorded on samples from a solid cast pig of the company I.S.T. made from polyurethane. The cut spherical pores from the production process are evident. Due to geometrical conditions at the face of the pig and the hydrodynamic differential pressure, a dragging current develops in the gap between the inner pipe wall and the pig, which leaves a lubricating film. The pores of the pig remain filled with residual liquid, which contribute thereby to maintenance of the lubricating film.

The thickness of the lubricating film, the so-called residual film thickness s_3 , is decisive for the contamination of the following product and is calculated in the following. For calculation by the model, physical processes are of importance.

Due to the pig geometry, a tapered gap forms between the pipe wall and the face of the pig into which the liquid is driven by the pig moving with constant speed u . This drag current is opposed by a volume flow, which is caused by the differential pressure between the propellant and the face of the pig. Decisive factors influencing

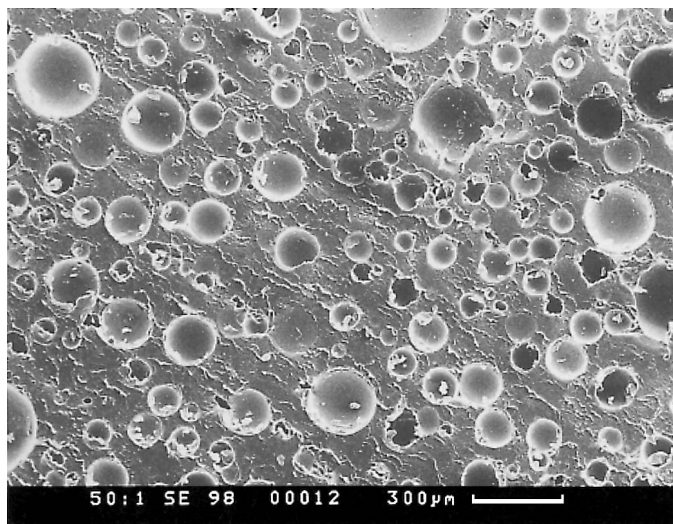


Fig. 10-5. Wear surface of a worn pig ($\times 50$)

the resulting net flow rate and hence the residual film thickness s_3 are the surface pressure between pig and pipe wall, which is determined by the pig oversize (see Section 3.3.1), the gap geometry, the viscosity of the pigged product, and the pig speed.

Surface Pressure

A new pig has a defined oversize which, after pressing into the pipeline, seals by means of surface pressure. The resulting deformation is taken up as work of elastic deformation by the pig material.

It can be assumed for the deformations considered here that most pig materials behave as linearly elastic bodies, i.e., with linear relationship between force and deformation. For polyurethane, this was confirmed by a compression test on a 4" pig (DN 100) from the company I.S.T. (Fig. 10-6).

It was shown that the pig material starts to creep under pressure. The force required for a certain deformation drops from an initial value to a final value that is reached asymptotically (Fig. 10-6). In the tested example the force relaxed at a deformation of $\Delta R = 4.9$ mm (PU 4" pig, DN 100, made of Vulkocell) from initially 682 N to a final value of 550 N, which was only achieved after several hours.

The assumption of linear-elastic behavior in this example for a pressure-loaded area of 462 mm^2 and a compression of $\Delta R/R_0 = 0.09$ (Fig. 10-7) gives a bulk modulus $K = 17.3 \text{ N/mm}^2$.

The bulk modulus K is the relationship of stress to compression and is a measure of the resistance to deformation.

From Hooke's law for linear-elastic bodies the surface pressure can be calculated (Eq. 10-8).

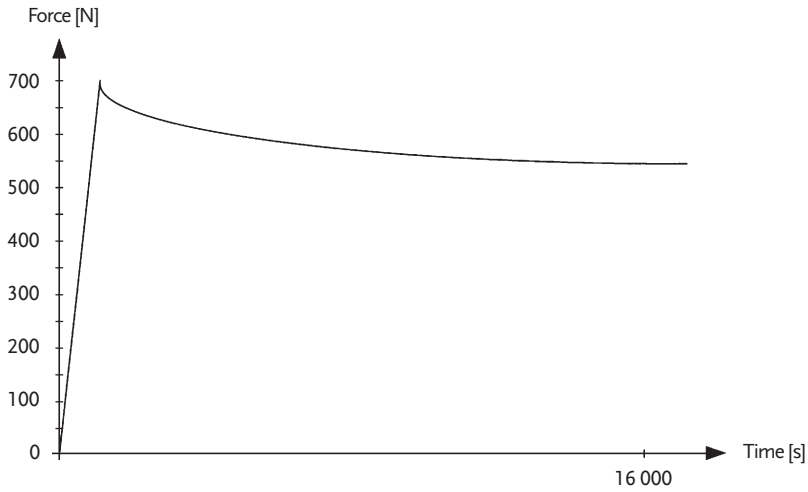


Fig. 10-6. Force/time curve of the compression test

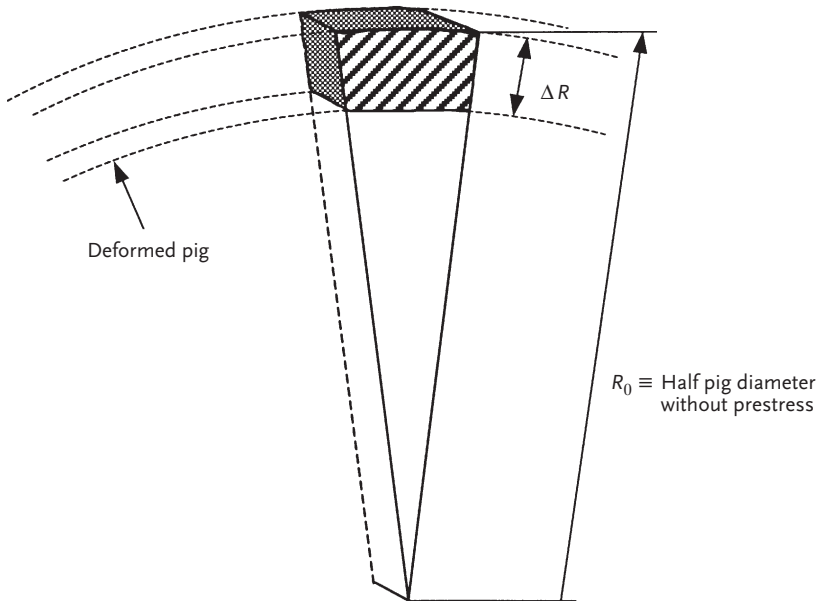


Fig. 10-7. Segment of the pig sealing surface

$$p = \frac{\Delta R}{\frac{d_i}{2} + \Delta R} \cdot K = 14.5 \text{ bar} \quad (10-8)$$

Of course this value decreases with increasing distance travelled by the pig and due to wear can approach a value close to zero. The quality of cleaning defines a limiting value for the running time. Since the connection between pressure and

oversize is almost linear, the contact pressure between a new pig and a worn one can also be interpolated linearly.

Gap Geometry

Under pressure the width of the sealing surface W decreases by the amount ΔW (Fig. 10–7), and this allows the gap geometry near the wall to be calculated approximately. The radius of curvature in the proximity of the wall is used together with the influencing factors viscosity and pig speed as parameters for the calculation of the residual film thickness in the numerical simulation.

It is calculated whether, due the tapered gap, a hydrodynamic pressure cushion can build up that is large enough to overcome the differential pressure before and behind the moving pig. Calculation of gap geometry for the nominal sizes 2", 3", 4", 6" (DN 50, 80, 100, and 150) showed that the nominal size of a solid cast pig does not have a decisive effect on gap geometry, and therefore a mean radius of curvature in wall proximity of $R_1 = 30$ mm can be assumed (solid cast pig).

Since the pig geometry contributes to the cleaning effect almost entirely via the surface pressure, the only further parameters remaining are the viscosity of the pigged liquid and the pig speed. Since the thickness of the residual film is determined by hydrodynamic parameters, it plays no role whether the pig has one, two, or more sealing lips, as long as the flexible behavior of a solid cast pig is maintained. Determination of the capillary forces in the crevices (see Section 10.3.1) shows that the liquid residing there can not be driven out by the pressure developed by the pig.

Under the assumption of laminar flow in the Hagen–Poiseuille law can be used to calculate the flow velocity in the crevices due to the maximum differential pressure generated by the propellant pressure. The maximum value of 0.01 m/s clearly lies below the pig speed. Thus the differential pressure cannot to empty the crevices. This would only be possible by drag current, generated by the pig itself. However, since the trenches form a network, the presence of transverse crevices rules this possibility out (see Fig. 10–1).

With unpickled or electropolished surfaces, the drawing grooves from fabrication retain liquid, which, in a worst case scenario, is not removed by pigging.

Viscosity and Pig Speed

Since the above-mentioned pressure build-up in the gap in front plays a crucial role, it is plausible that a high residence time of fluid particles in the gap during pigging increases the residual film thickness. This is the case if the mobility of the particles relative to each other is reduced (high viscosity) and their kinetic energy and inertia play a role (high speed). These interdependences are expressed by an empirical equation, which was developed for determining the amount of air included when a film is rolled (Eq. 10–9) [2].

$$s_3 = e \cdot R_1 \cdot \left(\frac{\eta \cdot u}{p \cdot R_1} \right)^{2/3} \quad (10-9)$$

The factor ϵ is viscosity-dependent and can be determined from tests with liquids of different viscosity. Including this function in Equation (10–9) gives the residual film thickness as a function of the four investigated parameters (Eq. 10–10).

$$s_3 = 0.679 \cdot \left(\frac{u}{p}\right)^{2/3} \cdot R_1^{1/3} \cdot \eta^{8/21} \quad (10-10)$$

u	[m/s]	Pig speed
p	[N/m ²]	Propellant pressure
R	[m]	Mean radius of curvature
η	[Pa · s]	Dynamic viscosity of the product
s_3	[m]	Residual film thickness

The residual film thickness thus calculated agrees with sufficient accuracy with experimental data from tests, in which the film thickness after pigging was determined from the concentration of chloride ions, determined by mass spectrometry (see Section 10.4).

The following example illustrates parameters influence that the residual film thickness.

It concerns a 2" pipe (DN 50), which is travelled by a solid cast pig and contains liquids of different viscosity. Using Equation (10–10) allows the residual film thickness to be expressed as a function of the surface pressure, which can serve as measure of pig performance, with consideration of various parameters (Fig. 10–8 and 10–9).

The points are the result of tests on a new solid cast pig made of Vulkocell.

The values calculated according to the model are confirmed with sufficient accuracy, as is also shown by the consideration of errors in Section 10.5 (see Fig. 10–10).

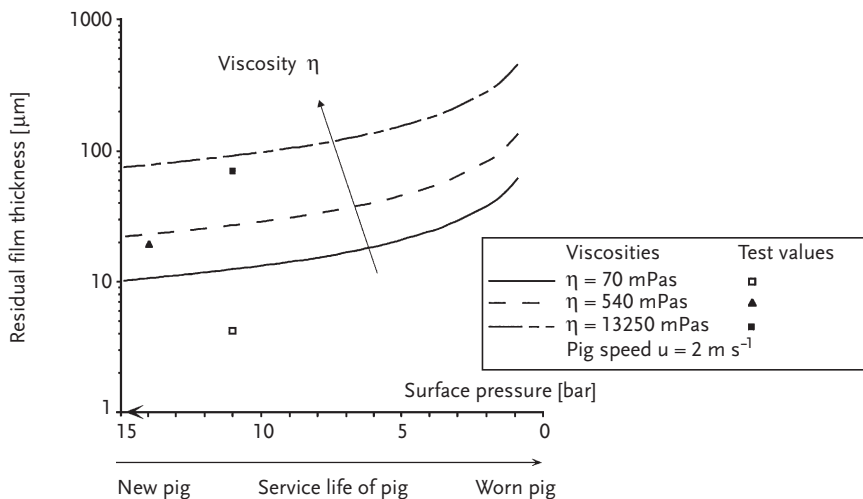


Fig. 10–8. Residual film thickness as a function of viscosity

Investigations at the Fachhochschule Köln [3] showed that the residual film thickness is larger in pipe bends than in straight pipe sections of comparable length. There is also a dependence on the radius of curvature. However, due to the short length of the pipe bends in comparison to the total system this effect is only of importance for a large number of bends. Depending on the speed of the pig, the residual film thickness in pipe bends is on average higher by a factor $f_B = 1.2$. In systems with up to ten pipe bends and total lengths of 100 m or more the effect of this difference is negligible.

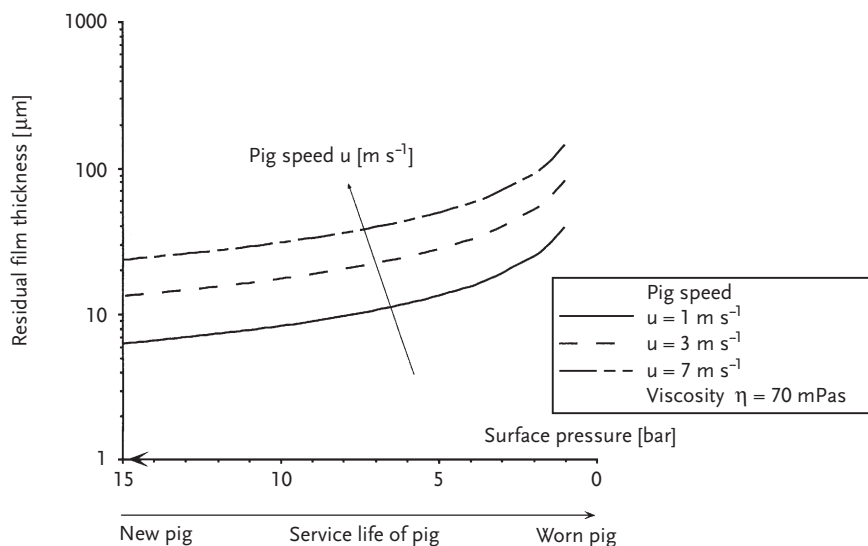


Fig. 10-9. Residual film thickness as a function of speed

The summation of the individual residual volumes presented in this chapter gives the total residual volume in the pigged plant.

As mentioned in Section 10.2, the residual volume is referred to the total volume of the unit in the filled state to give the concentration of contaminants in the following product, which is generally expressed in parts per million (ppm).

10.4

Exemplary Calculation for Residual Concentration in a Plant

Plant components

A tank farm with three storage tanks serves via a loading station tank trucks with a water-like product. On one side, the pig pushes the liquid out of the pipe and into the tank truck, and on the other (storage tanks) the branches of the product pipe run dry; the liquid in the nonpiggable supply pipes is returned through a pump and a filter to the respective storage tank. The pigging unit for the following exemplary calculation consists of the following components:

- Piggable pipe 4" (DN 100), overall length 150 m
- 10.5D pipe bends (type 5)
- 45 circumferential welding seams
- 4 flange connections
- 1 launching and 1 receiving station
- 1 T-piece (T-ring valve)
- 1 piggable loading lance

The T-ring valve does not contribute to the dead volume, since the pig blocks and then opens the product path each time. The left launching station need not be considered since it is always shut off by the pig. Thus the dead volume only consists of the contributions of the right receiving station and the piggable loading lance.

Calculation of the Residual Volumes after Pigging

Residual volume in the pipe roughness in a pipeline with a pickled interior surface including all valves:

$$V_1 = \pi \cdot 107.1 \text{ mm} \cdot 150 \text{ m} \cdot 0.15 \cdot 3 \mu\text{m} = 2.271 \cdot 10^{-5} \text{ m}^3 \quad (10-11)$$

Volume on both sides of the welding seam:

$$V_2 = 0.5 \text{ mm} \cdot 0.5 \text{ mm} \cdot \pi \cdot 107.1 \text{ mm} \cdot 0.2 = 1.682 \cdot 10^{-8} \text{ m}^3 \quad (10-12)$$

Volume of the welding pendentives:

$$V_3 = \pi \cdot 107.1 \text{ mm} \cdot 5 \text{ mm} \cdot 0.5 \cdot 0.5 \cdot 100 \mu\text{m}^2 = 4.206 \cdot 10^{-12} \text{ m}^3 \quad (10-13)$$

Volume of the flange gap:

$$V_4 = \pi \cdot 107.1 \text{ mm} \cdot 2 \text{ mm} \cdot 0.4 \text{ mm} = 2.692 \cdot 10^{-7} \text{ m}^3 \quad (10-14)$$

Dead volume of the launching and receiving station:

$$V_{\text{dead LS/RS}} = 2 \cdot \pi \cdot 20 \text{ mm} \cdot 1 \text{ mm} \cdot 0.4 \text{ mm} = 5.027 \cdot 10^{-8} \text{ m}^3 \quad (10-15)$$

Dead volume of the T-ring valve:

$$V_{\text{dead TRV}} = 2.2 \cdot 10^{-6} \text{ m}^3 \quad (10-16)$$

Dead volume of the loading lance:

$$V_{\text{dead LL}} = 2 \cdot \pi \cdot 107.1 \text{ mm}^2 \cdot 250 \mu\text{m} = 1.802 \cdot 10^{-5} \text{ m}^3 \quad (10-17)$$

Number of welding seams:

$$n_1 = 45 \quad (10-18)$$

Number of flanges:

$$n_2 = 4 \quad (10-19)$$

Number of launching and receiving stations:

$$n_3 = 2 \quad (10-20)$$

Number of T-ring valves:

$$n_4 = 1 \quad (10-21)$$

Number of loading lances:

$$n_5 = 1 \quad (10-22)$$

Number of elbows:

$$n_6 = 10 \quad (10-23)$$

Sum of the dead volumes of the unit without residual film:

$$\begin{aligned} V_{RO} = V_1 + (V_2 + V_3) \cdot n_1 + V_4 \cdot n_2 + V_{\text{dead LS/RS}} \cdot n_3 \\ + V_{\text{dead LL}} \cdot n_5 = 4.261 \cdot 10^{-5} \text{ m}^3 \end{aligned} \quad (10-24)$$

Residual film thickness of a new solid cast pig at a speed of 2m/s:

$$s_3 = 0.679 \cdot \left(\frac{2 \text{ m/s}}{14.5 \text{ bar}} \right)^{2/3} \cdot (30 \text{ mm})^{1/3} \cdot (0.001 \text{ Pas})^{8/21} = 2.8 \mu\text{m} \quad (10-25)$$

Sum of the residual volumes of the unit (dead volumes and residual film):

$$V_{Rm} = V_{R0} + \pi \cdot d_i \cdot L \cdot s_3 = 1.825 \cdot 10^{-4} \text{ m}^3 \quad (10-26)$$

Total volume of the filled unit:

$$V_G = \pi/4 \cdot d_i^2 \cdot L = 1.351 \text{ m}^3 \quad (10-27)$$

Residual concentration in the following product:

$$C_R = \frac{V_{Rm}}{V_G} \cdot 10^6 = 135 \text{ ppm} \quad (10-28)$$

In order to clarify the dependence of the residual concentration on nominal size and viscosity the respective ppm values are indicated in Table 10-2 for otherwise unchanged parameters. A distinction is made between pickled, unpickled and electropolished tubing interior surfaces.

Table 10–2 only gives an indication of the orders of magnitude of the attainable residual concentrations. The effect of the viscosity is clearly lower than that of the total volume of the unit. The square of the nominal size enters the calculation of the total volume, while only the linear film thickness over the surface is considered. For larger diameter lines the ratio V_{Rm}/V_G will be more favourable concentration will be less because the hdd-up of the total unit increases more than the residual volume.

Table 10–2. Calculated residual concentration in the following product for different viscosities, nominal sizes, and surface qualities.

Nominal size	Surface quality*	Residual concentration in the following product [ppm]		
		Viscosity η [mPas]		
		1	100	10000
2" (DN 50)	p	185	879	5968
	up	261	956	6044
	ep	153	848	5936
3" (DN 80)	p	128	594	4059
	up	179	645	4110
	ep	107	573	4038
4" (DN 100)	p	102	462	3170
	up	141	501	3209
	ep	85	446	3153
6" (DN 150)	p	73	318	2195
	up	100	345	2222
	ep	62	307	2184

* p=pickled, up=unpickled, ep=electropolished.

10.5 Errors

In an experiment the residual film thickness was calculated from the mass spectrometrically measured chloride ion concentration. A solution of known concentration was introduced into a piggyback pipe section, pigged, washed out, and analyzed. This section shows with which accuracy the residual film thickness can be determined in the tests when the maximal possible errors are considered in determining the individual parameters of the tests. Furthermore the effect of the parameters from the formula used for the theoretical calculation of the residual film thickness is to be clarified. First a list of all measured variables x_i is given with an estimation for the range of their individual errors Δx_i . The absolute error Δs_3 in the calculation of the layer thickness s_3 from a number n of independent measured variables x_i with individual errors Δx_i is given by the sum of the individual differentials of the function $s_3(x_i)$ in the respective position x_i (Eq. 10–28).

$$\Delta s_3 = \sum_{i=1}^n \frac{\partial s_s}{\partial x_i} \Delta x_i \quad (10-29)$$

However, for the comparison of the accuracy not the absolute error Δs_3 , but the relative error $\Delta s_3/s_3$ in % is used.

An individual differential represents the derivation of the function $s_3(x_i)$ at the position x_i in terms of this variable.

Measurement errors

Length of the measuring section:

$$\Delta f_1 = \frac{\Delta L}{L} = \pm 0.2 \% \quad (10-30)$$

Concentration of the chloride ion solution:

$$\Delta f_2 \approx \pm 0 \quad (10-31)$$

Pipe inside diameter:

$$\Delta f_3 = \frac{\Delta d_i}{d_i} = \pm 0.9 \% \quad (10-32)$$

Completeness of the chloride ion removal:

$$\Delta f_4 = \frac{\Delta m_1}{m} = \pm 0.9 \% \quad (10-33)$$

Determination of the chloride ion content:

$$\Delta f_5 = \frac{\Delta m_2}{m} = \pm 0.1 \% \quad (10-34)$$

Determination of factor f:

$$\Delta f_5 = \frac{\Delta f}{f} = \pm 10 \% \quad (10-35)$$

Determination of R_z :

$$\Delta f_7 = \frac{\Delta R_z}{R_z} = \pm 15 \% \quad (10-36)$$

Thus the total error is calculated to be $\pm 26\%$ for determination of the residual film thickness for the 2" (DN 50) used in the tests. The error can be used in good approximation for nominal sizes up to 6" (DN 150).

Error in Application of the Formulas

This is based on comparison of the experimental results (see Fig. 10-8) with the theoretically calculated residual film thickness (Eq. 10-10).

Determination of the radius of curvature R_1 :

$$\Delta f_8 = \frac{\Delta R_1}{R_1} = \pm 10 \% \quad (10-37)$$

Effect of the prefactor e :

$$\Delta f_9 = \frac{\Delta e}{e} = \pm 15 \% \quad (10-38)$$

Determination of the viscosity η (temperature-dependent):

$$\Delta f_{10} = \frac{\Delta \eta}{\eta} = \pm 8 \% \quad (10-39)$$

Measurement of the pig speed u :

$$\Delta f_{11} = \frac{\Delta u}{u} = \pm 10 \% \quad (10-40)$$

Determination of the contact pressure p :

$$\Delta f_{12} = \frac{\Delta p}{p} = \pm 10 \% \quad (10-41)$$

Thus the total error for the theoretical calculation of the residual film thickness is $\pm 22\%$ depending on the size of the individual parameters. This corresponds to an error in the determination of the residual concentration in the following product of the described pigging unit of $\pm 21\%$.

Figure 10–10 corresponds to Fig. 10–8 with the error bars determined here. It shows that the formula can calculate the residual film thickness with sufficient accuracy, especially when one considers that the residual film thickness only contributes fractionally to the calculation of the residual concentration in the following product. With the presented calculation method, predetermination of the cleaning degree, or at least the order of magnitude of the residual concentration, is possible if a client already requires this information in the planning stage.

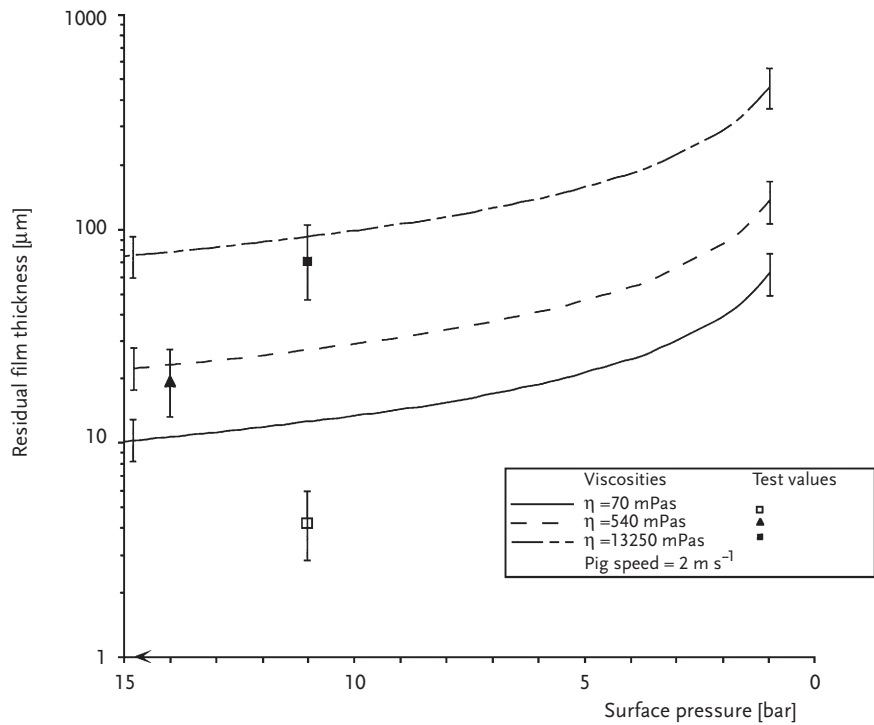


Fig. 10–10. Residual film thickness as a function of viscosity with error bars

11

Pig Wear

11.1

Fundamentals

The investigation of wear is a subsection of the field of tribology, the theory of wear, friction, and lubrication. Wear and friction can be decreased by lubrication.

Wear

According to DIN 50320 wear is defined as follows:

Wear is the progressive loss of material from the surface of a solid body caused by mechanical action, i.e., contact and relative motion with a solid, liquid, or gaseous counterbody.

- The stress on the solid body due to contact with the counterbody is called tribological stress.
- Wear is characterized by the presence of detached small particles (wear particles) and by material and shape changes of the tribologically stressed layer.
- In technology wear is normally undesired.
- The material lost by wear is called, according to DIN 50321, wear rate, and its reciprocal is the wear resistance. Wear is not a material property, but a system property.

Analysis of a tribological system includes:

- Investigation of the components taking in the wear: body, counterbody, intermediate medium, ambient medium
- Analysis of the stress collective: type of movement, course of motion, load, temperature, time
- Determination of the loss quantities: wear, friction, temperature rise, sound emission
- Determination of the mechanism of wear: Adhesion, tribo-oxidation, abrasion, surface, rutting.

A measuring methods for wear, the following quantities are suitable:

- Measurement of a change in dimensions due to wear
- Determination of the gravimetric or volumetric wear rate

- Collection and analysis of the wear particles
- Determination of the wear-determined life (service life).

The wear rate of pigs can be determined by changes in dimension (e.g., diameter reduction [μm] or the weight reduction [mg] after a certain running performance [km], the so-called glide path.

Vogelpohl compiled [1] for a large number of tribological systems the different wear-path ratios (see Fig. 11–1). As wear rate the change in dimension relative the

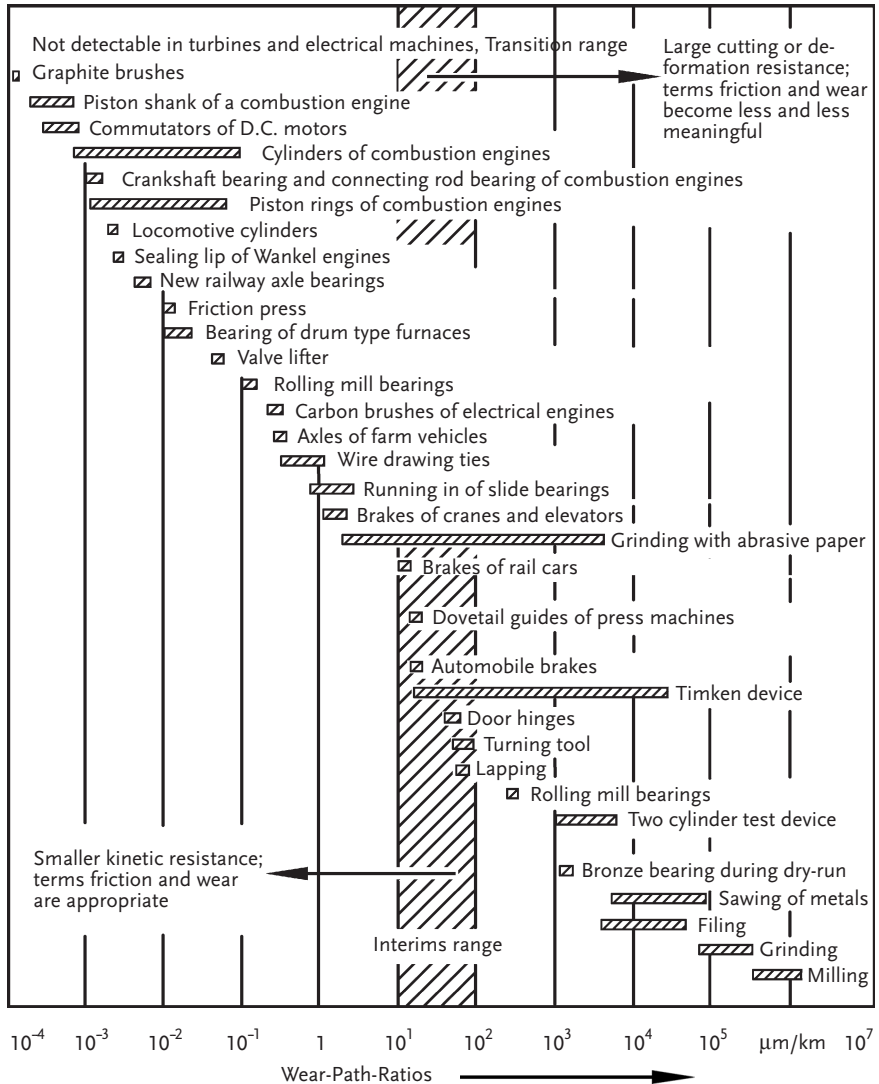


Fig. 11–1. Wear path ratios of various tribological systems

path travelled thereby was use [$\mu\text{m}/\text{km}$]. Above a rate of $100 \mu\text{m}/\text{km}$ the term wear is no longer appropriate. This range also contains the cutting finishing methods, which are by definition not wear. Below $0.001 \mu\text{m}/\text{km}$ the wear rate is extremely low and at the detection limit. As will be seen later, average pig wear is on the order of magnitude of 1 to $10 \mu\text{m}/\text{km}$. The wear rate of pigs lies in the order of magnitude of friction bearings, carbon brushes in electric motors, and brake linings. A further comparison: car tire achieves a wear-path ratio of $0.1 \mu\text{m}/\text{km}$.

A special form of the wear is running-in wear. Running in is a process which changes the geometry of the friction surfaces. The manufactured surface finish develops an operating roughness, and an equilibrium roughness becomes established. After running in the frictional force and the wear intensity usually drop, given constant ambient conditions.

In contrast to many other technical tribological systems a significant hardness difference is present in the pigging procedure: While the pig itself has a Shore hardness of ca. 50 Sh, the high-grade steel pipe has a Rockwell hardness of $\approx 45^\circ \text{HRC}$. This means that wear occurs predominantly on the softer partner, i.e., the pig. This effect is reversed in the combination of a brush pig and a plastic pipe.

Friction

The external friction of solid bodies is a process of energy dissipation, which occurs during tangential displacement of two touching bodies at their contact points. For quantitative evaluation the frictional force F_R is used; the frictional force is the resultant of the tangential strengths (Eq. 11–1).

$$F_R = \mu \cdot F_N = \mu \cdot p_{\text{press}} \cdot A_{\text{press}} \quad (11-1)$$

The normal force F_N is given by the surface pressure between pig and pipe (p_{press}), acting on the contact area (sealing surface area A_{press}).

The frictional force F_R is overcome by the pressure of the propellant p_{prop} (Eq. 11–2).

$$F_R = p_{\text{prop}} \cdot A_{\text{pipe}} \quad (11-2)$$

where A_{pipe} is the cross-sectional area of the pipe: $d_i^2 \pi/4$.

In the theory the coefficient of friction μ is regarded as being independent of the load and the friction area.

Lubrication

Lubricants are materials which decrease the friction and the wear of bodies moving relative to each other. Lubricants can be liquid or solid.

For the movement of the pig in the pipe, the product and/or the propellant must take on the function of the lubricant. A lubricant must exhibit the following characteristics:

- Separate body and counterbody
- Decrease friction
- Be unreactive
- Adhere well to sliding surfaces; wet the bodies
- Act as a force-transferring “component”
- Remove heat
- Seal

While for many technical problems, e.g., bearings for drive shafts and pistons in cylinders, highly developed special lubricants (mineral oils) have been developed, the latent lubricity of the product and/or propellant must be used in pigging.

To estimate the suitability of a liquid as a lubricant different physical characteristics can be examined. The most important of these is the viscosity, particularly its dependence on temperature, pressure, and shear gradient. Wetting ability, surface tension, and adhesion are much more difficult to measure.

11.2

Wear Characteristics and Service Life of Pigs

Experience of operating industrial pigging units has shown that each pigging unit has quite special characteristics. Prediction of the service lives of pigs is extremely difficult. Pigs in similar units and used for the same product families can subsequently be compared with one another and the service lives determined.

In the production of paints and coatings pigs made of Vulkollan with nominal sizes of 2" and 3" (DN 50 and DN 80) can be run up to ca. 50 km, which corresponds to 300 pig travels. That corresponds to a service life of about one year.

Vulkozell pigs with nominal sizes of 3, 4, and 6" (DN 80, DN 100, and DN 150) in the production of urea-formaldehyde resins run for up to 150 km (ca. 2400 pig travels). This corresponds to a pig service life of ca. 4–5 months.

Important criteria for the wear characteristics and hence the service life of a pig are material resistance to product and cleaning agent; specific product properties (abrasiveness, viscosity, stickiness, temperature); the quality of the pipes, pipe inner surfaces, welding seams, and connecting elements; the quality and bending radius of the pipe bends; the choice of correct fittings; and the normal and reliable function of the control units.

Of great importance is setting the correct pig speed. For propelling of the pig with air or nitrogen the ideal pig speed is less than 2 m/s, and 7 m/s should not be exceeded. When the pig is propelled with liquid the speed of the pig depends on the capacity of the pump and the pipe cross section. In practice speeds of ca. 2 m/s are selected.

11.3

Minimum Permissible Pig Diameter

During its period of operation the diameter of the pig decreases. If the maximum diameter of a new pig at the sealing lips is designated $d_{p_{new}}$, during operation its diameter d_p decreases due to pig wear and reaches the value $d_{p_{min}}$ at the end of its service life. Its sealing effects is then no longer present. The diameter $d_{p_{min}}$ must still be larger than the inside diameter of the pipe d_i :

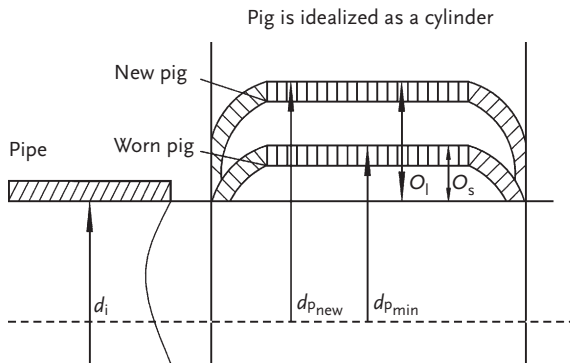
$$d_{p_{new}} > d_p > d_{p_{min}} > d_i$$

The determination of the minimum pig diameter $d_{p_{min}}$ is important for deciding whether the pig can be driven further or whether it must be changed. The following calculation estimates $d_{p_{min}}$ for a solid cast pig passing through a tube bend.

For the calculation the inside diameter of the pipe d_i and the radius of curvature of the pipe bend r must be known.

Half of the difference between $d_{p_{min}}$ and the inside diameter of the pipeline d_i is referred to as smallest possible oversize between the diameter of a new pig $d_{p_{new}}$ and pipe inside diameter d_i (Fig. 11–2).

The difference between the oversizes the so-called fitting tolerance $T = O_l - O_s$, is a measure for the elasticity of a pig.



- O_l : Largest possible oversized
- O_s : Smallest possible oversized
- $T = O_l - O_s$: Fit tolerance of pig

Fig. 11–2. Oversize characteristics

The actual pig diameter d_p is measured at the part at the pig which performs the sealing function. This measured value is compared with the minimum pig diameter specified by the manufacturer and preferably recorded in a data sheet at regular intervals, so that a statement about the remaining life of the pig can be made.

Table 11–1 lists the sizes for cylindrical pigs of different nominal sizes.

Table 11–1. Oversize parameters

			Numbers in mm			
Pipe:	nominal Size	DN	50 (2")	80 (3")	100 (4")	150 (6")
Pipe:	inner diameter	d_i	55.1	82.5	107.1	158.3
Pig:	greatest possible oversize	O_g	1.4	2.5	4.9	4.7
Pig:	smallest possible oversize	O_s	0.35	0.56	0.60	1.16
Pig:	fit tolerance	T	1.05	1.84	4.30	3.54
Pig:	diameter brand new	d_{new}	56.5	85	112	163
Pig:	minimal diameter	d_{min}	55.45	83.06	107.70	159.46

The importance of maintaining the minimum diameter is illustrated in Fig. 11–3 for a solid cast pig travelling through a pipe bend.

It shows that pigs which have only the minimum pig diameter d_{pmin} no longer seal over a ring area on the pipe inner wall as in travel through a straight pipe section, but only over circular line. Further wear of the pig would entail an immediate leakage at this linear gasket. The minimum pig diameter is determined by calculating the smallest possible oversize O_s from the geometrical relations (Eq. 11–3).

$$d_{pmin} = d_i (1 + c) \text{ where } c = \frac{O_s}{d_i} \quad (11-3)$$

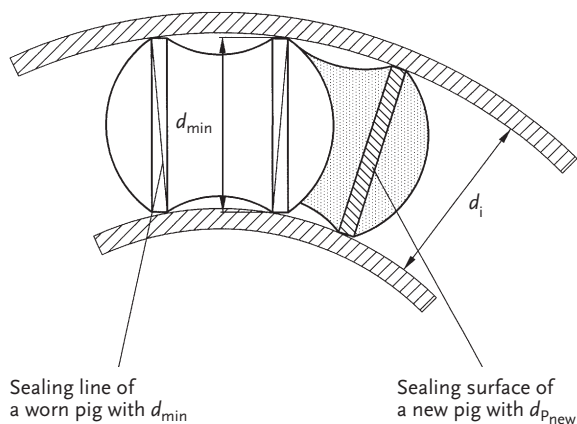


Fig. 11–3. Geometrical determination of the minimum pig diameter d_{pmin} .

11.4 Wear Inspection

The cleaning performance depends crucially on the state of the pig. For all kinds of pigs the pig outside diameter must always be larger than the pipe inside diameter. Degree of cleaning and pig material determine the required prestress and hence pig oversize. Therefore great importance is attached to inspection of the pig. Apart from visual examination of the pig for damage, regular measurements of dimensions must be carried out.

The state of a pig and/or its lips can best be examined in the built-in state in the launching station (see Fig. 11–4). The abrasion is determined by means of a pressure measurement. All fittings are equipped in this design with control drives.

The pig is in the launching station, and the product in- and outlets are closed. With long piggable pipes or large diameters it is advisable to decouple the launching station from the system by a piggable ball valve. Thus the volume and the waiting periods for the test procedure are reduced. Valves V_2 and V_3 are closed. Valves V_1 (air supply) and V_4 are opened. The air supply remains opened until the pressure gauge indicates an air pressure of e.g., 4 bar ($p_{\max}$).

When $p_{\max} = 4$ bar is achieved, the air supply valve V_1 and valve V_4 will be closed automatically. V_2 and V_3 are opened. After a waiting period based on experience (depending nominal size and position of pipe between 1 and 10 min) $p_{\min}$ is measured. If a pressure of 3 bar is not reached, the pig lips are still in a good state. If the pressure drops below the minimum, then malfunction is indicated, and the pig must be changed.

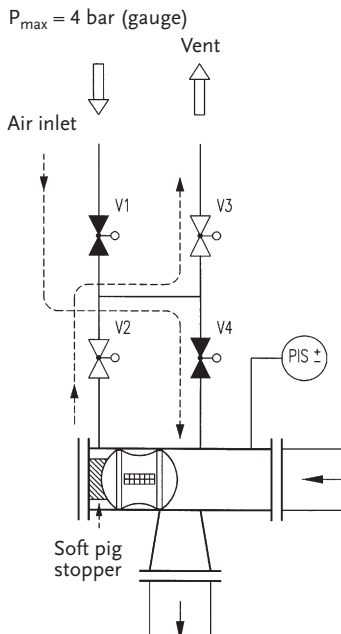


Fig. 11–4. Schematic for wear inspection

11.5

Operating Mode

For gentle treatment of pigs liquid-propelled operation with development of an elastohydrodynamic lubricating film is preferred. Dry running the pig is the least favorable method and has the highest pig wear.

For returning the pigs to the launching station the operating mode gas/pig/gas should be avoided where possible. Since it can lead to excessive operating speeds that can cause substantial damage to pigs, pipes, and valves (see Chap. 14). If this is not possible, a throttle must be installed in the pressure-relief line to maintain sufficient back-pressure ahead of the pig. The same effect can be achieved by back-pressure ahead of the pig, e.g., with air or nitrogen. The pressure difference between the front and back of the pig should not drop below about 1 bar. The throttle is dimensioned according to this differential pressure criterion.

Depending on the size of the pig, prestress, pig material, type of pig, pipe material, and product properties, the pressure required to drive the pig can differ. Normally a pig should travel trouble-free at ca. 2 bar differential pressure (propellant pressure minus product pressure). To overcome static friction a somewhat higher value is used for start-up.

12

Medium-Specific Characteristics

12.1

Introduction to Fluid Dynamics

The question of pressure drop does not only arise in dimensioning of the product pump, but also when a pasty product must be pushed out of a pipe by a pig, for example, creams or cocoa mass.

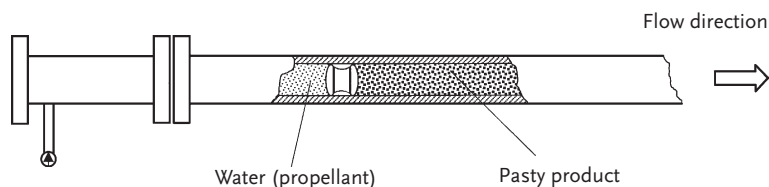


Fig. 12-1. Liquid-propelled pig

In the example shown in Fig. 12-1 the pig is driven by water and drives a non-Newtonian liquid whose flow behavior has a major effect on the pressure drop which must be overcome.

With pasty or highly viscous materials the pressure drop calculation is only possible with extensive detailed knowledge. In practice liquids exhibit different flow behavior. When a fluid flows through a circular pipe, outside forces act due to the friction at the pipe-wall. These forces cause a shear stress τ in the fluid due to the deformation of its volume elements. The components in wall proximity are delayed by friction and thus strongly deformed, while those in the center of the pipe remain almost undeformed (Fig. 12-2).

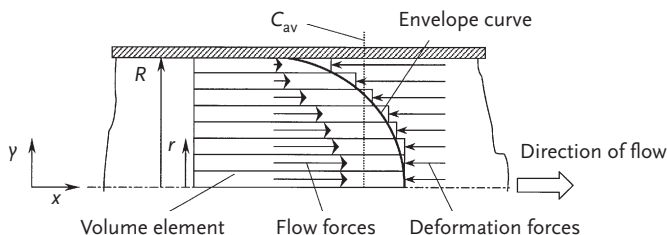


Fig. 12-2. Model of the volume elements within a flow

The enveloping curve of the volume elements is called the velocity profile, the shape of which depends on the velocity. The resistance of a liquid to forced change in position of its volume elements is the viscosity η . Since the viscosity depends on the velocity profile, the relationship between the viscosity η and the shear stress τ is important. Newton discovered the basic law of viscosimetry, which describes the behavior of an ideal fluid (Eq. 12-1).

$$\tau = \eta D \text{ [N/mm}^2\text{]} \quad (12-1)$$

where D is the velocity gradient corresponding to the aforementioned velocity profile, i.e., the change in velocity radial to the flow direction (Eq. 12-2).

$$D = \frac{dc}{dy} \text{ [s}^{-1}\text{]} \quad (12-2)$$

This derivative, which is also called shear rate, has the unit s^{-1} and, as seen from the formula, is position-dependent.

Fluids with linear relationship between shear stress and shear rate are called Newtonian fluids. Their viscosity does not vary with shear rate. Bernoulli recognized the connection between pressure drop, flow velocity, and viscosity in Newtonian fluids, and developed an equation for calculating the pressure drop (see Section 12.3). Fluids with nonlinear relationships between shear stress and shear rate, i.e., whose viscosity depends on shear rate, are called non-Newtonian fluids. Most liquids belong to this group, whereby different relationships between shear stress and shear rate can occur. Neither the distribution of velocity over the pipe cross section nor the pressure drop can be determined accurately and straightforwardly. The velocity profile is strongly flattened at the core of the flow (Fig. 12-3).

Calculation of viscosity and pressure drop is dealt with in more detail in Sections 12.3.1 and 12.3.2.

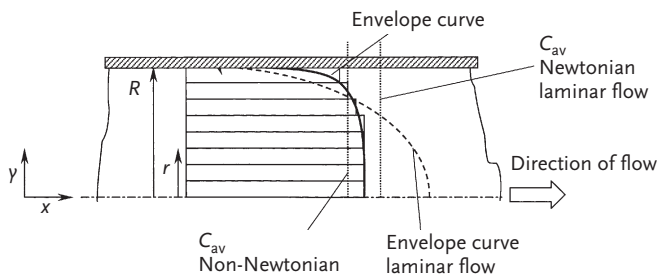


Fig. 12-3. Velocity profile of the flow of a non-Newtonian fluid

12.2

Classification of Fluids with Examples

To discuss the differences between Newtonian and non-Newtonian behavior, it is helpful to have a classification, which assigns each medium to a group with similar

properties. The dependence of viscosity on shear gradient is called viscosity curve and is a suitable distinction criterion. To clarify the visual representation a double-logarithmic representation was selected. In the following classification, examples are given and the behavior of the fluids is described.

12.2.1

Viscosity Curves

Newtonian Fluids (Ideal Behavior: Fig. 12–4)

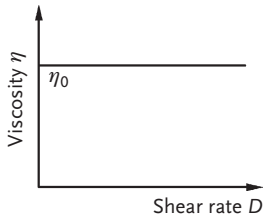


Fig. 12–4. Newtonian behavior

All liquids whose dynamic viscosity is independent of the shear rate D are Newtonian fluids. Their viscosity depends only on pressure and temperature, whereby technically only the viscosity decrease with increasing temperature is of importance. Examples are water, organic solvents, and most chemically pure liquids.

The viscosity of all liquids decreases with increasing temperature, while that of gases decreases. This also holds for non-Newtonian fluids.

Non-Newtonian Fluids

This group shows the whole variety of rheological properties, which frequently have a major influence on their handling. The different properties are evident in the shape of the viscosity curve.

Plastic Behavior (Fig. 12–5)

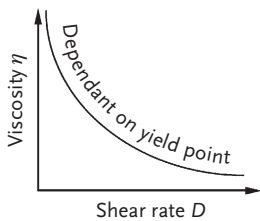
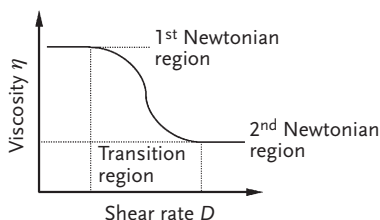
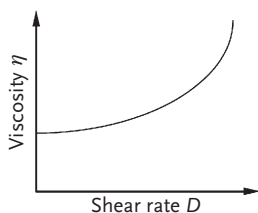


Fig. 12–5. Plastic behavior

Up to a certain shear stress (yield stress) these materials behave like solids, after which they deform and flow. Examples are toothpaste, creams, and chocolate.

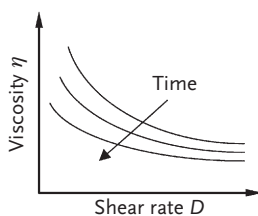
Pseudoplastic Behavior (Shear Thinning, Fig. 12-6)**Fig. 12-6.** Pseudoplastic behavior

Liquids containing chain-like or drop-like constituents may undergo re-orientation of these with increasing shear rate, so that the viscosity decreases. In state of rest the components of such fluids endeavour to retain their unordered state. Examples are polymer solutions, adhesives, and mayonnaise.

Dilatant Behavior (Fig. 12-7)**Fig. 12-7.** Dilatant behavior

Dilatant behavior (shear thickening) in liquids is rare. Since this flow behavior usually complicates production processes, it is advisable to change the recipe to minimize the tendency to dilatant behavior.

Examples of this behavior are “solid paints”, paper paints, and silicones.

Thixotropic Behavior (Time-dependent Viscosity: Fig. 12-8)**Fig. 12-8.** Thixotropic behavior

In a state of rest a three-dimensional structure (gel) forms as a result of binding forces between the particles of the fluid. These linkages are relatively weak and easily broken when the fluid is subjected to shearing. The viscosity decreases with shear time. Examples of this behavior are yoghurt, some medicaments, and ketchup.

Rheoplectic Behavior (Fig. 12–9)

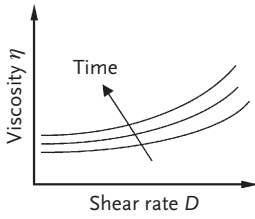


Fig. 12–9. Rheoplectic behavior

Genuine rheopexy is rare. Some fluids exhibit rheoplectic behavior only due to physical or chemical changes. In these cases the original viscosity is not attained after shearing ceases, in contrast to true rheopexy.

Examples are gypsum and special lubricants.

12.2.2

Principles of Calculation

In practice, only a few technical or practically important liquids strictly follow the above classification. For examples, depending on shear rate, which is dependent on flow velocity and pipe diameter, certain materials can behave as plastic or pseudoplastic, e.g., toothpaste.

For this reason, it is important to have an indication of the magnitude of the shear rate so that the measuring range of the viscosity curve can be defined. The majority of the pigging units have volumetric flow rates of $5 \leq \dot{V} \leq 20 \text{ m}^3/\text{h}$.

The shear rate D depends on $\dot{V}$ and on the radial component γ (see Fig. 12–2). For laminar flow of Newtonian fluids, Equation (12–3) applies.

$$D = \frac{4\gamma}{\pi R^4} \cdot \dot{V} [\text{s}^{-1}] \quad (12-3)$$

In wall proximity the largest shear stress and hence the largest shear rate occur, and the latter is given by Equation (12–4).

$$D = \frac{4}{\pi R^3} \cdot \dot{V} [\text{s}^{-1}] \quad (12-4)$$

Laminar flow was assumed, since most non-Newtonian media have dynamic viscosities greater than $1 \text{ Pa} \cdot \text{s}$. If turbulent flow is present at lower viscosities, the shear gradient in wall proximity is given by Equation (12–5).

$$D = \frac{0.175}{\pi R^3} \cdot \dot{V} [\text{s}^{-1}] \quad (12-5)$$

The evaluation of laminar or turbulent behavior is determined by the so-called Reynolds number Re , a dimensionless parameter (Eq. 12–6).

$$Re = \frac{2 c R \rho}{\eta} \quad (12-6)$$

For Reynolds numbers $Re < 2300$ flow is laminar; otherwise, it is turbulent.

Due to the steeper velocity profile for non-Newtonian fluids (see Fig. 12-3), the shear gradient in wall proximity in these fluids is lower by a factor of about 0.84. Typical shear rates of Newtonian media with laminar flow lie between 7 and 28 s^{-1} and, for non-Newtonian fluids between 6 and 24 s^{-1} . For a nominal size of 4" (DN 100) and volumetric flow rates of 5–20 m^3/h , measured at the position of average velocity. For the further treatment, recording of the viscosity curve with a viscometer is required. The rotational viscometer has a rotor and a stator, with a constant gap between them. The rotational speed of the rotor adjusts the volumetric flow in the gap, from which the resulting shear stress is determined and a viscosity–shear stress curve is plotted.

From the shape of the viscosity curve and the considered range of shear rate a model can be selected from the tabular classification made above, with which the behavior of the fluid can be described best.

In two examples calculations following the selection of the model are dealt with. However, a deeper treatment of the model would exceed the scope of this book. Here the reader is referred to specialist literature on rheology.

12.3

Examples and Applications

12.3.1

Newtonian Behavior

Solvent based paints prior to solvent evaporation exhibit Newtonian behavior. Therefore, for dimensioning the feed pumps, simple calculations can be performed with the Bernoulli equation, since the properties of the paint do not change in the pipe. The viscosity curve recorded with a viscometer confirmed the independence of the viscosity from the shear rate and gave a measured value of $\eta_0 = 2 \text{ Pa} \cdot \text{s}$.

The paint has a density of $\rho = 1000 \text{ kg/m}^3$ and flows with a flow rate $\dot{V} = 10 \text{ m}^3/\text{h}$ through a 4" pipe (DN 100) of length 30 m. This corresponds to a mean speed of $c_{av} = 0.3 \text{ m/s}$. The presence of laminar or turbulent behavior is given by the Reynolds number (Eq. 12-7).

$$Re = \frac{107.1 \text{ mm} \cdot 0.3 \text{ m/s} \cdot 1000 \text{ kg/m}^3}{2 \text{ Pa} \cdot \text{s}} = 16 \quad (12-7)$$

Thus laminar flow is present. The pressure drop after Bernoulli is given by Equation (12-8).

$$\Delta p = 32 c_{av} \frac{L}{(2R)^2} \eta_0 = 0.5 \text{ bar} \quad (12-8)$$

Ignoring pressure drops in the valves, the pump performance is given by Equation (12-9).

$$P = \Delta p \dot{V} = 0.14 \text{ kW} \quad (12-9)$$

12.3.2

Non-Newtonian Behavior

Water-based paints are pseudoplastic, but by using rheological additives (thickeners) a yield stress similar to that of a plastic fluid, can be achieved. These paints require a low viscosity for spraying (high shear rate) to keep the pressure drop low, and a high viscosity (low shear rate) when impinging on the substrate to prevent running.

The high polymer content of the paint was responsible for a zero-shear viscosity of $350 \text{ Pa} \cdot \text{s}$. The further course of the viscosity curve at higher shear rates suggested using the so-called Cross approach, which describes the dependence of the viscosity on the shear rate in the transition region by a shear rate between 0.1 and 300 s^{-1} .

The set of equations for this must be solved iteratively but have good convergence. The density of the paint is $\rho = 1000 \text{ kg/m}^3$ and a 4" pipe (DN 100) of 30 m length was used. The Cross model gives a pressure drop of $\Delta p = 54 \text{ bar}$. This requires a mechanical handling capacity of $P = 15 \text{ kW}$, which would require electrical performance of a motor of 50 kW. If the properties of the liquid were not considered, errors of several hundred per cent could result in the calculation of pressure drops. This is shown by comparison of pressure drops calculated with the Cross model and with the Bernoulli equation (Table 12–1) for various feed rates.

Table 12–1. Comparison of calculated pressure drops according two reological models

$\dot{V}$ Flow rate [m ³ /h]	Δp_1 pseudoplastic [bar]	Δp_2 Newtonian [bar]	Difference $\frac{\Delta p_1 - \Delta p_2}{\Delta p_1} \cdot 100[\%]$
0.1	23	29	26
0.2	40	59	46
0.3	54	88	64
0.4	65	117	80
0.5	75	146	95

Assumption of Newtonian behavior would lead overdimensioning of up to 100 %. With high throughput the pressure drop rises substantially more slowly than calculated after Bernoulli, and since the pressure drop is proportional to the pump capacity, this has direct implications for pump size. In each case, in addition to the rough calculations using the measured viscosity curves, tests are necessary to determine the actual behavior and to dimension valves and machines correctly.

13

Checks before Start-up

13.1

Checking Equipment

13.1.1

Piggable Pipes

The isometric drawings for the piggable pipe must be checked for agreement with the piggable pipe actually installed, the most important part of an industrial pigging unit. Special attention must be paid to the correct position of in- and outlets with compensation for expansion. The welding seams are inspected externally if they were not already subject to welding monitoring. The supports for the piggable pipe must be strong enough and present in sufficient numbers to resist the impact forces (Chap. 19).

A newly constructed piggable pipe must be free of any contamination. For the protection of the piggable valves and their sealing surfaces and gaskets, the valves should be replaced by fitting parts before the pipe is cleaned with cleaning agent.

Cleaning can be accomplished with a cleaning agent suitable for the system and compatible with the following product or with cleaning pigs, which are available in different versions. The cleaning agent can simply be pumped through the pipe, or introduced between two pigs. This tandem can then be driven several times in both directions depending on the required degree of clearing. The amount of cleaning agent can be kept low if it is enclosed between two pigs, and depending on nominal size it ranges between 5 and 100 L. The cleaning effect can be optimized by changing and repeatedly renewing the cleaning agent.

Before start-up and after cleaning the pipe the piggable valves must be installed and the actuators connected. For the pneumatic actuators the required operating pressure must be ensured in the compressed-air system.

If the pipe is subject to regulations for pressure vessels it must be submitted to a hydraulic pressure test. The date of the next inspection is noted in the protocol (see Chap. 19).

The characteristics specified by the manufacture are checked in test pigging and concentration measurement.

13.1.2

Pigs

Just as important as the state of the piggable pipe and valves is checking the supplied pig. It must be resistant to the product, the type of the pig must meet the requirements of the piggable pipe, and dimensions of the pig must be checked, as well as the position of the permanent magnet in the pig (see Section 3.5).

13.1.3

Additional Equipment

An industrial pigging unit is usually integrated in a production plant, e.g., as a connecting element between storage tanks and loading facilities. Before start-up these components must also be checked for functionality and cleanliness. Adhering product residues or foreign product residues must not be present in the tanks or in the incoming or outgoing nonpiggable pipes and feed pumps. Instrumentation, such as level controls, level control switches, and temperature measurement, in the nonpiggable plant sections are also included the check before start-up.

Before start-up all legally required licenses must be present (see Chap. 19).

13.2**Function Checks**

13.2.1

Test Pigging

In test pigging propellant pressure and time are measured, and thus pressure peaks, caused, e.g., by flange misalignment, welding seam dips, pipe bends, valves, dents, etc., can be detected and located. The ratio of back pressure to peak pressure is a measure for the quality of manufacturing and erection of the piggable pipe.

Each test pigging is documented and evaluated in a test protocol (pressure – time diagram).

If the dimensions of the piggable pipes do not lie in the range of tolerance and/or the piggable pipe is inadequately welded and installed, then the pig will be hindered in its running and damaged. The type of damage to a pig permits conclusions on the obstacle, which can be also a valve or a pig trap.

In principle test pigging can be carried out not only in new piggable pipes but also in pipes installed for a longer time, which were originally not intended for a pigging procedure. The result of the test pigging shows clearly whether, after removal of all sources of disturbance, the pipe can be made piggable. The better way, however, is to install a new piggable pipe.

Test pigging is a component of the function guarantee and is required by all companies which design, supply, and erect industrial pigging units.

Principle of the Measurement

A measuring instrument is connected to the pipe (Fig. 13–1). It has transducers for measuring pressure and flow rate. The pig is pushed through the pipe with an incompressible propellant (water, oil). A new pig must be used. Optimal measurement are obtained with a solid cast pig (e.g., made of Vulcocell) with max 2 % pre-stress. The speed of the pig should be ca. 0.1 m s^{-1} . The scanning rate is 0.5–7 kHz, depending on the length of the pipe. Thus, each millimeter of the pipe is scanned 5 to 70 times. The measured data can be recorded by a continuous line recorder or be stored in an electronical database. After completion of the measurement, the data are analyzed.

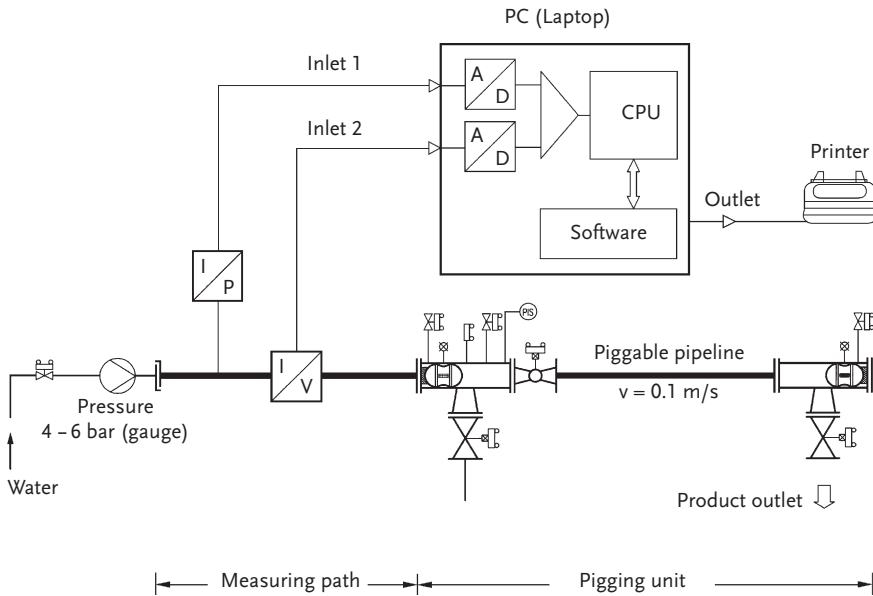


Fig. 13–1. Block diagram of a test pigging

Function Test

If the result of test pigging is not satisfactory, welding seam dips may have to be eliminated or entire pipework components exchanged.

The further procedure differs for manually operated and automatic industrial pigging units.

In manually operated industrial pigging units the residual concentration of a product in its successor can now be determined and the industrial pigging unit can be put into operation after acceptance by the customer.

With automatically operated industrial pigging units the total unit must be examined for functional capacity of all control valves, position indicators, and pig detectors, as well as the program execution with the predetermined switching times. This also includes simulation of malfunctions, in order to analyze the behavior of the control system in such cases. Only then, if necessary, is a concentration measurement performed, followed by start-up.

13.2.2

Concentration Measurement

Test pigging cannot recognize dead spaces in valves, at welding seam dips, at the interior roughness of the piggable pipe, or on the surface of the pig due to open pores. For this a concentration measurement is required, as described in Chap. 10. For product families in which small degrees of mixing are permitted by the customer, the concentration measurement can be dispensed with.

13.2.3

Test Pigging: a Practical Example

When test pigging is carried out on a piggable or nonpiggable pipe, the total spectrum of disturbance sources will not occur in the evaluation. Hence, the results of test pigging are investigated and analyzed in different piggable pipes.

Of interest is how, e.g., pipe bends, flanges, welding seams, and damages appear in the pressure–time diagram.

Measurement Assembly and Function

At the launching station a measuring section is flanged on; it is equipped with transducers for flow rate and pressure, as well as a propellant connection. Pressure and flow rate are measured and converted to a standardized signal (4–20 mA). These signals are processed in a laptop and printed by a printer.

Test Pigging and Evaluation

For the depiction of disturbance sources in the pressure–time diagram, five sections of a test pigging were selected (see Fig. 13–2). The sections were recorded with different resolutions (scanning rates), since the tested pipes have different lengths. The pressure rise is a measure for the hindrance of pig travel by a disturbance source.

Example 1

The section is of a piggable 2" pipe (DN 50) made of steel in a production plant. The total pipeline connects two production plants transports chromium oxide.

The analysis of the pressure–time diagram shows the following features:

- Rise of pressure to $p \approx 6.5$ bar, bends B1 to B5
- Rise of pressure to $p \approx 4.5$ bar, flanges F1 to F5
- Rise of pressure from $p \approx 0.75$ to $p = 6.5$ bar at $t = 0.9$ min to 1.3 min

The pig was substantially obstructed in its travel in the range $t = 0.9$ to $t = 1.3$ min. After accurate inspection an outside damage of the pipe was found, which led to the decrease in the pipe cross section. The damage was then repaired.

Example 2

This pipe section is a nonpiggable 3" pipe (DN 80) made of stainless steel (1.4541), which forms the connection between a piggable manifold and a storage vessel in a tank farm. This pipe section is to be tested for piggability. The pipe conveys water-like substances.

The analysis of the pressure–time diagram shows the following features:

- Pressure rise to $p \approx 2.0$ bar, welding seam S1
- Pressure drop to $p \approx 0.4$ bar, flanges F1 to F3.

The rise of pressure to $p = 2.0$ bar is due to a welding seam whose root dip is too large. The root dip must be ground. Small increases in diameter in the flange regions cause the pressure drop to ca. 0.4 bar. The result of the test pigging is that the pipe is piggable, with the required degree of cleanliness.

Example 3

Here a piggable 2" (DN 50) was tested made of stainless steel (1.4571), in which liquid paints are conveyed, wastested. The pipe section depicted in the pressure–time diagram was built into the production plant. The total pipeline connects production to a tank farm.

The analysis of the pressure–time diagram shows the following features:

- Pressure rise to $p \approx 4.5$ bar, elbows B1 to B3
- Pressure rise to $p \approx 3.0$ bar, welding seam S1 to S9.

In this example, the elbows and the welding seams in the piggable pipe are clearly recognizable by the different rise of pressure. The stick/slip behavior of the pig in the pipe bends is indicated by the rapid change from pressure rise to pressure drop in short intervals.

Example 4

A nonpiggable 4" pipe (DN 100) made of stainless steel (1.4541) is pigged with a spherical pig. The pipe, in which poly-THF is conveyed, connects production with a filling station. For example 4, a pipe section on a pipeline bridge was selected. In pigging with the spherical pig a propellant pressure of $p = 7$ bar became established.

By changing the pig type, i.e., use of a lip pig, the propellant pressure could be lowered to ca. 2.2 bar, and substantially quieter pig travel was achieved.

The analysis of the pressure–time diagram shows the following feature:

- Symmetrical rise of pressure to $p \approx 2.2$ bar, flanges S1 to S4.

Example 5

A ca. 100 m long 3" pipe (DN 80) made of stainless steel (1.4571) in a branched pigging unit for detergent raw materials forms the connection between production and a loading station. During a pigging procedure in winter the pig did not reach the receiving station. Test pigging identified the cause.

The analysis of the pressure–time diagram shows the feature:

- Pressure drop at $t = 0.9$ to $p = 0$ bar.

Here frost damage had widened the pipe to such an extent that the product could bypass the pig. After replacement of the defective pipe section, the pipeline could be pigged as usual.

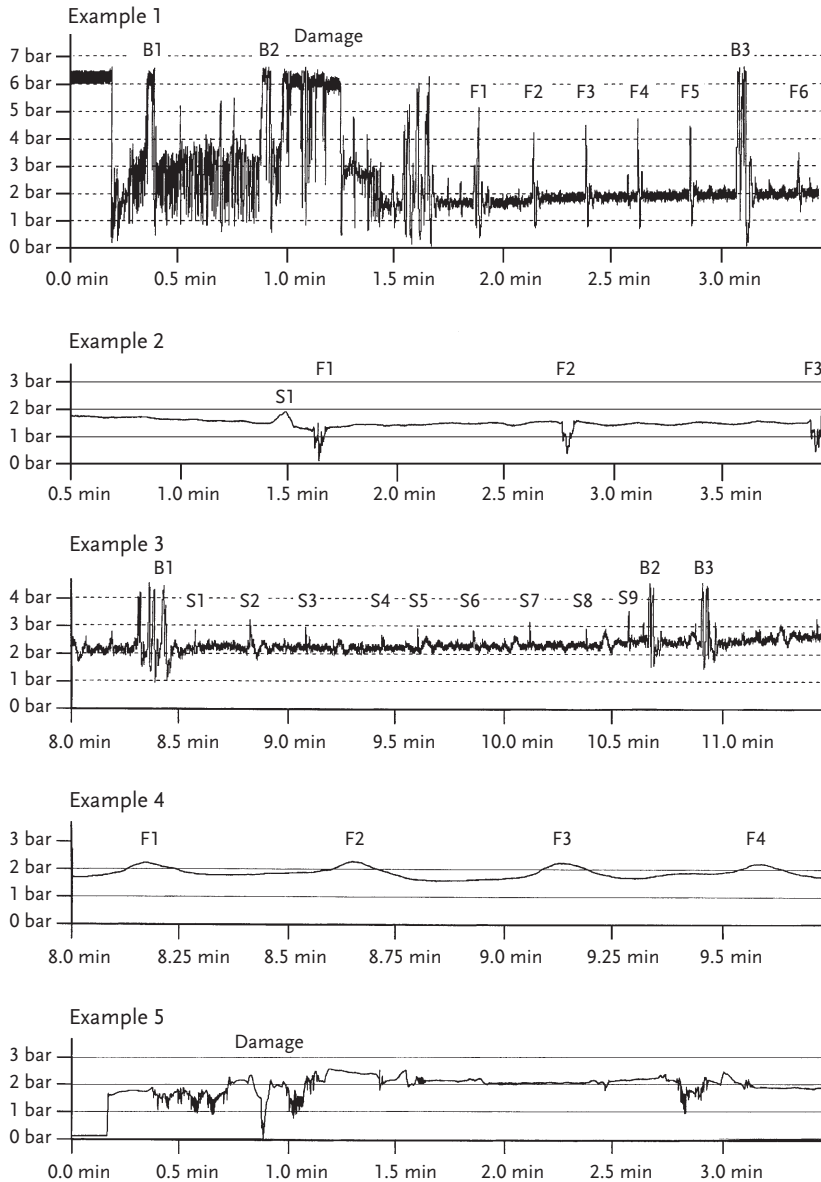


Fig. 13–2. Pressure–time diagrams of several test piggings.

In summary test pigging in piggable and nonpiggable pipes can easily locate, mounting seams, pipe bends, flanges, misalignments, ovality, and damage to a pipe. For this reason a pigging unit should never be started without test pigging.

14

Experiences with Pigging Units

14.1

Experiences before Start-up

This chapter collects and describes experiences from existing industrial pigging units (IPUs).

Positive and also negative experiences from IPUs are intended to help the project engineer or operator to conceive the unit in such a way that it can be operated trouble-free. Experiences from the individual phases in the life of a pigging unit are successively considered:

- Decision-making process
- Planning
- Procurement
- Erection
- Equipment defects
- Disturbances during start-up and during operation
- Documentation of rare events

In the case of an order for a unit, an examination before start-up (see Chap. 13) is performed by the supplier by means of test pigging, and any defects revealed are eliminated with no cost to the customer. In this case it is not guaranteed always that the customer is informed of all eliminated defects.

In the case of a one-off order the operator is directly confronted with the defects in items of equipment or problems at the interfaces during their examination before start-up.

14.1.1

Decision-Making

Decision making (see Chap. 9) should always be preceded by a calculation of production costs. The examination of the resistance of the pig material and the piggability of the product is unavoidable. In multiproduct plants the individual products must be tested for their suitability for inclusion in product families. Insufficient

consideration of these criteria is frequently the reason for subsequent failure of the industrial pigging unit.

It must be clarified whether the products really belong to a product family, i.e., exhibit similar physical and chemical properties. This is crucial for the compatibility of successive products and their purity.

14.1.2

Planning

In planning an industrial pigging unit the experience of the project engineers is especially important. They must have accurate knowledge of the properties of the products and design the industrial pigging unit accordingly. The best results are obtained when a pigging plant is designed as a unit, including planning of the pigging technology, instrumentation, procurement, erection and start-up, with guarantee of function.

Function guarantee means achieving successful operation of the whole pigging system after an acceptance test; thereby optimal interaction of pipes, valves, pigs, and instrumentation is sought.

Usually, companies, which supply complete pigging units also have the necessary experience. Together with the knowledge of the customers about their products the unit concept is the optimal solution for planning of an industrial pigging unit. An important criterion thereby is that the total responsibility for the project up to start-up lies exclusively with the supplier. Often the unit solution is also more economical. If an industrial pigging unit is ordered as a unit, the well-known interface problems are excluded from the beginning.

The sequence of the pigging procedure and/or the definition of the operating mode is required in the form of a table (see Section 2.4.1). A test pigging unit in which pigging tests can be carried out is especially convenient for larger projects. Some companies offer tests in their test pigging units.

14.1.3

Procurement

If the fundamental technical and product-specific problems are clarified, the industrial pigging unit can be ordered and procured. It must be ensured that all specifications and the suitable requests of the customer are contained in the order. Experience has shown that inadequately prepared technical information at this stage later leads to substantial additional costs. If the customer chose a unit solution, then the pigs, piggable valves, piggable pipes, instrumentation, and supply pipes with valves are supplied and mounted by a single contracting party.

Besides the items of equipment for the industrial pigging plant, the unit also includes planning and erection, as well as start-up and documentation with guarantee and/or function guarantee.

With the procurement of single components the probability of problems occurring in their interaction is relatively large, and the guarantee lies only with the sup-

pliers of the individual components. With individual components it has been experienced that the elimination of defects at the interfaces and achievement of reliable function require substantial time and costs. In addition, technical personnel with specific knowledge of pigging technology is required. Here, the complexity of pigging technology was often greatly underestimated.

14.1.4

Installation

If the installation of the components is carefully carried out malfunctions on start-up will also be insignificant. Thus, a great importance is attached to the mounting of the pipes, valves, and instrumentation, which must be supervised constantly by trained personnel. Recognized weak points must be eliminated immediately.

When assembling the industrial pigging unit the following points must be observed:

Pipes and Pipe Bends

- Inspection on receipt, examination of the inside diameter, the wall thickness of the material, and the ovality; pipes and pipe bends must be stored carefully to avoid damage.
- The pipe ends are examined for roundness. Oval pipe ends are realigned by means of a calibrating mandrel.
- The pipe ends are deburred and planed before orbital welding.
- The welded joints are examined immediately after production by an independent welding inspector. Faults must be eliminated immediately. They can result from pipe misalignment or changes in welding parameters. Examination of the root dip is especially important. If the specified values are not achieved, the inner seam must be smoothed or removed and renewed. The piping interior is inspected for welding splashes, which must be removed.
- If branches are installed in the pigging line, then it must be ensured that no pipe ends protrude into the piggable pipe.
- During the installation of pipes and the valves loose parts must not remain in the piggable pipe.

Piggable Valves

At the beginning and end, as well as at branches, flanges must be welded into the piggable pipe to allow the incorporation of valves. The flanges must be centerable (see chapter 5.4.1). Before insertion of the valve, its piggable inside diameter must be compared with the inside diameter of the piggable pipe; it must be absolutely the same. If gaskets are used, these must not project into the pipe. Gaskets which project into the pipe lead inevitably to malfunctions; these, however, are already revealed by pigging.

Process Control Devices

The construction errors which can occur in process control engineering are not restricted to pigging units. They can just as well occur in erecting a conventional section of a chemical plant. Great importance is attached to checking the software. Software errors, e.g., in a PLC, have so far caused the most malfunctions in checks before start-up. For start-up and trouble shooting it must be ensured that sufficient documentation is present.

14.2**Experiences after Start-up****14.2.1****Equipment Defects***Pipes*

If pipe was not supplied in accordance with its specification, then problems result in welding together two pipes. If the pipe ends are not round, then a misalignment occurs when they are joined. An excessive welding root dip is then unavoidable. Orbital welding is increasingly used. At present it is used straightforwardly up to wall thickness of 3.2 mm. For greater thickness (up to 5 mm) it requires extensive experience in the production of welding seams with maximum permissible root dip (see Section 5.4.2).

It is found again and again that test welding in a workshop can not be compared with the welding conditions on the construction site. If pipe is delivered in different batches, the welding parameters must be changed from batch to batch. The quality of the pipe bends is also important. If they are oval, then misalignment occurs at the joint to the pipe; unfortunately, this is not a rare occurrence.

It is observed more rarely that the inside diameter of the pipe does not agree with the inside diameter of a piggable valve. This is equivalent to misalignment of pipes, and both cases are a source of disturbance for the pig. However, such a malfunction is clearly seen in the protocol of the test pigging.

Checking the pipe supports for the piggable pipes is extremely important, since they must absorb the impact forces. The supports must be strongly built and must not contribute to corrosion of the piggable pipe. Intermediate liners may be required.

Piggable Valves

With piggable valves the following defects can occur:

- Gaskets are not resistant to the product and swell.
- With sticky or polymerizable products, hardened product residues remain in dead volumes.
- Solidified product lowers the restoring force of springs, and valves leak.

- Leakage of the valve outwards due to incorrect tightening of the gland or the use of a gasket material with the wrong specification.
- Sticking or insufficiently fast movement of the connecting rod with pneumatically driven valves, because the pneumatic cylinder is too small for the given operating pressure.
- Failure to reach the end position, e.g., in a pig trap, since the stroke limit of the cylinder was not precisely adjusted. The consequence is damage to the pig and the pig trap.

Pigs

Before a pig is inserted into the pipe, it must be examined (see Section 3.5). The pig shows its strengths and weaknesses only after a longer period of operation.

The most frequently defects are:

- Running time too low.
- Insufficient resistance to the product.
- Destruction by an obstacle projecting into the pipeline.
- Magnet ripped out of the pig.

Control System

Frequent malfunctions in the control of an industrial pigging unit include errors in the logic diagrams which were taken over in programming. Due to these errors the system cannot proceed from one in programming. Errors in signal processing also occur often. Wrongly adjusted response times in the sequence control also lead to malfunctions, since the pig may not achieve its end position and is thus not indicated, i.e., the control system indicates a malfunction.

The same effect occurs with wrongly positioned, unsuitable, or defective pig sensors. Accurate and reliable indication by pig sensors should be checked by a special function test. This particularly applies to air-driven IPU's with large-diameter pipes.

14.2.2

Malfunctions during Operation

Malfunctions which occur during start-up can be of the same nature as malfunctions during operation after a longer service life. According to experience a checked and approved piggable pipeline with suitable maintenance is subject only rarely to malfunction.

If a malfunction does occur it is often one that was already detected in the examination before start-up (Fig. 14–1). Nevertheless, specific events are described here, which can also occur after repairs to or modification of the plant. Most malfunctions are due to errors in installing the pipeline and the control system. Programming errors in the software of the control system are another cause of malfunctions.

Pig is Stuck

If the pig does not arrive at the receiving or launching station, then it may be stuck on an obstacle in the piggable pipe. This obstacle can be:

- Excessive welding seam dip.
- Pipe misalignment.
- Flange or a gasket misalignment.
- A T-ring valve or a pig trap in intermediate position.

Further reasons can be:

- The pressure-relief line in the receiving station is blocked by product.
- The pig is too strongly worn, so that, e.g., the propellant air can bypass it and no longer drives the pig.
- The propellant supply has failed.
- The pig was destroyed at an obstacle.
- The control system has an error.

Extreme Stick/Slip Movement of the Pig

When the pig is driven by a compressible propellant, it generally moves with non-uniform speed. Over long straight distances it accelerates, and then is braked at pipe bends. The propellant pressure rises and accelerates the pig when it leaves the bend. This process is normal and is controlled by throttling the exhaust air ahead of the pig, e.g., by release at the receiving station or the pressure-relief vessel.

Extreme stick/slip movements of the pig occur when:

- The propellant is throttled instead of the exhaust air, i.e., insufficient propellant is available.
- The prestress of the pig is too large.
- A welding seam dip is too high.
- The pipe is too rough, e.g., when nonpiggable pipes are used in a pigging unit or a nonpiggable pipeline is to be pigged.
- Dry running of the pig (air/pig/air) or low lubricity of the product.

Pig is not Detected

This is the most frequent malfunction, since the source of the disturbance, the pig sensors, are easily moveable components. If the pig is not indicated at its predetermined position, this can be for the following reasons:

- The pig sensor is unsuitable.
- The pig sensor is defective and must be exchanged.
- The pig sensor is misaligned.
- The control system does not process the input signal.
- The pig left its initial position and for the above reasons has not reached the expected position. For example leaving of the launching station is indicated but the pig does not arrive after a given time at its target; the control system indicates a malfunction.

The Pig Does not Completely Reach the Target Station

A pig detector locates the pig in the target station, although the pig sensors there do not indicate it, even though they are correctly adjusted. That means that the pig cannot be driven completely into the target station, because a pressure has built up before it, which is larger than the propellant pressure. This can happen if, e.g., hardened product residues are present in the target station and block a pressure-relief pipe.

If a pig does not completely reach its end position or a pig gets stuck, the reasons are often the same.

Pigs Leaves the Desired Resting Position

The pig reached its receiving or target station and was detected. At a later time, however, the signal disappeared and the next pigging step could not be initiated. The reason could be that in a pumping procedure the pig was pulled a little from its end position and then carried into the pipeline. Indication of the pig is then no longer possible. This can also happen if enclosed air expands due to temperature rise, and the pig is pressed out of its end position. The pig can also leave its end position due to a control error of the personnel in manual operating mode.

Pig was Destroyed

The speed has a decisive effect on the service life of a pig. If it is too high, e.g., if the exhaust air is not throttled, the pig may be driven at high speed into the receiving station, and may be damaged or destroyed. This can also occur if the pig is driven at high speed against an obstacle in the piggable pipe. The pig quality and the resistance of the pig material to the product also has a major effect on the service life of the pig. However, this is less important in practice, since the pig material usually was selected accordingly.

14.2.3

Documentation of Rare Events

Some extreme events are very rare, but have a high danger potential and are therefore mentioned here:

- A solid cast pig turns around its transverse axis in the pipeline and gets stuck: the pig was braked by an obstacle in the pipe, compressed, and turned through 90°. The product can then pass by at the pig as if through a throttle.
- The Magnet is ripped out of the pig, due to its inertia when a solid cast pig is suddenly braked. The pig is destroyed and is no longer conveyed and detected. The magnet may be far away from the pig.
- The pig can no longer be found in the piggable pipeline: due to an operating error or an error in the control system the pig left the pipe and was recovered during a cleaning procedure in a tank.
- The pig escapes from a launching or receiving station into the open: work on an open pigging unit should only be carried out when the plant is not in opera-

tion. The unit was put back into operation by error although the launching station was still open.

- The pig exits at a 90° pipe bend into the open: during a pigging procedure in a 3" pipe (DN 80, PN 16) with a wall thickness of 1.85 mm, a high backpressure occurred, probably due to product caking. Because of problems in the control system and a too high driving pressure the pig broke through the pipe bend and was destroyed. Pig parts flew up to 240 m in to the open (see Figs. 14–1 and 14–2).



Fig. 14–1. Destroyed pipe bend



Fig. 14–2. Shattered pig.

15

Applications in the Chemical Industry

15.1

Polymer Dispersions

15.1.1

Production Plant

A production plant in the chemical industry produces polymer dispersions. After batch production the products are stored in finished-product tanks for the filling process. To produce over 100 different products, about 100 different raw materials are used.

The total production plant includes a raw-materials tank farm, several production buildings, a large storage tank farm for the finished products and a dispatch building. All buildings are connected by pipelines on pipe racks; the buildings are about 250 m apart.

All products are liquid and are filled into tank trucks, rail cars, or containers [200 L drums and 1000 L intermediate bulk containers (IBCs)].

15.1.2

Product Properties

Polymer dispersions are dispersions of natural or synthetic homopolymers or copolymers. They are liquid to semiliquid (viscosity range: 600–2000 mPa · s) and generally milky white. The polymer is finely distributed in stable state in an aqueous phase. The dispersions often also contain dispersing agents and/or other auxiliaries. The products form films under the influence of air, and some of them are inclined to foaming. Aqueous dispersions are frost-sensitive. Dead volumes which are not continuously washed around by products are constant source of infection and consequent contamination by microorganisms.

Batch operation and the large number of products make frequent and complex cleaning procedures necessary. These lead to high wastewater costs. Hence this plant is suitable for pigging. However, a very complex TPS with demineralized water as propellant is required. Outside of the buildings the piggable lines are insu-

lated and heat-traced (frost protection). The plant contains almost 4000 m of pig-gable pipe.

15.1.3

Purpose of the Pigging Unit

- Use of one single pipe for several products.
- Cleaning the pipe by almost complete removal of the product.
- Keeping pipes not used for product feeding constantly filled with demineralized water.
- Flexibility with large number of products and frequent product changes, free allocation of the products to storage tanks, flexible use of the existing production lines.
- Substantial savings in wastewater costs.
- Recovery of valuable products.

15.1.4

Technical Data of the Pigging Lines

Within the production plants there are the following pigging lines:

- Between storage tanks and heat exchangers.
- Between vessels and the deodorization columns.
- Between conditioning tanks and the filters.

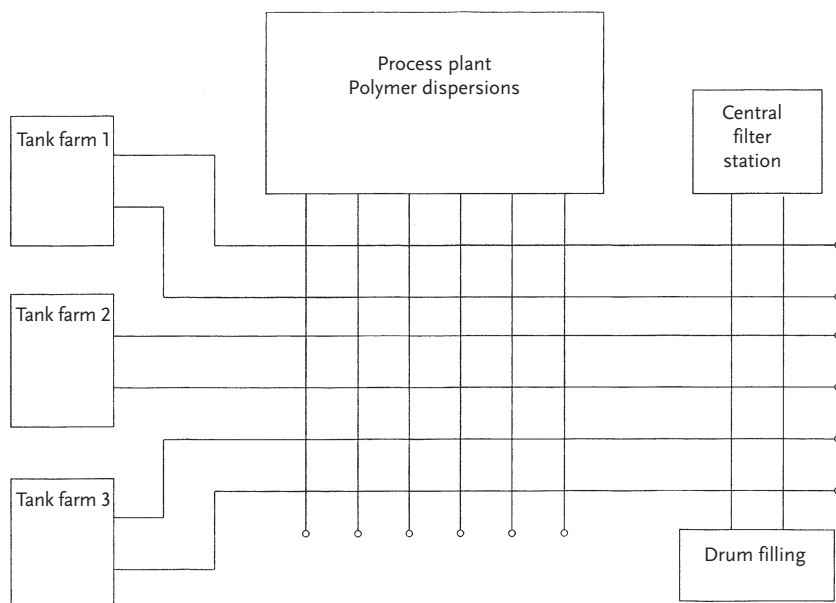


Fig. 15-1. Overview of the pigging lines in a dispersions plant

Between the storage tanks and the loading facilities there are the following pigging lines (Fig. 15–1):

- To all storage tanks in three tank farms.
- To the tank truck filling station.
- To the drum filling station

The pigging lines have the following properties:

- Nominal diameter: 4" (DN 100)
- Nominal pressure: PN 25
- Material: stainless steel (DIN 1.4541)
- Pipes longitudinally welded, during erection all necessary circumferential welding seams by orbital welding
- Each line has a launching and receiving station
- Pig loading and unloading at the launching station
- No switches (unbranched pigging unit)
- Branches via piggable T-pieces with a ball valve
- Propellant is demineralized water
- Two-pig system (TPS)
- Application frequency: several times daily (average)
- Cleaning degree: D
- Lip pigs made of Vulkollan (PU), lips replaceable
- Service life of pig body: 4 years; lips: 15 km
- Average length of a pigging line: 200 m
- Control system: sequence control in the automatic operating mode, monitoring and operating components, programmable logic controller (PLC), visualization by a process and instrumentation flowsheet with indication of the current pig location (Fig. 15–2).

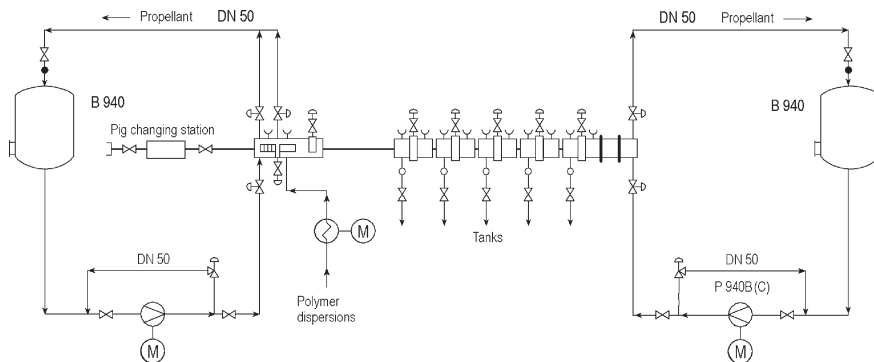


Fig. 15–2. Process and instrumentation drawing (PID) of the pigging line

15.1.5

Description of the Function

Nearly all pigging lines operate with the two-pig system (TPS). Only then can it be ensured that air is never in the pipe and that the product is always contained by demineralized water or by pigs. Table 15–1 illustrates the working principle of a pigging line for product feed from a storage tank to the loading station.

Table 15–1. Sequence table of a pig run at the dispersions plant*

Sequence no.	Sequence	Pig position or travel direction	Pigging line	
			Content	Propellant
1	Initial 1 position	$P_1, P_2 = \text{LS}$	DMW	–
2	extend pig trap PT_1	–	–	–
3	pig run	$P_1, P_2 \rightarrow \text{PT}_1$	DMW	DMW
4	back pigging	$P_1 \rightarrow \text{LS}$	DMW	product
5	retract pig trap PT_1	–	–	–
6	pig run	$P_2 \rightarrow \text{RS}$	product	product
7	open T-valve	–	–	–
8	extend pig trap PT_2	–	–	–
9	pig run	$P_1, P_2 \rightarrow \text{PT}_2$	DMW	DMW
10	close T-valve	–	–	–
11	retract pig trap PT_2	–	–	–
12	initial position	$P_1, P_2 \rightarrow \text{LS}$	DMW	DMW

* P = pig, LS = launching station, RS = receiving station, PT = pig trap, DMW = demineralized water. =: pig resting position, $\rightarrow$: pig run.

Description of the Individual Steps:

1. Initial position: pigs P_1, P_2 in the launching station. Pigging line is filled with propellant, pressure relieved.
2. Pig trap PT_1 is set at the product inlet.
3. Pig travel: pig P_1 and P_2 by propellant up to the pig stop PT_1 .
4. Pig P_1 is driven with product back to the launching station back (to release the product inlet).
5. Pig trap PT_1 is extended.
6. Pig travel: the product drives pig P_2 to behind the selected product branch.
7. Branch valve opens, when enabled by the connecting line.
8. Filling procedure terminated. Pig trap PT_2 set at the selected branch.
9. Pigging procedure: pigs P_1 and P_2 are driven by propellant up to the pig trap PT_2 , the pigging line is emptied.

10. Branch valve closes.
11. Pig trap PT_2 extended.
12. Pigs P_1 and P_2 are driven by propellant back to the launching station. The content of the pipe is emptied into the tank.

The propellant remains in the pigging line until the next pigging procedure.

15.2

Urea–Formaldehyde Resins

15.2.1

Production Plant

A plant produces about 500 000 t/a of aqueous ureaformaldehyde condensation products, mainly for the chipboard industry. For the production of the ca. 30 different product types, mainly aqueous urea, formaldehyde solutions, melamin, caustic soda, and formic acid are required. The degree of conversion of the reaction partners has a decisive effect on the type of product.

The total plant consists of:

- The production plant with production-intermediate vessels and a distribution station, both of which located in the process building.
- Two large tank farms, which are connected to the process building by pipes on pipe racks. The connecting pipelines between the production plant and the tank farms are up to 300 m long.
- Loading stations for tank trucks and rail tanks supplied with products from the tank farms.

The aqueous ureaformaldehyde condensation products are continuously produced and stored in the finished-product tanks (volumes up to 1000 m³) in the tank farms and, after a final inspection, are held for dispatch.

15.2.2

Product Properties

Aqueous urea formaldehyde resins are glues with a solids content of ca. 65 %. They are liquid and, depending upon product and temperature, have viscosities of 500–6000 mPa · s. The products are usually clear or milky white. The desired properties of these products, however, result in difficult handling during production, which finally led to the application of pigging technology:

If product remains in pipes, tanks, tank trucks, or rail tanks for several days under the influence of heat (e.g., exposure to the sun), the temperature can exceed the permissible storage temperature. The product then continues to condensate (polymerizing), becomes increasingly viscous, can no longer be pumped, and becomes so solid that it can be removed only with shovel and pick, e.g., from tanks.

Inside emptied pipes, crusts can develop under the influence of air and heat. Since the products are naturally sticky, dead spaces and narrow pipes easily clog.

Before the installation of the pigging unit frequent cleaning with water was necessary. Apart from product losses this led to high wastewater costs.

15.2.3

Purpose of Pigging

- Using one pipeline for several products of a product family.
- Emptying and cleaning of the pipeline by almost complete removal of the product.
- Rapid product change by complete separation of the products from each other.
- Avoidance of product losses by cleaning.
- Prevent the clogging of pipes due to condensation of the product.
- Substantial savings in wastewater costs.
- Achieving a uniformly high product quality.

The product properties, which long led to difficulties in handling in the existing plant, clearly speak for the application of pigging technology in this field of production.

15.2.4

Technical Data of the Pigging Lines

The individual pigging lines were equipped with a TPS without cleaning agents. Depending on the frequency of use, the piggable pipes between production plant and tank farm must be insulated against radiant heat. In the production plant, on the pipe racks, and the tank farms ca. 2000 m of piggable pipe is installed.

In the production plant there are the following pigging lines (see Fig. 15–3):

- From tank group A to the manifold station (10 three-way switches).
- From tank group B to the manifold station.
- From the manifold station to tank farms I and II.

Between the storage and the filling facilities, there are the following pigging lines:

- From tank farm I to tank farm II.
- From three groups of tanks to the tank truck loading facility.
- From three groups of tanks to the rail tank loading facility (see Fig. 15–3).
- Nominal size: 4" (DN 100) or 6" (DN 150)
- Nominal pressure: PN 10
- Material: stainless steel 1.4541
- Pipes: longitudinally welded, during erection all necessary circumferential connections by welding sleeves
- A launching and receiving station in each piggable pipeline
- Pig loading and unloading possible at each launching and receiving station

- Pigging lines in the tank farms unbranched, branched with switches in the process building
- Propellant: product or air ($p=4$ bar g)
- Application frequency: on average several times daily
- Cleaning degree: D
- Pig type: solid cast pig
- Pigging system: two-pig system (TPS)
- Average length of the pigging lines: discharge lines from production to the tank farm: 150 m, and of from the tank farm to the transport container: 70 m
- Control system with a programmable logic controller (PLC) with monitoring and operating components, sequence control in automatic operating mode, visualization of the pigging lines with all control valves and indication of the pig location in launching and receiving stations, monitor-oriented operation with light-pen input and user interface.

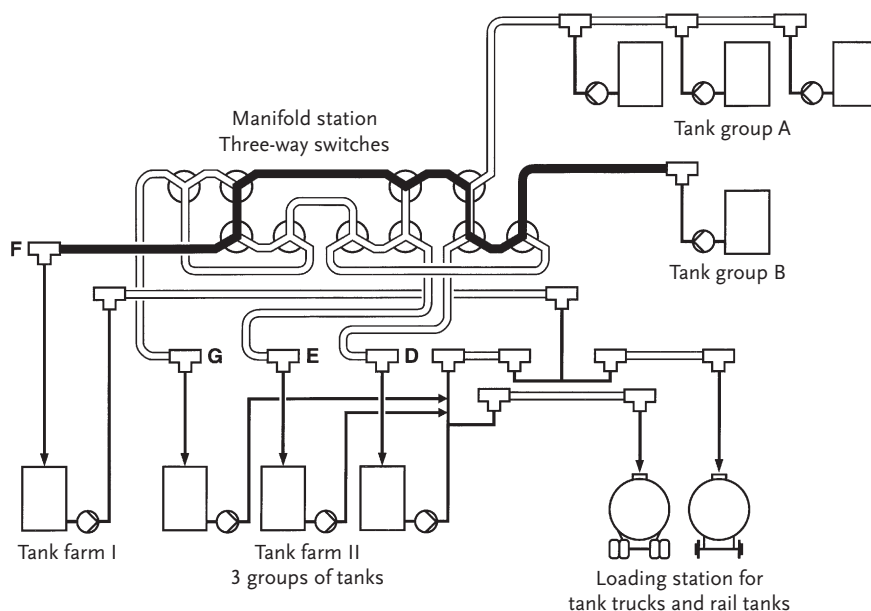


Fig. 15-3. Example of a branched pigging unit

15.2.5

Description of the Function

Most of the piggable pipelines here use a two-pig system (TPS) thus, inclusion of air is avoided to a large extent. In this case air is not harmful to the product, it can lead however to pressure peaks in the pipe and to faulty measurements during flow metering.

Table 15–2 shows the sequence of procedures of a pigging line for tank truck filling.

The product feed from tank farm II, tank group D with six storage tanks to the filling station for containers can be seen in Figs. 15–3 and 15–4.

Table 15–2. Sequence table of a pigging procedure in a plant for urea formaldehyde resins*

Sequence no.	Sequence	Pig position or travel direction	Pigging line	
			Content	Propellant
1	initial position	$P_1 = \text{LS}, P_2 = \text{RS}$	air	–
2	open T-ring valve	–	–	–
3	pig run	$P_1, P_2 \rightarrow \text{TR}$	–	air
4	pig run	$P_1 \rightarrow \text{LS}, P_2 \rightarrow \text{RS}$	–	product
5	pig run	$P_1 \rightarrow \text{LS}, P_2 \rightarrow \text{TR}$	–	air
6	close T-ring valve	–	–	–
7	pig run	$P_1, P_2 \rightarrow \text{LS}$	–	air
8	pig run	$P_2 \rightarrow \text{RS}$	–	air
9	initial position	$P_1 = \text{LS}, P_2 = \text{RS}$	air	–

* P = pig, LS = launching station, RS = receiving station,
TR = T-ring valve, =: pig resting position, $\rightarrow$: pig run.

1. Initial position: pig P_1 is in the launching station, pig P_2 in the receiving station. The pigging line is filled with air and pressure-relieved.
2. The T-ring valve is opened at the preselected tank for product inlet.
3. Pig travel: pigs P_1 and P_2 are driven by the propellant air up to the T-ring valve.
4. The pigs P_1 and P_2 are pushed by product to the launching and receiving station, respectively. The product flow to the filling station can start.
5. Pig travel: both pigs are pressed by air, P_1 from the launching station and P_2 from the receiving station to the T-ring valve. The product remaining in the line is pressed thereby back into the source tank with a bypass.
6. The T-ring valve is closed and the product inlet is sealed.
7. Pig travel: pigs P_1 and P_2 are driven simultaneously by propellant from the T-ring valve to the launching station.
8. Pig travel: pig P_2 is pushed by propellant from the launching station to the receiving station, pig P_1 remains in the launching station.
9. Initial position: pig P_1 is in the launching station, pig P_2 in the receiving station. The pigging line is filled with air and pressure-relieved.

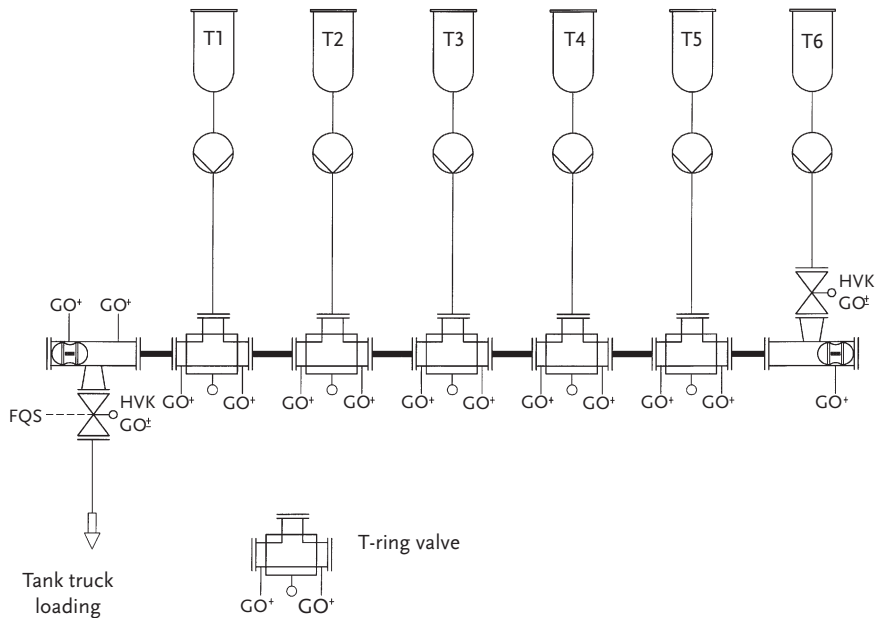


Fig. 15-4. Overview of a pigging unit for urea-formaldehyde resins

15.3

Dispersion Adhesives

15.3.1

Production Plant

In a production plant with three automatic filling machines, liquid and pasty adhesives (e.g., tile and parquet adhesives) are filled into different small drums, cans, and pails from 0.5 to 10 L. Each of the three filling machines is suited to a particular type of drums e.g., cans with contents of 0.5 to 1 L. Hence all three machines must be fed with different products. To minimize warehouse storage, smaller orders with different products must also be processed.

The entire plant consists essentially of:

- Temporary storage tanks in the upper floor of the building
- Filling station with three filling machines

In the intermediate tanks, product changes are carried out at larger intervals.

15.3.2

Product Properties

The water-based dispersion adhesives have solids contents of ca. 80 %. Depending on the product, they vary from liquid to very viscous and cover a viscosity range of ca. 500 to 30 000 mPa · s.

The decisive properties for this type of products make handling in the production plant often very difficult: on loss of water, the product tends to harden by condensation. This can lead to defective pipes, tanks, and machines. The only possibility to prevent this is regular cleaning of these components. Especially for pipelines this means substantial expenditure for rinsing water and its disposal. These were the reasons for equipping this part of the plant with several piggable pipelines.

15.3.3

Purpose of Pigging

- Using only one pipeline for about 10 different products.
- Emptying and cleaning of the pipeline by almost complete removal of the product.
- Rapid product change with perfect separation of the products from one another.
- Substantial decrease in change-over times due to omission of the complex pipe cleaning process.
- Avoidance of contaminated wastewater from flushing of pipelines in the conventional system.
- Reduction of the costs for cleaning agent and wastewater.

Due to the aforementioned product properties the costs for flushing the conventional pipelines were very high. In addition, there were more frequent difficulties with peripheral devices, e.g., pumps, valves, etc., which resulted from an insufficient cleaning. The need to expand production and regulations limiting the output of contaminated wastewater led to the application of pigging technology. Since this had already been attempted once in the past without success, a short pipeline was constructed for testing. Due to the overwhelming success the complete solution was already executed after the first experiences with the test unit.

15.3.4

Technical Data of the Pigging Lines

The pigging line connects four intermediate vessels each with 10 m³ volume, via three separate piggable pipelines with three filling machines. The overall length of the three pipelines is ca. 90 m (Fig. 15–5). Due to the product properties and the often long downtimes of individual pigging lines water was partially used as propellant, which remains in the pipe after the pig run until the pipe is required again. This measure reliably prevents hardening of the products in the pipes and valves.

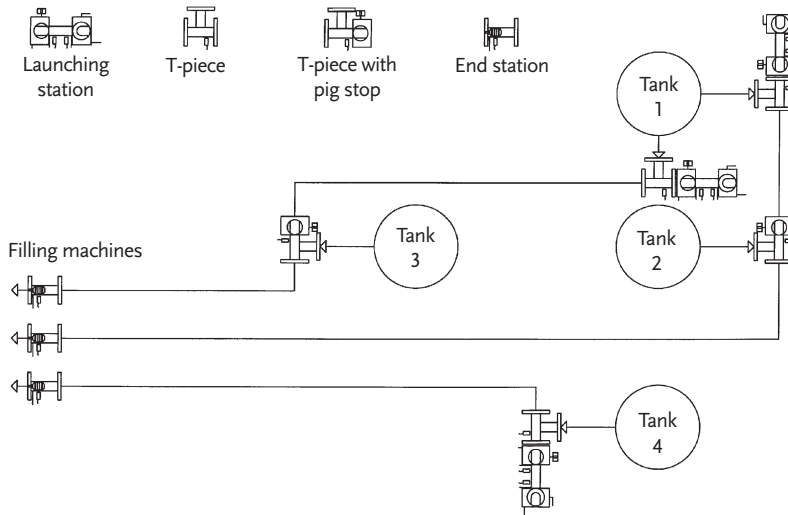


Fig. 15-5. Scheme of a pigging unit for emulsion adhesives

- Nominal size: 4" (DN 100)
- Nominal pressure: PN 16
- Material: stainless steel 1.4571, pickled
- Pipes longitudinally welded, during erection all necessary circumferential welding seams by orbital welding.
- For each pigging line a launching station with the possibility to change the pig, one or two product inlets, and a product outlet as receiving station.
- The pigging lines have no switches (unbranched).
- Propellant fluid: Water with $p=6$ bar g and compressed air with $p=6$ bar g
- Application frequency: up to 10 times per week
- Cleaning degree: E
- Overall length of the piggable pipeline: 90 m.
- Pig type and material: solid cast pig, silicone rubber, with bar magnet.
- Control system by a programmable logic controller (PLC) with a control panel for the service personnel. All valves are represented by a block diagram, and the respective positions of the valves and pigs can be monitored.

15.3.5

Description of the Function

The pigging lines are operated with a one-pig system, whereby the contents of the pipe are always pushed into the filling plant.

Table 15-3 lists the sequence for transport from one of the intermediate vessels to one of the three filling machines.

Table 15–3. Sequence table of a pigging procedure in the manufacturing plant for dispersion adhesives*

Sequence no.	Sequence	Pig position or travel direction	Pigging line	
			Content	Propellant
1	initial position	P = LS	DMW	–
2	pig run	P → PI	–	air
3	metering valve/outlet open	–	air	–
4	Product pumping	–	product	–
5	Close metering valve	–	product	–
6	pig run	P → LS	–	DMW
7	initial position	P = LS	DMW	–

* P = pig, LS = launching station, RS = receiving station, PI = product inlet valve, DMW = demineralized Water, =: pig resting position, →: Pig run.

1. Initial position: pig P is in the receiving station. The pigging line is filled with water and pressure-relieved.
2. Pig travel: pig P is driven by compressed air to the selected product inlet, whereby the water is pressed out.
3. The product inlet and product outlet are opened.
4. The product is pumped to the filling machine.
5. The product inlet is closed.
6. Pig travel: pig P is driven with water as propellant to the receiving station and pushes the pipe empty toward the filling station.
7. Initial position: pig P is in the receiving station. The pigging line is filled with water and pressure-relieved.

The pig is only driven to the launching station for inspection and replacement.

15.4

Fragrances

15.4.1

Production Plant

A mixing plant produces ca. 200 t/a of liquid fragrances on the basis of orange oil as additive for ca. 150 finished products in the areas of personal hygiene and laundry detergents. In the production of the ca. 120 mixtures, about 200 different materials are mixed in batch processes with highly accurate dosage.

The entire plant (see Fig. 15–6) consists essentially of:

- Starting material tank farm and dosing plant in a building.
- Tank farm for finished mixtures, consisting of 15 stirred vessels.
- Barrel filling of finished mixtures.

The fragrance mixtures are manufactured by batch mixing in one of the stirred vessels and temporarily stored there. After final inspection all products are sent via a pigging pipeline to the drum filling station and filled into 200 stainless steel drums. These are supplied to about 30 customers, who process the mixtures.

15.4.2

Product Properties

The fragrances are mixtures of the most diverse liquid raw materials, in each case with a typical olfactory note. They are liquid and, depending on type, have a viscosity of 100–1500 mPa · s at 20 °C. Usually the products correspond in color to the respective raw materials and vary from colorless to milky yellow.

Since the number of different products is very high, high priority is attached to cleanness during the total process, i.e., no mixing of different types must occur. Furthermore, many of the products are extremely expensive due to the cost-intensive raw materials (up to 8000 €/kg).

15.4.3

Purpose of Pigging

- Using only one pipeline for about 200 different products.
- Emptying and cleaning of the pipeline by almost complete removal of the products.
- Rapid product change owing to complete product separation.
- Shortening of the batch times by automated transport of finished products to the stirred vessels.
- Avoidance of contaminated wastewater from flushing of pumps and hoses, which was required before with manual handling.
- Assurance of extremely high purity demands by the automated process.

Due to the multiplicity of finished products, the emptying times of the mixing machine which were extremely high due to the manual handling of the products, and labor costs were no longer economically acceptable. The economic production of these products was possible only by means of a pigging line.

15.4.4

Technical Data of the Pigging Line

The pigging line connects the areas storage of starting materials/metering plant with the mixing area/temporary storage by one ca. 150 m long pigging line. The pig-

ging unit operates without additional cleaning measures and is insulated in the outside area to prevent heat loss and/or damage by cold weather.

The system was installed as an unbranched pipeline and twice extended by inserting further fittings and valves, so that today a second metering station and a direct possibility for drum filling are integrated.

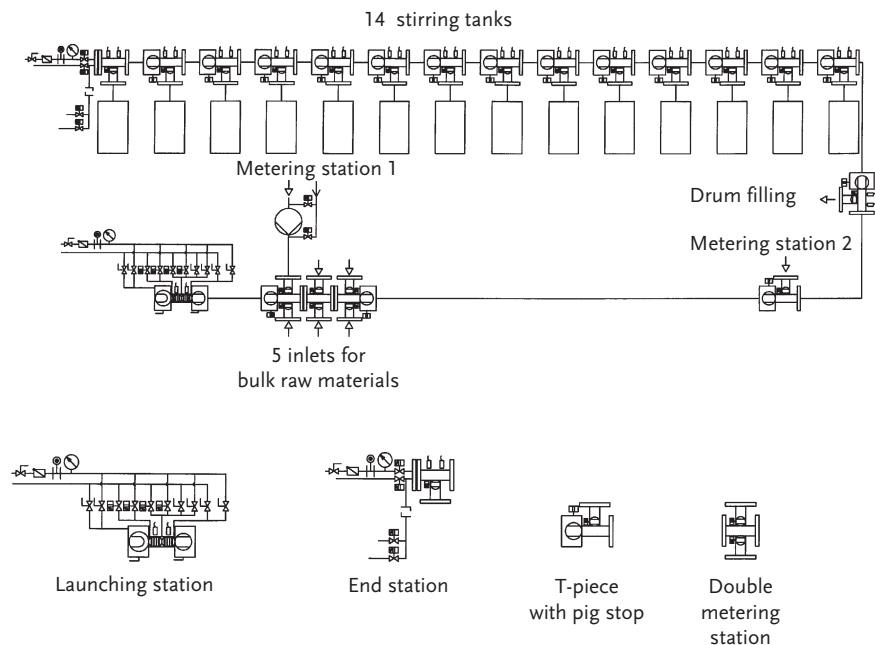


Fig. 15–6. Overview of a pigging unit for fragrances on the basis of orange oil

- Nominal size: 2" (DN 50)
- Nominal pressure: PN16
- Material: stainless steel 1.4571
- Pipes longitudinally welded, during erection all necessary circumferential welding seams welded by orbital method
- A launching station with the possibility of changing pigs, seven product inlets and 15 product outlets, one outlet as receiving station
- The pigging unit has no switches (unbranched)
- Propellant: compressed air $p=6$ bar g
- Application frequency: about 8 times daily
- Cleaning degree: F
- Length of the piggable pipeline 150 m
- Solid cast pig, silicone rubber with bar magnet

- Control system with a programmable logic controller (PLC) with integrated touch screen for visualization by the service personnel. All valves are represented in a block schematic. The respective position of the valves and pigs can be monitored with this system. Apart from controlling the actual pigging unit also the control of the metering plant with recipe administration is integrated in the PLC.

15.4.5

Description of the Function

The pigging line is a two-pig system (TPS) in which the contamination of the pipeline after the pig run cannot be further reduced by pigging.

Table 15.4 shows the product transport from the first metering station to an stirred vessel.

Table 15–4. Sequence table of a pigging procedure in the production of fragrances on the basis of orange oil*

Sequence no.	Sequence	Pig position or travel direction	Pigging line	
			Content	Propellant
1	initial position	P ₁ , P ₂ = LS	air	–
2	open LS/close stopper – ball valve	–	–	–
3	pig run	P ₁ → RS	–	air
4	open metering valve	–	air	–
5	product pumping	–	product	–
6	close metering valve	–	product	–
7	pig run	P ₂ → RS	Product	air
8	close product outlet valve	–	air	–
9	pig run	P ₁ , P ₂ → LS	–	air
10	initial position	P ₁ , P ₂ = LS	air	–

* P = pig, LS = launching station, RS = receiving station,
=: pig resting position, →: pig run.

1. Initial position: pigs P₁ and P₂ are in the launching station. The pigging line is filled with air and pressure-relieved.
2. The launching station is opened. The stopper ball valve for P₁ at the selected stirred vessel is closed.
3. Pig P₁ is positioned by means of compressed air at the stirred vessel.

4. Suitable product inlet (or inlets) and the product outlet are opened.
5. Product is pumped to the stirred vessel. The flow metering is performed by an installed flow meter outside of the pigging line or by a dosing facility outside of the pigging line.
6. The product inlet (or inlets) is closed.
7. Pig travel: P_2 is driven by compressed air to the stirred vessel up to pig P_1 and pushes the pipe contents into the stirred vessel.
8. The appropriate product outlet is closed.
9. Pig travel: pigs P_1 and P_2 are driven simultaneously by compressed air back into the launching station. The launching station is closed.
10. Initial position: pigs P_1 and P_2 are in the launching station. Pigging line is filled with air and pressure-relieved.

15.5

Raw Materials

15.5.1

Production Plant

In a production building with six reactors liquid products are produced, which are further used additives for numerous finished products, e.g., agents for lowering the surface tension of water. In the production of these ca. 30 mixtures in batch processes numerous different raw materials are used.

The entire plant (see Fig. 15–7) consists essentially of:

- Raw material tank farm in the outside area
- Production building with six reactors

By alternating use of two new storage tanks in the external tank farm, the possibility exists for storing in each case two raw materials which are currently required for production.

15.5.2

Product Properties

The materials in the two storage vessels are very different in their chemical structure. They are liquid and cover a viscosity range of ca. $0.33\text{--}2000\text{ mPa} \cdot \text{s}$. Since the two different products in the two storage vessels are often required alternatingly and these tanks often contain several different materials each week, clean separation of the highly diverse materials from one another must be ensured. This is made more difficult by the fact that, besides largely harmless materials, also combustible and highly aggressive substances are used, which are subject to hazardous materials regulations. The selection of the pig material for such materials is particularly difficult and can not be performed without preliminary tests.

15.5.3

Purpose of Pigging

- Use only one pipeline for ca. 20 different raw materials.
- Emptying and cleaning of the pipeline by almost complete removal of the products.
- Rapid material change with perfect separation of the materials from one another.
- Shortening of the batch times by automation of materials transport to the reactors.
- Avoidance of contaminated wastewater from flushing of pumps and hoses, which was required before with manual handling.
- Achieving of economy due to the largely automated process. Due to the multiplicity of starting materials the downtimes of the reactors due to the manual operation were too high. To increase the capacity of the plants new starting material tanks and connections of these tanks to the plant were required. The numerous materials used and the frequent material changes required the installation of a pigging line. The new capacity requirements of the production plant were, among others, only realizable by the installation of a pigging unit, with the help of which the high downtimes of the reactors could be reduced.

15.5.4

Technical Data of the Pigging Line

The pigging line connects the two new 30 m³ storage vessels via a ca. 130 m long pigging line to six production reactors in two buildings. The pigging unit is de-

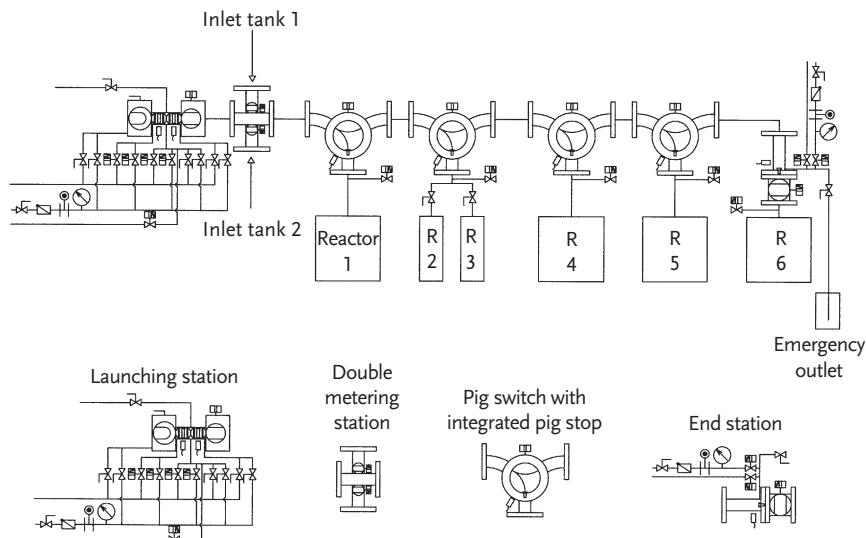


Fig. 15–7. Overview of a pigging unit for raw materials

signed such that tandem pig cleaning (cleaning agent between two pigs) is possible as an additional cleaning measure. If required, the cleaning procedure can be partly automated. The system is insulated and electrically heat traced to facilitate pumping of the raw materials, some of which are not pumpable at ambient temperature. The system was built as a simple pigging line.

- Nominal size: 2" (DN 50)
- Nominal pressure: PN 16
- Material: stainless steel (1.4571)
- Pipes longitudinally welded, during erection all necessary circumferential welding seams by orbital welding.
- One launching station with the possibility to change the pigs, two product inlets and five product outlets, one outlet as receiving station
- The pigging unit is unbranched
- Propellant: compressed air $p = 6$ bar g
- Application frequency: up to 7 times daily
- Cleaning degree: F
- Length of the pigging line: 130 m
- Pig: special pig with changeable lips, highly resistant plastic with bar magnet, suitable for contact with strongly aggressively chemicals
- Control system with a programmable logic controller (PLC) with integrated display control by the service personnel. All valves are represented in a block scheme. The respective position of the valves and pigs can be monitored with this system. Apart from the control of the actual pigging unit, the volume flow measurement is also integrated in the PLC.

15.5.5

Description of the Function

The pigging line is operated as a one-pig system (OPS). The volume flow measurement is carried out between the two storage vessels and the inlet to the pigging system with magnetically-inductive flow meters.

Table 15–5 shows the transport from one of the two storage vessels to one of the first reactors, whose connection to the pigging line was realized by means of a special piggable switch.

1. Initial position: pig P is in the launching station. The pigging line is filled with nitrogen and pressure-relieved. In the launching station is another pig, which is used only for cleaning procedures.
2. The appropriate raw material inlet and raw material outlet are opened.
3. The product is pumped to the reactor; flow metering is performed by a flow meter installed outside of the pigging line.
4. The appropriate raw material inlet is closed.
5. Pig travel: after opening of the launching station the pig P is driven by nitrogen to the reactor, into which it pushes the pipe contents. In the corresponding piggable switch, the pig P is finally stopped.

6. The piggable switch is turned with the pig P, whereby the path to the reactor is sealed.
7. Pig travel: The pig P is driven by nitrogen back into the launching station. The launching station is closed.
8. Initial position: the pig P is in the launching station. The pigging line is filled with nitrogen and pressure-relieved.

Table 15–5. Sequence table of a pigging procedure in the production of raw materials

Sequence no.	Sequence	Pig position or travel direction	Pigging line	
			Content	Propellant
1	initial position*	P = LS	N	–
2	open metering valve and product outlet valve	–	N	–
3	product pumping	–	product	–
4	close metering valve	–	product	–
5	pig run	P → RS	–	N
6	close product outlet valve	–	N	–
7	pig run	P → LS	–	N
8	initial position*	P = LS	N	–

P = pig, LS = launching station, RS = receiving station, N = nitrogen,
 =: pig resting position, →: pig run

* For occasional cleaning there is another pig in the launching station.

16

Pigging Units for Sterile Technology

16.1

Characteristics of Sterile Technology

The term “sterile technology” refers here to all pigging applications in which special requirements must be fulfilled concerning cleanliness and hygiene. This particularly applies to the food and beverage industry, the cosmetic industry, and pharmaceutical industry including biochemistry and genetic engineering, and special applications in chemical plants.

In fully automated processes in the food and beverage industry the cleaning procedure is of equal importance to production itself for hygienic reasons. The cleaning procedures must take place cyclically; the frequency is high, often daily to guarantee the required freedom from bacteria. The products are predominantly of high quality and product losses must be minimized. Cyclic cleaning procedures lead to high disposal costs.

Lines in sterile technology must be particularly smooth inside and outside; the valves must be free of dead spaces.

Pigging is highly suitable as an automatable cleaning method for pipelines in sterile plants. It makes closed piping systems possible.

Examples of applications for industrial pigging units in sterile areas:

Food industry:	yoghurt, cheese, mustard, pastry, jam, chocolate
Beverage industry:	dairies, breweries, and wine cellars; syrup, fruit, and cola concentrates
Cosmetics:	sunscreens, shampoos, lotions, creams, tooth pastes
Pharmaceuticals:	ointments, cough mixtures
Chemical industry:	cleaning agents, detergents, vitamins, dispersions, paints and coatings

Many of the above-mentioned products are pasty or contain solids (e.g., paints and coatings with different degrees of filling) and therefore do not exhibit Newtonian behavior. The rheological properties must be considered in the piggability check and in the design of the pigging unit (see also Chap. 12).

Hygiene-Friendly Design

Hygienic aspects must be considered in the design of vessels and other components for the food industry and the pharmaceutical industry. For the construction of hygienic and cleanable components (hygienic design) there are special rules, which must also be observed for the components of pigging units. The construction takes into account the special characteristics of microorganisms, the adhesive forces of product molecules on the surfaces of components, the avoidance of inclusions in cracks, slots, and other dead volumes, as well as contamination from the outside at untight parts (penetration). The plant must be cleanable and thus free of micro-organisms (aseptic). Product accretions, demixing processes, and drying of products lead to microbial decay. Growth of microorganisms in constructional weak points must be avoided.

The cleaning must function safely and reliably with minimization of the cleaning expenditure and must already be considered in the planning phase of the plant. For plant cleaning an optimum balance between plant and operating costs must be aimed for. Units which can be cleaned in situ and freed from the most important microorganisms without dismantling, and are automatable have advantages over plants which can be cleaned only after dismantling.

Examples of common problems in sterile technology:

Pigging is essential in the chocolate industry, because chocolate production without pigging has a series of problems: Chocolate is conveyed through pipes at a temperature of 35 to 50 °C. At a lower temperature the pumpability and storability are no longer given. Therefore, many manufacturers used a complex warm-water-heated double-jacket pipe. During plant shut down, e.g., over the weekend, the pipeline can be not completely emptied. Aging of the product leads to quality loss, particularly with fillings and with white chocolate. With diet chocolate the fructose can crystallize and lead to an off-spec batch. Product changes in nonpiggable pipelines lead to long phases of product mixing due to the high viscosity of the products. One of the largest German chocolate manufacturers (100 000 t/a) is a satisfied customer with 15 years experience of pigging, which allows heated pipelines to be dispensed with.

Differences to Conventional Industrial Pigging Units

- Nominal size is 1" (DN 25) to 4" (DN 100)
- Strictest requirements for welding of the pipe circumferential welding seams
- Strictes conditions for design without any dead volume
- Temperature stability up to 140 °C
- Automated cleaning procedures
- Additional system functions: apart from product pumping and pig travel: cleaning and steam cleaning.

Requirements for Pigging Units in Sterile Technology

- Use of physiologically perfect materials
- Use of particularly smooth pipes
- Steam stability, also of the pigs
- Application of valves free of dead spaces
- Automated operation of all cleaning procedures (CIP, SIP stations)

Important Regulations and Standards

GMP (Good Manufacturing Practices, USA)

Recommendations for “adequate production practice” of medicaments, issued by the WHO for the first time in 1968. Apart from product hygiene and the avoidance of contamination the guidelines concern the avoidance of confusion, assurance of all operations, quality control, and documentation. The later revised GMP guidelines have since become common property in the pharmaceutical and other industries.

FDA (Food and Drug Administration, USA)

Code of Federal Regulation (CFR)

EHEDG (European Hygienic Design Group)

Updates *Trends in Food Science and Technology*

BGA (Federal Health Ministry in Germany, Bundesgesundheitsamt)

Guidelines and recommendations

16.2**Terms in Hygienic Design***Dead Space:*

Spaces in to which product and/or dirt penetrates, in which however little or no exchange (no turbulence) takes place during cleaning and production. Dead spaces or volumes are to be regarded as a surface defect. Crevices are narrow dead spaces. Circumferential weld seams, flange connections, and valves lead to many such pockets. With regard to the pigging process a dead space is a volume not cleanable by a pig (deviation from the ideal pipe inside diameter).

Strictly speaking there are no valves completely without dead space; there are only those with low dead volume. In industrial pigging systems low-dead-space, valves must always be used. In sterile technology, extremely low dead volumes are required.

CIP/SIP (Cleaning in Place/Sterilization in Place)

Cleaning methods can be classified as cleaning after dismantling of components and cleaning without dismantling into component parts. The latter method is called CIP, i.e., cleaning/sterilization of plant components (e.g., pipes, valves, vessels) in a closed circuit, i.e., without removal of components, which thus avoids contamination from the outside. If the cleaning procedures take place regularly and in short

time intervals, automation is desirable and practical. The pipelines can be cleaned by pigging. Additionally, in sterile technology the pig is cleaned and/or sterilized. This can be carried out in the pig launching or receiving station. For this, the pig must be washable and steamable from all sides in the station.

Sterilization

Sterilization is freeing of an item from living microorganisms, whereby it is not demanded that the dead and/or inactivated germs be removed. Sterile therefore means freedom from viable microorganisms. Sterilization can be carried out with hot air, steam, or disinfectants. Pasteurization takes place below 100 °C and does not kill heat-resistant spores. Sterilization temperatures are over 100 °C.

Disinfectants

Disinfectants (antiseptics) are materials, that attack pathogenic microorganisms (bacteria, mold fungi, yeasts, viruses, spores) by being present on their surface. Their effect must always be germ-killing (germicidal); a growth-retarding effect is not sufficient. Example of disinfectants are mixtures containing formaldehyde, peracetic acid, phenol, propionic acid, or 20–30 % hydrogen peroxide solution.

Steaming

Resistance to steam and condensate, also over a long contact period, is required. Usually, saturated steam is used at 4 bar. For sterility, 130 °C is required for 30 min.

Dirt

Dirt encompasses all organic and inorganic contaminants that can endanger product or the functioning of the plant. It also includes all unwanted and harmful substances, including product residues (with or without microorganisms). In particular, abraded material, residues of cleaning agents and disinfectants, microorganisms and toxins are components of dirt.

Dirt can vary in structure from crystalline to very viscous and slimy. Binding to surfaces can be weak (flakes) to very strong coatings. Drying of dirt substances can increase both the strength of binding of these substances to one another (cohesive forces) and their adhesion to the surface of the component (adhesive forces).

Cleaning

Cleaning is removal of dirt. Different degrees of cleaning are distinguished.

- Removal of coarse dirt
- Removal of fine particles and coatings
- Removal of microorganisms (sterile cleaning)

Contamination, i.e., dirtying with dirt and/or harmful substances, is the opposite of cleaning.

Cleaning methods can be mechanical or chemical. Simple rinsing is not mechanical cleaning. Coatings on pipe inner walls can not be removed by simply rinsing. Because of the laminar boundary layer of the current near the wall practically no

mechanical cleaning effect is present. The removal of coatings can best be achieved by pressure jerks (turbulent current). The scraping effect of the pig can also clean the pipe inner wall mechanically. If pigging is not used, the required hygienic conditions can only be achieved by sufficient cleaning time.

Chemical cleaning can be accomplished with alkaline or acid media. For example, alkaline cleaning can be carried out with 5 % caustic soda solution at temperatures up to 140 °C for ca. 10 min. Acid cleaning can be performed with, e.g., nitric or phosphoric acid.

Microorganisms

Microorganisms are bacteria, yeasts, mold fungi, and spores.. Bacteria are generally ca. 0.15–10 µm in size, i.e., small bacteria lie on the order of magnitude of the roughness depth of cold-rolled steel sheet ($R_a = 0.2\text{--}0.8\text{ }\mu\text{m}$), the starting material for pipes. A scratch on a stainless steel sheet is ca. 10 µm deep.

Microorganism can have spherical, rod-like or threadlike forms. Bacterial growth is possible in the temperature range from –7 to +70 °C . Bacteria also differ in their demand for oxygen (aerobic growth in the presence of oxygen, anaerobic in the absence there of), their pH sensitivity, and requirements for the growth medium. Most bacteria grow at moderate temperatures in the pH range of 5–8 in the presence of water.

Product-Contact Areas

The product-contact areas include all surfaces of components which intentionally or unintentionally (e.g., by splashing) can come into contact with product and from which product or condensate can run off, drip from or enter the product by another way. Furthermore all other surfaces that can cross-contaminate the indirect product-contact areas are included. This EHEDG definition is very strict and high demands are also made on the external surfaces of the components.

16.3

Materials for Sterile Technology

Materials must be nontoxic under operating conditions, resistant to products and cleaning agents, and nonabsorbent. The main demands on the material often result not from product itself, but from the cleaning agent at its application temperature.

Physiological safety and absence of effects on taste (food-grade materials) are ensured by the stainless steels used in the food and beverage industry. Aluminum and nickel- and chromium-plated surfaces must be avoided.

For the use of plastic and elastomers there are also BGA and FDA recommendations.

The benefit of using pigging technology is that many pig materials are already approved for sterile applications because the materials are used in conventional sterile units as gasket materials.

Recommended Stainless Steels

AISI, DIN, ACI (casting products) grades, depending on their corrosion characteristics

Products with low chloride content (risk of pitting corrosion):

AISI-304 or DIN 1.4301

Products containing chloride, moderate temperature (< 60 °C), risk of stress corrosion cracking:

AISI-316 or DIN 1.4401

AISI-316L or DIN 1.4404

Products containing chloride, high temperature (60 – 150 °C), no stress corrosion cracking:

AISI-410 or DIN 1.4006

AISI-409 or DIN 1.4512

AISI-329 or DIN 1.4460

Incoloy 825

Recommended plastic and elastomers (selection)

Polypropylene (PP) Novolen

Poly(vinyl chloride) (PVC) Hostalit

Polycarbonate (PC) Makrolon

High-density polyethylene (PE) Hostalen

Polyetrafluorethylene (PTFE) Teflon

Ethylene-propylene-diene monomer (EPDM) Vistalon

Nitrile butyl rubber (NBR) BUNA-N

Silicone rubber (VMQ) Silopren

Fluorocarbon rubber (FKM) Viton

16.4**Elements of Sterile Pigging Technology****16.4.1****Pigs**

A pigging unit in a sterile area is still an industrial pigging unit. Apart from the characteristics of the pigs discussed in Chap. 3, there are some further requirements for use in sterile technology.

- Material physiologically harmless (BGA approved), closed-cell elastomer
- Resistance to product, cleaning medium, and steam
- Wear-resistant, i.e., no formation of wear particles
- Thermal stability and steam stability, i.e., resistance to steam at 140 °C
- Flow-friendly design to exclude detachment of the current during cleaning and achieve washing from all sides
- Design without any dead volume, without crevices and undercuts (solid cast pigs), i.e., changeable lip pigs are unsuitable.

Sterile pigs from different manufacturers are shown in Chap. 3. They are all solid cast pigs (uniform material, one-piece design, simple geometry):

- Dumbbell-shaped I.S.T. Duo pig
- Cylindrical edges rounded (Kiesel)
- Double-spherical shape, strongly overlapping (Tuchenhagen).

Sterile pigging units are highly automated, including the cleaning procedures. Tandem pigging is frequently used: a liquid cushion is dosed between two pigs travelling in the same direction. This allows cleaning and disinfecting to be carried out without having to flood the entire pipeline. As propellant distilled water or dry, oil-free, sterile air is used.

16.4.2

Pig Cleaning Stations

As in an industrial pigging unit the pig is used for the cleaning the pipeline. In sterile areas there is additional need to clean the pigs themselves. Since this must be carried out very frequently, it is preferable to make pig cleaning an automated CIP process. The pig cleaning station (Fig. 16.1) is the key component of a sterile pig-



Fig. 16-1. Pig cleaning station, (Tuchenhagen, Büchen, Germany)

gig unit. Only with the development of an CIP-able pig station did pigging become completely exploitable in sterile technology. It is sufficient if one of the stations is CIP-able. For cleaning the pig in the station, removal of the pig is not required (avoidance of contamination). Despite continual cleaning procedures, the pigging system is closed, and the pig must be removed only at the end of its service life. Flushing of the pig cleaning station with product, cleaning agent, or steam is possible in both directions.

The station has no areas free of flow. The station is designed for low pressure drop by having equal flow areas in the pipe and around the pig in the station. The position of the pig in the station is such that it can be washed from all sides. Thorough cleaning of the pig faces, which have direct product contact, must be ensured. The valves connected of the pig station must be also perfectly cleanable. Automated operation desirable.

16.4.3

Pipelines

The interconnection of pipelines with cleaning circuits results in very complex product pipeline systems in sterile technology.

In principle longitudinally welded and seamless pipes made of stainless steel can be used (see also Chap. 5). Hygienic conditions require an accurate and strict specification, both for the inside and the outside surface finish. Pipes suitable for sterile areas are standardized in outside diameter and wall thickness (DIN 11850: Stainless steel pipes for foodstuffs).

Materials for standard pipelines are 1.4301 or 1.4571. Other frequently used high-grade steels are 1.4401, 1.4435, and 1.4541. The surface quality inside is metallicly bright and the welding seam region is smoothed. The average roughness value is between $R_a = 2.5 \mu\text{m}$ and $R_a = 0.8 \mu\text{m}$, and in the welding surface region $R_a = 1.6 \mu\text{m}$. In the some pharmaceutical applications higher surface qualities are required ($R_a = 0.2 \mu\text{m}$), and outer surface of the pipeline is ground to 400 grit or polished. According to the technical terms of delivery, the pipes are labelled with the manufacturer's name, the material number, and the surface finish.

16.4.4

Pipe Joints

Welded Pipe Joints

For pipelines according to DIN 11850 for application in the food and pharmaceutical areas special welding regulations apply.

Welding joint preparation:

The manufacturer has to arrange the design of the welding seams in such a way that they are mechanically weldable and testable. Butt welds must be prepared in such a way that the seam flanks remain parallel, sharp-edged, and burr-free, with an ovality of less than +1 % of the pipe outside diameter. Any contamination within the region of the seam flanks must be removed.

The effectiveness of the protective gas must be determined with a residual oxygen meter before welding; below 60 ppm residual oxygen, welding can be started. An argon/hydrogen mixture with 2 to 10 % hydrogen is used as protective gas. Non-destructive examination is carried out visually, by endoscopy, or videoscapy, with documentation by photos or video prints of the welding seams. In the test report, the quality of the welding seams is documented for random samples, and the dimensions of the pipe are included. The pressure test must be carried out with chloride-free water.

Detachable Pipe Joints

Detachable pipe joints are particularly important in the foodstuffs industry, since the pipelines are often dismantled here for cleaning purposes (if there is no pigging) or new connections have to be made. Besides flanged connections there are quick-opening pipe joints, which are opened with a slotted nut spanner.

A detachable connection in hygiene-friendly design for sterile technology, which also must be piggable, must meet many requirements some of which are contradictory:

- No dead volumes, no tongue and groove flanges
- Centering must be guaranteed
- Gasket area free of crevices

Construction principle of a hygiene-friendly bolted connection is to create by means of a radial centering and an axial stop of the connector parts compression of the gasket independent of the bolting force.

Examples of proven constructions are:

- Pipe joints according to DIN 11851 ("milk pipe joint")
This pipe joint is available in designs for rolling in and for welding to pipes according to DIN 11850. It consists of four component parts: threaded end with round thread, cone connecting piece, groove connector nut, and gasket. The gasket is a sealing ring (O-ring) made of EPDM, FKM, HNBR, MVQ, or NBR. Liquid-contacted inner surfaces have the surface quality $R_a < 1.6 \mu\text{m}$, and the outer surfaces $R_a < 3.2 \mu\text{m}$. The coupling is piggable.
- Aseptic flange connection according to DIN 11864-2
The standard DIN 11864 on valves for foods, chemicals, and pharmaceuticals is based on the recommendations of the EHEDG. The standard applies to aseptic couplings with O-ring or shaped gaskets. The EPDM gaskets are chambered (O-rings or shaped gaskets). After tightening they seal gap-free flush with the inside diameter, but do not project into the interior. The aseptic couplings are suitable for operating pressures 1½" (DN 40) up to 25 bar, 4" (DN 100) up to 16 bar, and 6" (DN 150) up to 10 bar. The pressures can be applied up to a temperature of max. 140 °C. The connections can be butt welded to pipes according to DIN 11850 or DIN EN ISO 1127, ISO 2037, or BS 4825. The connection is piggable. A typical design is shown in Fig. 16–2.

- Aseptic pipe joint according to DIN 11864-1

This pipe joint is similar in design to the milk pipe joint and also has a grooved connector nut. The gasket is designed in accordance with part 2 of the standard. The connection is piggable.

- T-ring connector according to ISO 2853

This pipe joint is available in designs for rolling in and for welding and is piggable. Component parts: the two welding/rolling in connecting pieces with and without buttress threads, round or hexagonal nut, thrust ring, and shaped gasket. This pipe joint is intended for pipes according to ISO 2037.

- Stainless steel clamp connector according to ISO 2852

This quick-release pipe joint according to ISO 2037 consists of two cone-shaped outside shoulders, which are pressed over a conical shell. Between them a gasket is clamped. The clamp connection is piggable.

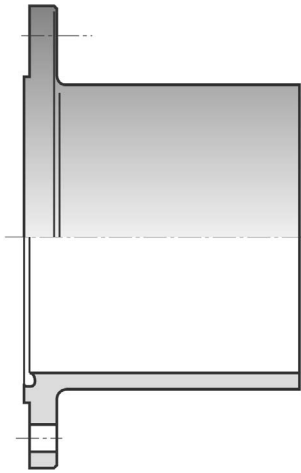


Fig. 16-2. Aseptic joint (Tuchenhagen, Büchen, Germany)

16.5

Example

As example of a sequence control in a sterile area a pipe in the beverage industry, cleanable by pigging, is described. A one-pig system (OPS) is used with compressed sterile air as propellant (see Fig. 16-3 and Table 16-1).

Working principle

1. Initial position
The pig is located in the pig cleaning unit of the launching station. The pipeline is filled with air. The product valves are closed.
2. Product pumping:
The product enters via connecting piece A, bypasses the pig, and exits at the receiving station in direction F.

3. Pig travel (product driven out):
A is closed, the pig presses the product toward F. When the pig is detected by the magnetic switch G04, valve F is closed.
4. Pig travel:
The pig travels back to the launching station.
5. CIP procedure:
Cleaning agent is inlet at the connecting piece A. The cleaning agent flows through the pipes in the directions FGC. The pig is cleaned by the flow through the cleaning station.
6. Steaming:
Steam can be introduced via A or F. Depending on the steam flow direction the condensate can be removed at A or F.

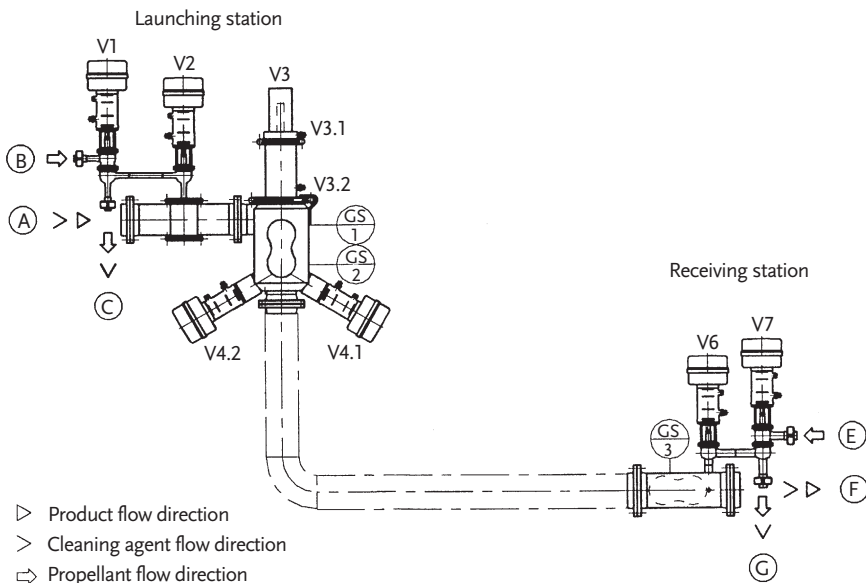


Fig. 16-3. P&ID of a sterile pigging system

Table 16–1. Sequence table: sterile pigging*

Sequence no.	Sequence	Pig position or travel direction	Pigging line	
			Content	Propellant
1	Initial position	P = LS	air	–
2	product pumping	P = LS	product	–
3	pig run	P → RS	–	air
4	pig run	P → LS	–	air
5	cleaning	P = LS	CA	–
6	steaming	P = LS	steam	–
7	initial position	P = LS	air	–

* P = pig, LS = launching station, RS = receiving station, P = product, CA = cleaning agent, =: pig resting position, →: pig run

17

Pipeline Pigging

17.1

Distinction from Industrial Pigging Units

Contrary to the industrial pigging units discussed so far, this chapter deals with the application of pigging technology in large, long pipelines.

This book is not concerned with pipeline pigging; instead it is primarily aimed at the chemical industry. Nevertheless no book on pigging would be complete without a chapter on this important and oldest field of application. Many problems and their solutions in long-distance pipeline technology also occur in industrial pigging units in similar way, so it is worth while dealing with this special area of pigging in more detail.

Pipelines transport primary energy and pumpable bulk goods. They are used between energy reservoirs and process industries and the consumption centers. Pipelines can be intended exclusively for the transport of only one product, but there are also multiproduct pipelines, e.g., for conveying different crude oil grades.

Pipelines have different characteristics to pipes on pipe bridges and in plants. Apart from the length and the diameter, there are the following fundamental differences:

- Pipelines are laid in the terrain; hence they are not free of siphons (i.e., not self emptying). Installation without siphons is not possible, while in the chemical industry a siphon-free pipe installation can be achieved to a certain extent. The volumes of the siphons are very large (field-erected bends).
- The hold-up of a pipeline is extremely large. Amount or flow balance systems are prescribed.
- Large parts of the pipeline are not accessible from the outside or only accessible with difficulty; this applies in particular to offshore pipelines.
- Pipelines in an industrial plant have substantially more fittings (elbows, T-pieces) and shaped sections (pipe bends, branches).
- Pipelines are used for a few products: crude oil, refined oil, natural gas, and water, whereas pipelines in industrial plants transport the total spectrum of chemicals.

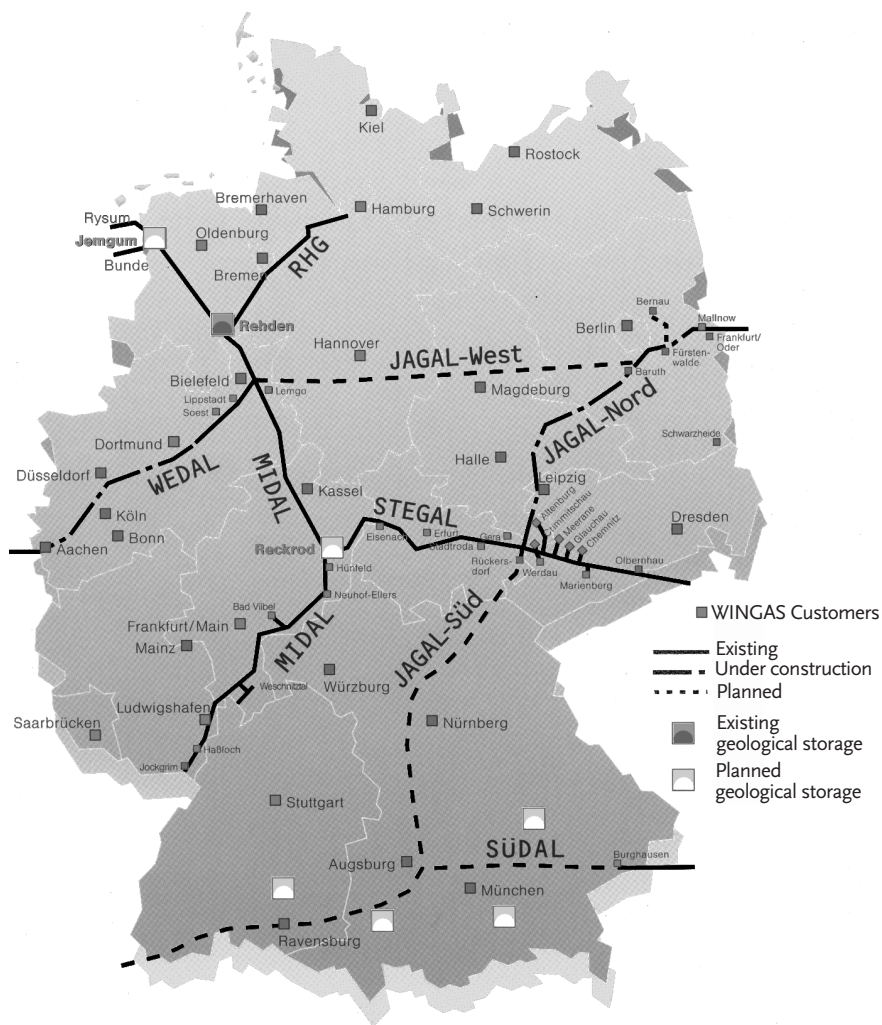


Fig. 17-1. Pipeline net in Germany

- Pigging technology and pigging systems are substantially more complex in industrial pigging units. For a long-distance pipelines a sequence diagram is unnecessary.

However, a clear distinction between long-distance pipelines and plant pipelines is not possible; in practice a wide overlap range exists. Chemical plants can also have extremely long pipelines of large nominal size, for example, naphtha pipelines as steam cracker feed between a ship unloading facility and a tank farm.

In this regard the pigging systems, the pigs, and the pigging procedures also have different functions. Some differences relevant to pigging technology are listed in Table 17-1.

Table 17–1. Differences between industrial pigging units (IPU) and pigging of pipelines (PP)

	Industrial Pigging Units	Pipeline Pigging
Nominal size	50–200 mm	150–1400 mm
Total length	< 1000 m	150–1000 km
Wall thickness	< 5 mm	< 50 mm
Pressure rating	up to 25 bar	up to 150 bar
Travel frequency	regular	occasional
Degree of automation	high	manual
Material	stainless steel	carbon steel
Cleaning degree	high	coarse

Table 17–2 lists some piggable pipelines; their characteristic data illustrate the differences to the industrial pigging units treated so far, Fig. 17–1 shows a plan of these pipelines.

Pipelines are classified as onshore, offshore, and subsea pipelines. Each of these areas has special requirements regarding strength, resistance, and pipelaying technology. During construction and for inspection of such pipelines, the pig must fulfill the most diverse functions.

Table 17–2. Examples of long-distance piggable pipelines

Name	Explanation	From	To	On/ off- shore	Me- dium	Dia- meter	Pres- sure, bar	Length, km
MIDAL	Mitte-Deutschland-Anbin- dungsleitung	Rysum (Belgium)	Tockgrim	On	NPG	800 mm	84	640
STEGAL	Sachsen-Thü- ringen-Erdgas- Leitung	Olbernau (Germany)	Reckrod	On	NPG	800 mm	84	320
TOM	Total Oil Marine PLC	Frigg Field (Scotland)	St. Fergus Gas Terminal	Off	NPG	32"	149	36
Forties	BP Forties Field Line	Forties Field (Scotland)	Cruden Bay	Off	Crude Oil	32"	142	169
TAPS	Trans Alaska Pipeline System	Prudhoe Bay (Alaska)	Valdez	On	Crude Oil	48"	92	1300
AGEC	Alberta Gas Ethylen Corp.	Red Deer (Canada)	Edmonton	On	Ethyl- ene	12"	90	180

Usually a pipeline is divided into several sections, which are separated by stations. In pipeline technology these stations have the function of shutting off the pipeline section by section, creating and controlling the pressure (compressor and pumping stations), and measurements. The station also permits pig travel. Facilities for pigging are also located in sections where the diameter of the pipeline changes. The longest distance between two pigging stations is at present 800 km. Such distances naturally occur in the subsea region.

17.2

Pipes and Fittings

In principle every pipeline is piggable. However, the result of the pig run is not subject to the same criteria as in industrial pigging units. Differences arise not only from the size effect, but also as a result of the different requirements in pipeline pigging.

These characteristics of pipes and shaped parts in pipelines are dealt with in more detail in the following sections.

17.2.1

Pipes

Large pipe diameters and high operating pressure require stricter requirements on the pipe material to resist cracking and crack propagation, i.e., the fracture toughness (minimum notched-bar impact strength). Particularly the need to lay pipelines also in critical areas such as permafrost zones and offshore regions range led to a constant improvement in the weldability of the materials. Their resistance to hydrogen sulfide was also developed further, since in the past damage by sour gas corrosion (hydrogen-induced cracking) had occurred.

The requirements regarding materials and production for steel pipes for the transport of combustible liquids and gases was already regulated in the mid-1960s by DIN 17172. This standard has since been supplemented with tubular steels of higher strength developed in the meantime. Since December 1996 there is a (draft) European standard: E DIN 17172-100, parts 1-3. The materials defined in this standard are unalloyed and alloyed stainless steel, e.g., St E 290, St E 360, St E 480 according to DIN 17172 and L 290, L 360, L 485 according to ISO 4948.

Seamless Pipes

These pipes are manufactured by hot working, which can be followed by dimensional forming or cold forming for the achievement of the desired dimensions.

Thick-walled pipes up to ca. 660 mm in diameter can be optimally and economically produced in seamless form. The following manufacturing techniques dominate:

- Continuous pipe rolling technique:
Diameter range 21 to 140 mm, thickness range 2 to 25 mm

- Plug mill rolling technique:
Diameter range 140 to 406 mm, thickness range 3 to 40 mm
- Cross-rolled pilger mill technique:
Diameter range 250 to 660 mm, thickness 3 to 125 mm

Welded Pipes

For the construction of particularly large pipelines welded pipes predominate. The raw material for pipe production is hot- or cold-rolled sheet, whose edges are cut uniformly to accurate width. A distinction is made between

- High-frequency resistance welding (HFW):
Diameter to 508 mm (20")
- Submerged-arc welding (SAW):
Diameter up to 1620 mm (64")
- Combined inert gas and submerged-arc welding (COW):
Diameter up to 1620 mm (64")

As with pipelines for chemical plants, these welded pipes can be longitudinally welded (SAWL, COWL); helically seam-welded pipes are also possible (SAWH, COWH).

17.2.2

Tolerances

Pipeline pipes are standardized according their outside diameter. Table 13–3 lists the limiting dimensions for outside diameters and unroundness. There are different

Table 17–3. Tolerances for the outer diameter and the ovalness

Outer diameter D mm	Tolerances of the diameter				Tolerances of the ovalness	
	Pipes without the ends		Pipe ends		Pipes without the ends	Pipe ends
	Seamless	Welded	Seamless	Welded		
D < 60	± 0.5 % mm or ± 0.75 D (the higher number is valid)	± 0.5 % mm or ± 0.5 D (the higher number is valid), but at most ± 3.0 mm	± 0.5 mm or ± 0.5 D (the higher number is valid), but at most ± 1.6 mm		See tolerances of the diameter	
60 < D < 610					2.0 %	1.5 %
610 < D < 1430	± 1.0 D	± 0.5 D (but at most ± 3.0 mm)	±2.0 mm	±2.0 mm	1.5 % for D/T ≤ 75 2.0 % for D/T > 75	1.0 % for D/T ≤ 75 1.5 % for D/T > 75
D > 1430	As agreed upon		As agreed upon			As agreed upon

tolerances for the pipe sections between the ends and for the pipe ends (a section of 100 mm of length).

The wall thickness has tolerances of up to 1 mm (see Table 17–4). Further tolerances apply to straightness, to the radial misalignment of the sheet edges, and to overhang of the welding seam (height of seam, see Fig. 17–2).

Table 17–4. Tolerances for the pipe wall thickness

Pipe wall thickness T , mm	Tolerance
Seamless pipes	
$T \leq 4$	+0.6 mm/–0.5 mm
$4 < T < 25$	+15 %/–12.5 %
$T \geq 25$	+3.25 mm/–3.0 mm or $\pm 10\%$ (the higher value applies)
Welded pipes	
$T \leq 10$	+1.0 mm/–0.5 mm
$10 < T < 20$	+10 %/–5 %
$T \geq 20$	+2.0 mm/–1.0 mm

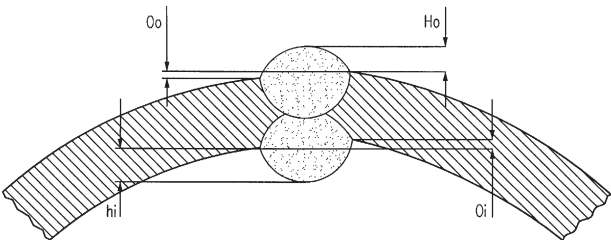


Fig. 17–2. Height of the welding seam

Example:

Analogous to the treatment in Section 5.3.1 the tolerance for pipeline pipes are described here in comparison to plant pipes.

Calculation of the tolerance (difference between maximum and minimum dimension) of the pipe:

Seamless pipe EN 10208-2-L415MB-813 · 14.2-r2

Diameter 32" (DN 800), PN 84

Outside diameter D : 813 mm, wall thickness T : 14.2 mm

Diameter tolerance: $\pm 0.5\% D = \pm 4$ mm

$D/T = 57.2 > 20$ wall thickness tolerance: $\pm 15\%, -12.5\%$

Smallest inside diameter for maximum permissible tolerance:

Combination of smallest outside diameter and thickest wall

$$D_{\min} = 813 - 4 - 2 \cdot 14.2 - 2 \cdot 2.13 = 776.4 \text{ mm}$$

Largest inside diameter for maximum permissible tolerance:

Combination of largest outside diameter and thinnest wall

$$D_{\max} = 813 + 4 - 2 \cdot 14.2 + 2 \cdot 1.775 = 792.0 \text{ mm}$$

$$\text{Difference: } \Delta D = 792.0 - 776.4 = 15.6 \text{ mm}$$

In the case of maximum tolerance the pig would have to be able to compensate for a change in diameter of 15.6 mm.

17.2.3

Fittings

Pipe fittings and shaped parts are divided into the following types: pipe bends, branches, reducers, and adapters. For the application of pigging pipe bends and branches are of interest.

Reducers are concentric or eccentric connectors for pipes of different diameters. Adapters are used to compensate for different wall thickness at the same diameter; they are only piggable to a limited extent with special pigs.

Pipe Bends

Pipe bends are manufactured, as the case of the smaller pipes for industrial pigging units, with different radii of curvature. The elbows are available in $1.5 d_o$, $3 d_o$ and $5 d_o$ designs. The $1.5 d_o$ design is only suitable for spherical pigs. For the piggability the basic rule is: the larger the diameter of the pipeline, the smaller the permissible bend.

Table 17–5. Minimum bending radii of pipeline bends

Diameter		Bending radius r
$\leq 4''$	($\approx$ up to DN 100)	$10 d_o$
$6'' - 12''$	($\approx$ DN 150–DN 300)	$5 d_o$
$> 12''$	($\approx$ from DN 300)	$3 d_o$

There are different methods for the industrial production of pipe bends. Inductive elbows are manufactured in an inductor from a piece of straight pipe. A narrow zone of the pipe is briefly heated. Half-shell bends are manufactured by welding two or more segments. These tight bends are usually encountered in the stations and not between them. Shank extensions are preferred.

Up to 20 % of the pipes are bent on the construction site in special hydraulic bending machines [cold bends, pipe bends with large radius ($r > 40 d_o$)]. During bending, the pipe is supported internally by a mandrel. Self-deformation of the pipe line due to gravity also occurs. These pipe bends are of little interest for the pigging procedure, since the radii lie on the order of magnitude of several 100 m.

Segment elbows are problematic for pigging and must not be used.

Branches

Branches are outlets oriented perpendicular or diagonal to the pipeline. They are manufactured by extrusion, welding, or forging. The size of the branch relative to the nominal size of the pipeline and its position (upwards or downward) determines whether the branch must be constructed with or without guide bars. The diameter ratio product branch to pipe ($q = d_b / d_p$) can have the values 0.3 to 1.0. Outlets with small q -values (0.1–0.3) are unproblematic for the pigging (welding-on connector). Most pigs run over branches up to $0.5 d_p$ (in exceptional cases up to $0.6 d_p$). Here it is not the L/D ratio that is crucial but the relative distance of the sealing rings (L^*/D relationship).

Also of interest for the piggability is the distance between two branches lying close together, so that tilting and wedging of the pig can be safely excluded (see Fig. 17–3).

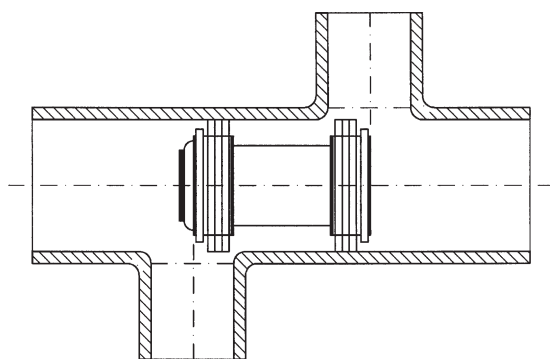


Fig. 17–3. Tilting of a pig during passage of two close-lying product branches

17.3

Function of Pigs in Pipelines

Construction and operation of pipelines are not possible without pigging technology. Numerous tasks can only be performed economically by pigs; pipeline technology is closely connected with pigging technology. All pipelines are equipped with pig stations.

Therefore, the first application of pigs were associated with the construction of the first pipelines. Around 1870 in the USA the first long-distance lines for crude oil were laid. At this time the term pig was used for the first time. Pigs are used in the erection, operation, inspection, maintenance, and even repair of pipelines:

Applications during construction

- Removal of coarse dirt
- Removal of liquids, drying
- Documentation of the state of laying

Application during start-up

Complete flooding during the pressure test
Calibration of volumetric flow meters

Application during operation

Cleaning (removal of waxes or solids)
Condensate removal
Separate different product batches

Applications for inspection

Examination of geometry
Detection of corrosion, tears, and errors
Leakage detection

Application for repair

In situ in-line coating
Corrosion inhibition
Closing pipeline sections
Putting pipes out of operation

Already in the construction of pipelines pigging is an integral component of pipe-laying technology. The first application of pigging technology is usually the travel of a cleaning pig through a completed section. Coarse dirt, welding seam residues, sand, stones, and other solid particles, which entered the pipeline during construction are removed. A brush or scraper pig driven by compressed air (see Fig. 17-4) is used for coarse cleaning. Often several pig travels are necessary.

In the next step the geometry is examined, primarily to check the minimum inside diameter. Apart from the welding seam dip and the ovality of pipe bends, deformations occurring during pipe laying lead to changes in diameter. Usually a calibrating disk made of aluminum is used. For large nominal sizes these disks are segmented. The diameter starts at ca. $0.9 d_i$. Depending upon the damage to the periphery of this disk, $0.95 d_i$ is used and then $0.97 d_i$.

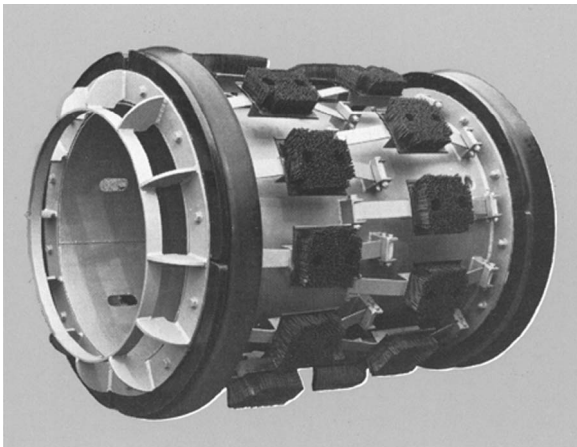


Fig. 17-4. Brush scraper pig

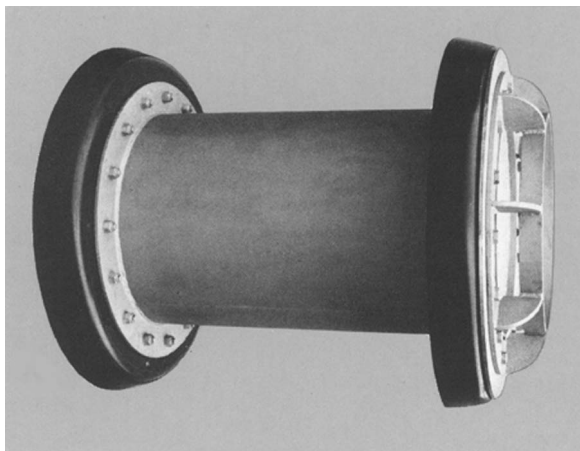


Fig. 17-5. Cup seal pig

With very long test sections or inaccessible pipeline sections (e.g., subsea pipelines) a bidirectional pig should be used for safety reasons.

Substantially more accurate information is supplied by so-called intelligent pigs. The distance to the tubing inside wall can thus be measured and recorded contactlessly for the entire circumference and length of the pipe. This log can be used to locate errors and if possible to initiate necessary repairs. The geometry pig travels through the pipeline without damaging itself or the pipeline. Preliminary cleaning with the coarse cleaning pig is advisable. Intelligent pigs with signal recording react sensitively to fluctuations in speed (stick/slip effects). Therefore they are best driven by a liquid propellant.

Once the as-laid pipeline has been examined and the errors eliminated, the water-pressure test (stress test) is carried out. Only by using a pig driven by the water pumped in can a pipeline laid in the landscape be completely flooded. In the pressure test, air bubbles and high points filled with air must be avoided completely.

Pigs are also used for completely removing the water after the pressure test and for drying the pipeline, see cup seal pig Fig. 17-5. For example natural gas pipelines must be very well dried, to avoid the formation of hydrates.

The calibration of volumetric flow meters also exploits the fact that only by means of a pig ahead of the product the pipeline can be filled completely without inclusion of air. In the same way, the pipeline can be started up, i.e., filled with product. If a pipeline is filled with natural gas without application of a pig, the slowly rising concentration of the product stream must be monitored carefully until it reaches the desired specification at the end of the pipeline. Much product is lost thereby.

During the operation of the pipeline various product-specific functions can be performed by pigs. In gas pipelines regularly pig travels remove the condensate. In crude oil pipelines the wax adhering to the insides must be removed. The quickly growing layer of wax already increases the pressure drop after a few 100 operating hours and can even stop the flow completely.

Inspections during operation monitor the inside diameter and thus corrosion effects. In in-line inspection these data are determined without opening the pipeline or removing the product. Leak-detector pigs can locate a leakage point by acoustic measurements. Other possible detections and measurements are described in more detail in the Section 17.4.2.

Even repair work can be carried out by special pigs. Many natural gas pipelines are coated inside. There are pigs which can apply this coating while travelling through a pipeline.

By using tandem pigs corrosion inhibitors can be brought into the pipeline in a batch process.

Finally, pigs can be used for emptying, cleaning, or drying pipelines out of operation.

17.4

Pigs for Pipelines

Depending upon function, different pig designs are used. A distinction is made between mechanical pigs and smart pigs. Separating pigs, sealing pigs, and cleaning pigs belong to the group of mechanical pigs, while testing pigs, detection pigs, and inspection pigs are assigned to the smart pigs.

Pig Detection

For pig detection in pipelines different principles are available: mechanical, ultrasonic, and radioactive detection, and transmitter/receiver systems.

Since pipelines consist of ferritic steel, pig detection via built-in permanent magnets, as in industrial pigging units, is not possible. The mechanical detectors have the disadvantage that for these devices a hole must be drilled in the pipeline. They are maintenance-intensive and relatively trouble-prone. There are designs for the detection of pig passages in both directions.

Pigs which carry a radioactive isotope can be located by a Geiger counter. In the ultrasonic detector a 1000 kHz signal transmitted radially through the pipe is interrupted by the passage of the pig.

Large pigs are equipped with a transmitter, which sends a low-frequency signal. This signal penetrates both the pipe wall and the soil and can be received by an antenna. The pig can be located with an accuracy of ca. 50 cm.

17.4.1

Mechanical Pigs

Solid cast pigs for application in pipelines are mostly made of open-cellular polyurethane and not from solid plastics as in industrial pigging units. Pigs made of open-cellular polyurethane are available in different densities or with polyurethane strips on the periphery. These foam pigs (poly pigs) possess a bullet like form (see Fig. 17–6). Often they are used for simple cleaning functions (wiping, drying) as dispos-

Pig Type	STYLE	SIZES	DENSITY	FUNCTION
LD (low density)		2" to 48"	LOW 35 kg/m ³	pipeline Drying
AB (Apua Bare)		2" to 60"	MEDIUM Approximately 80 kg/m ³	Regular Drying Up to 10 MI
ACC (Apua Criss Cross)				Longer Wiping Up to 25 MI
ACC-WB (Apua Criss Cross Wire Brush)				Longer Scraping Up to 25 MI
ACC-SC (Apua Criss Cross Silicon Carbide)				Longer Scraping Up to 25 MI
SBD (Scarlet bare durafoam)		2" to 60"	HEAVY Approximately 128 kg/m ³	Heavy Drying Up to 200 MI
SCC (Scarlet Criss Cross)				Heaviest Wiping Up to 300 MI
SCC-WB (Scarlet Criss Cross Wire Brush)				Heaviest Scraping Up to 300 MI
SCC-SC (Scarlet Criss Cross Silicon Carbide)				Heaviest Scraping Up to 300 MI

SPECIAL APPLICATIONS

UNICAST		2" to 60"	320 kg/m ³	Long Range cleaning Up to 2000 MI
GRAY HARD SCALE		2" to 60"	HEAVY Approximately 128 kg/m ³	Industrial Scraping Up to 300 MI
MAXI-BRUSH (Light Wire)				Maximum Scraping Up to 300 MI
MAXI-BRUSH (Heavy Wire)				Maximum Scraping Up to 300 MI

Fig. 17-6. Foam pigs (Kopp, Lingen, Germany)

able pigs. Heavy cleaning procedures, such as removal of wax or other firmly adhering deposits, require metal brush pigs.

Due to their size pigs for pipelines are multicomponent pigs. A modular system is used: a uniform basic body can be provided with different attachments (see Fig. 17-7). Worn parts can be exchanged in this way.

In the case of purely mechanical pigs, different disks, sealing lips and/or brushes can be attached to the basic body. Depending on the assembly they can be uni- or bidirectional.

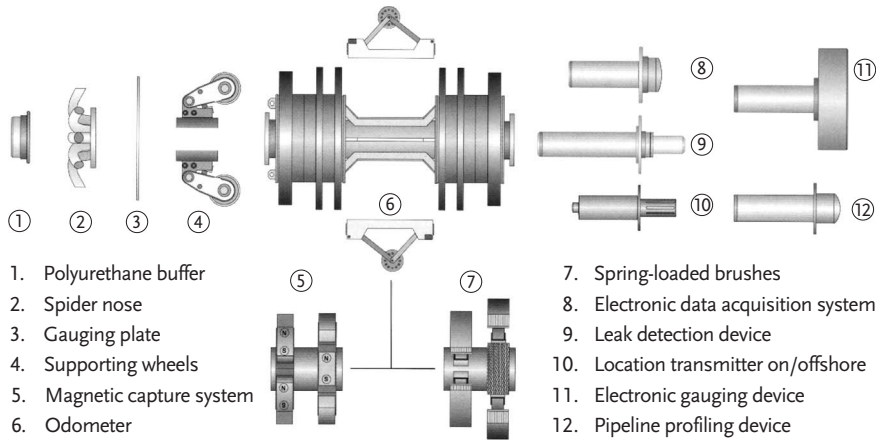


Fig. 17-7. Modular system for multicomponent pipeline pigs
(H. Rosen Engineering, Lingen, Germany)

17.4.2

Smart Pigs

Pigs which not only consists of mechanical components (mechanical pigs), but also have an electrical/electronic part for measuring, processing, storing, and transmitting data are termed smart pigs. The mechanical part is a pig body, designed as the structural support for the electrical/electronic components. Also, several pig bodies can be connected by joints for better pipebend travel. In this case the first body is a driving pig equipped with sealing lips.

The mechanical part includes the guidance devices, which take up the weight of the pig and provide for centering and movement. These pigs are driven as in industrial pigging units by a propellant in the pipeline and by sealing lips on the pig.

The electrical/electronic part in most cases consist of transducer (sensor technology) and signal processing, storage, and/or –transmission, as well as an electrical power supply. Sensitive electronics which must not come into contact with product or propellant must totally enclosed in a pressure-tight fashion for up to 120 bar so that the pig can be used in oil and gas pipelines at the usual operating pressure. Furthermore, electronics must be shockproof to resist extreme acceleration.

These pigs are used for the in-line inspection of pipelines by the methods of non-destructive testing of materials or optical inspection (video technology). In smart pigs, above all the following methods of nondestructive testing are applied:

- Magnetic stray-field technology
- Ultrasound
- Eddy current

Application of the magnetic techniques requires the presence of magnetic flux and is thus applicable only to ferromagnetic materials. The Hall effect is used: A

plate carrying an electric current in a magnetic field supplies an electrical voltage at its sides. If the Hall sensor is calibrated in a known fields the magnetic flux density and/or change thereof can be measured.

With the aid of special brushes magnets induce a magnetic field in the pipe wall, which becomes magnetically saturated. Faults can be detected, since in weakened parts the intensity of the magnetic field passing through the wall is higher than in intact parts.

With ultrasonic probes the wall thickness is directly measurable, and calibration is not necessary. In the transition from one medium to another, the larger the difference between the acoustic independence of the two media, the stronger is the sound reflected at the interface. Therefore, the air film between ultrasound generator and pipe wall must be displaced by oil or water. For ultrasonic application a coupling medium is required. In oil pipelines oil can be used as coupling medium. In gas pipelines water must be used. From the reflections of the ultrasonic sensors on the inside and outside, which are designed as transmitters and receivers, the wall thickness can be calculated.

Eddy current sensors can be made small and are easily built. They are therefore more suitable for the inspection of smaller pipelines.

Detection of Material Removal

Material removal occurs due to the surface defects corrosion (pigging, pitting corrosion, CO₂ corrosion, corrosion at welding seams) and wear by mechanical actions (scratches). The pigs for this purpose are called corrosion pigs.

In the development of these measuring pigs and with the selection of a manufacturer, the following criteria are important:

- Defect recognition (minimum defect size)
- Correspondence between signal and a certain type of defect
- Accuracy of localization (distance, circumferential position) of the defect.

An example is the HRE (H. Rosen Engineering, Lingen) CDS (corrosion detection survey, pig (Fig. 17–8). It uses magnetic stray-field technology and has Hall sensors.

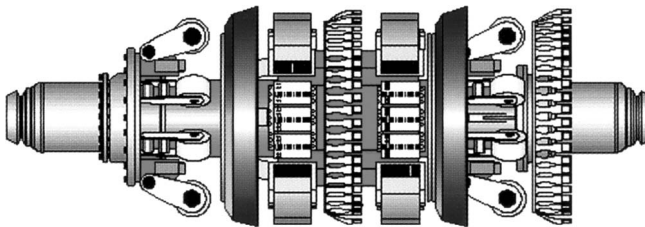


Fig. 17–8. Corrosion detection survey pig (H. Rosen Engineering, Lingen, Germany)

3P services, Geeste has also developed a corrosion measuring pig. The piCoLo (pig corrosion logger, Fig. 17–9) is intended for small-caliber pipelines (8", DN 200).



Fig. 17-9. PiCoLo (3P services, Geeste, Germany)

A new pig, based on the physical principle of ultrasound, is the Archinger SAMS (self-guided autonomous Molch system, Fig. 17-10). Archinger, originally specialized in nondestructive materials testing, developed an intelligent pig especially for narrow and small-diameter pipelines with a diameter of 3 to 6" (i.e., DN 80, DN 100, and DN 150); larger diameters are also possible. The System SAMS is still in the test phase.

SAMS is most frequently used in testing the thickness of pipeline walls which are not accessible from the outside (pipelines, feed pipes in refineries, chemical installations, public energy and water networks, but also storage tanks, heat exchangers, reactors, etc.). Essentially, the aim is to determine precisely the extent of corrosion (pitting) and/or erosion of both the inner and outer surfaces of the pipes.

To provide the most precise results possible in particularly endangered areas, the system is equipped with highly sensitive contact sensors, with which even the sharpest curves and angles can be measured and the testing process exactly controlled. This means that the unit does not lose contact with the pipe walls, ensuring consistent results between curved/angled and straight-line sections.

Current launching stations used for tubing of this diameter are usually designed for passive pigging systems and therefore are not suitable. For SAMS, with a total length of approximately 90 cm, a special device for pig loading is needed.

SAMS consist of four components: energy source for up to 6 h of running-time, contact sensor, data collection and processing, and the ultrasonic test-head module.

The computer has sufficient power to perform the enormous amount of calculations required as well as enough memory capacity to store the data, so that final

analysis can be conducted after the testing is completed. Following completion of the testing, results can be exported and saved for further evaluation.

A special feature of SAMS is its ability to reduce the overall volume of data. During pipe testing, an algorithm especially developed for SAMS is utilized. The effect of this is a dramatic reduction in the memory capacity necessary, which has lead to a significantly smaller unit.

Additional technical data of the SAMS-Pig:

Pipe diameter:	3–6"
Minimum required inside diameter:	86 % ID
Minimum pipe bending radius:	$r = 1.5 \cdot d_o$
Minimum wall thickness:	1 mm
Maximum wall thickness:	8 mm (larger possible)
Wall-thickness resolution:	0.1 mm
Detectable pits:	≥ 5 mm diameter
Maximum inspection length:	up to 5000 meters (depending on use)
Maximum pressure:	10 bar
Drive speed:	≤ 250 mm/s

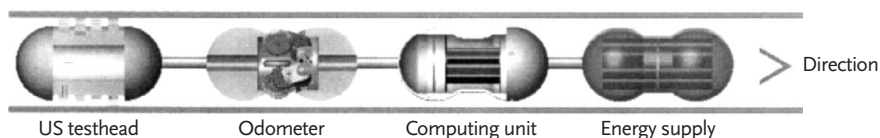


Fig. 17–10. SAMS-Pig (Archinger, Nuremberg, Germany)

Sampling of Geometric data

A pipeline is exposed to many effects after construction: earthquakes, displacements setting, frost, floodings, and damages to the outside.

Is the pipeline laid according to specification? Has the pipeline been damaged, can an expensive intelligent pig pass through without damage? These questions are answered by geometry pig. These pigs supply data on the as-laid pipeline. There are contactlessly operating systems and pigs equipped with rollers. Pipe bends, dents, ovality, fittings, flanges, circumferential weld seams, and changes in the inside diameter can be registered in such a way.

An example for this is the geometry measuring pig from H. Rosen, EGP (electronic geometry pig, Fig. 17–11). It is used for pipelines of 6–8", 10–14" and 16–56".

Its characteristic dimensions are:

- Maximum inspection length: 1000 km
- Maximum pressure: 150 bar
- Minimum required inside diameter: 85 % ID
- Minimum size for the detection of dents and ovality: 1 % ID.

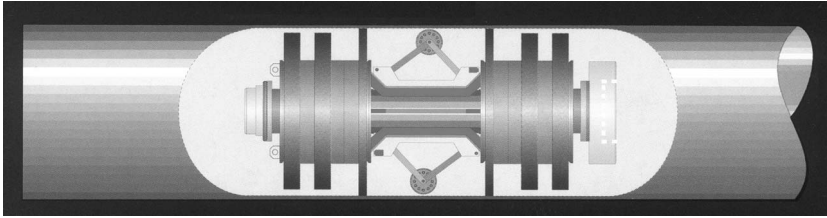


Fig. 17–11. Electronic Geometry Pig (H. Rosen Engineering, Lingen, Germany)

A pig which was developed particularly for pipeline measurement, is the Scout-Scan of Pipetronix. It covers two fields of application:

- Recording of geodetic coordinates and thus the spatial orientation (space curve)
- Recording of deformations, from which the stress on the pipe can be calculated (stress analysis).

The ScoutScan consists of two bodies, connected by a joint. The first body is a tension-force module equipped with sealing sleeves. The second body is led on rollers. The first module contains the power supply and the antenna system for detection in the field, while the second module contains the data recording (gyroscope) and storage unit. A friction wheel (odometer) pressed onto the pipe inner wall measures the distance travelled by the pig.

Detection of Cracks

For the detection of cracks in pipelines, Pipetronix, the Forschungszentrum Karlsruhe (FZK), and the Institut für Zerstörungsfreie Prüfverfahren in Saarbrücken have developed a special pig (UltraScan CD, Fig. 17–12).

The novelty of this pig is the arrangement of the sensors. In contrast to the usual ultrasonic pig, they are not at right angles to the pipe wall but inclined by 45° relative to the pipe wall. The impulses sent at this angle propagate pipe walling in a zigzag fashion, whereby the pulse amplitude decreases with increasing distance.



Fig. 17–12. Crack detection pig (Pipetronix, Stutensee, Germany)

When an impulse meets a crack, it is partly reflected. From the running time the device can locate the damage, and the amplitude of the reflected signal permits conclusions on the kind and size of the crack. Up to 896 of these sensors thus find cracks which are less than 1 mm deep and less than 30 mm long.

Detection of Leakage

The detection of leakage in pipelines is also required by regulatory authorities. Besides continuous monitoring of operation and differential pressure measurements, detector pigs are used. Especially in large pipelines, it is extremely difficult to detect and locate leakages in the range of 10 to 100 L/h ("slow" leakages). Gases and liquids leaking through small outlets generate noises in the ultrasonic range which can be detected by highly sensitive microphones built into pigs. With the pig developed by the company Maihak the signal level due to the leak noise is recorded with the running time and additional marker signals, so that an accurate localization of the leak is possible.

The leak detector pig is driven by means of sealing sleeves and product, but is guided by rollers in the pipeline, so that only low inherent noise is generated.

Visual Inspection

Visual inspections in pipelines are predominantly accomplished by means of video technology. Together with electronic storage and image processing, this is a very reliable and informative technique. Cameras with color, black-and-white, and infrared technology are available for application in explosion-hazard areas. Either the signal is carried by a cable or the information is recorded. Storage on disks or CD-ROMS is possible; for evaluation, video prints in photo quality can be created.

Channel Inspection

This technique is particularly well known in sewage engineering. Due to the large nominal sizes which are often encountered in sewers (e.g., inside diameter of 2800 mm), self-propelled camera vehicles are used. Pulled devices and devices pushed by rods are also used. The limits to the definition pig (sealing body with propellant) are reached here. Many channel and pipe cleaning and renovation companies now offer video inspection.

Speed-Controlled Pigs

An interesting development is the variable-speed pig (Apache Industries). By means of a remote-controlled variable screen, the flow through a bypass in the pig is reduced or increased, and the speed of the pig thus controlled. Actual speed and desired pig speed are recorded. Applications are above all for speed-sensitive inline-measurements with smart pigs, which should have constant speed (gas pipelines).

17.4.3

Gel Pigs

Pigs do not necessarily have to consist of a solid. Substances with a higher viscosity than the product can also be used as pigs. The condition for the application of such a substance, which is directly in contact with the product, is chemical compatibility and insolubility. The plug often consists of a gel-like mass and is called a gel pig.

These gel pigs are pumped in lengths of several meters, without or with one- or two-sided limitation by mechanical pigs, through the long-distance pipeline. This special method is particularly suitable to ensure the separation of different products with changing pipe diameters.

17.5

Pig Launchers and Receivers

Pig launching and receiving stations for pipelines are also pig loading and unloading stations and due to their size have more character of an air-lock. They can be mobile (pigging of a construction section) or fixed in the pumping (compressor) station of the pipeline. Contrary to industrial pigging units the pig is often introduced during product pumping.

The pig station essentially consists of a cylindrical part for loading the pig (see Fig. 17–13), which is lockable on one side by a sturdy locking cap. On the other side a conical part acts as an adapter for the inside diameters of inlet and pipeline. Between conical part and the start of the pipeline is a separating valve. The locking

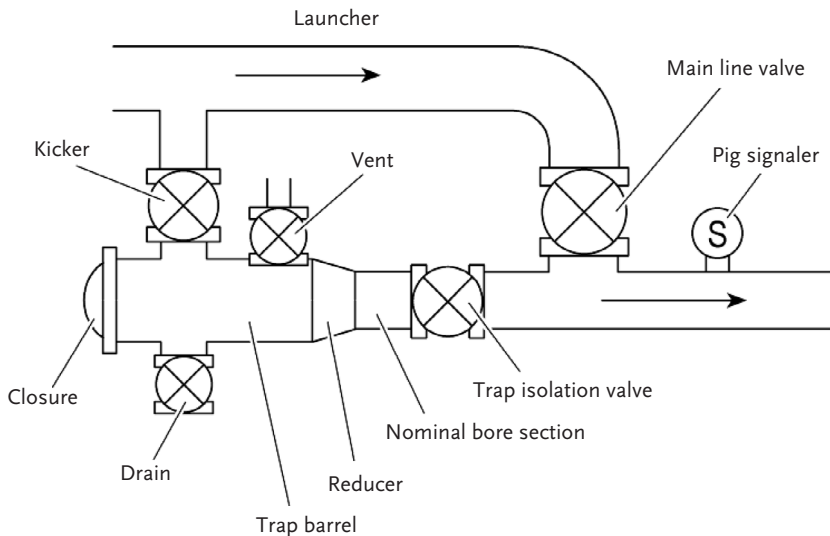


Fig. 17–13. Launching station for pipelines

cap is usually equipped with a safety lock and a hydraulic turning device. Opening of the launching trap is only possible in a pressure-free state.

The pig loading cylinder for the pig has opposite oversize relative to the pipeline (see Table 17-6).

Table 17-6. Approximate oversize values for pig loading cylinders

Diameter range		oversize
< 10"	(< DN 250)	2"
12"–26"	(DN 300–DN 660)	4"
> 28"	(< DN 700)	6"

With large pigs an eccentric cone part with an insertion vehicle or an additional centering facility (guide bars) is used. Several pigs can be arranged in a basket with glide rails.

The separating valve and/or an air-lock slide valve separates the pig station from pressure and flow of the pipeline. Further pipe connections at the pig station serve for flooding, relieving, and emptying.

For inserting and removing large pigs a chain hoist or a hydraulic crane is required.

In dimensioning the pig loading cylinder, the use of very long pigs must be considered, i.e., a certain excess length is practical. With use of modular pigs (e.g., pig with articulated connected measuring and battery parts) extremely long cylinders are necessary. The axial free space between the longest pig and the sealing cap should be on the dimensions of the diameter.

In multiproduct pipelines the individual products are separated by pigs. Such a multiproduct pipeline can be operated economically only if the boundaries of the batches are recognized accurately. Mixing and buffers between two incompatible products can be avoided if separating pigs are used (batch pigging). For this function, besides the usual separating pigs with two sealing sleeves, also spherical pigs are used. An automatic transfer unit with a magazine for ball pigs is shown in Fig. 17-14.

Even more than with the launching station attention must be paid to sufficient length at the receiving station, where the pig exits and comes to a stop.

The pig loses its speed as soon as its last gasket enters the conical section of the receiving station. Without drive it is rapidly braked by the exhaust-air throttle and stopped. It must then be ensured that the back of the pig is no longer in contact with the separating valve, so that the valve can be safely and completely closed.

For emergencies it is even practical to dimension the station for loading two pigs at the same time. Then when the first pig is stuck another pig can be used to free it.

Before the procurement of a receiving station for a pipeline, the dimensions (lengths) of commercially available inspection pigs should be clarified first.

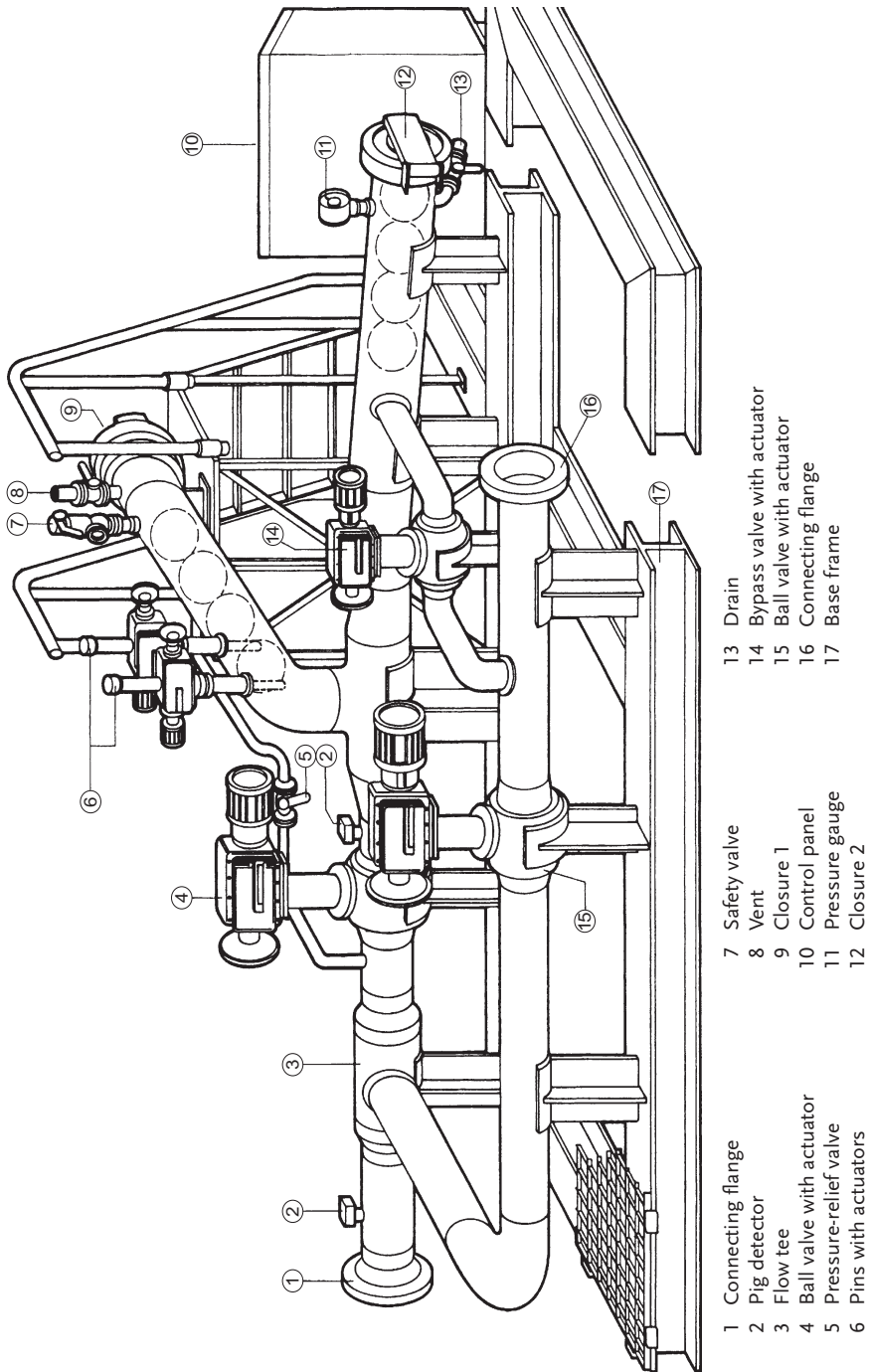


Fig. 17-14. Launching station for ball pigs

18

Pigging of Pneumatic Conveying Lines for Bulk Materials

18.1

Pneumatic Conveying of Bulk Materials

Pneumatic conveying is often used to transport bulk goods like pellets, granulates, and powders through a pipe.

In pneumatic conveying the bulk material flows together with the conveying medium (propellant) in the same pipe. When different bulk materials are conveyed in the same pipeline the same problem arises as in the case of the transport of liquids: contamination of a product by residual amounts of its predecessor must be minimized for quality reasons, i.e., the pipe must be cleaned. Cleaning is complicated by product residues that adhere due to electrostatic charging. Pipes with smooth inner surfaces and dead-space-free valves and flanges are used in accordance with criteria similar to those for a piggable pipe for liquids. With regard to centering of flange connections and the supports and fixing of the pneumatic conveying line, the same criteria apply as for a pigging line.

The residual bulk material that remains in the line after product conveying is usually removed by blowing out. However, dust, which sticks on the pipe walls due to electrostatic charging can not be completely removed in this way. When another product is conveyed, this coating is removed by the new product. Thus, the first part of this product is contaminated, and this leads to quality losses. With colorants this can lead to the complete product loss due to contamination with another color.

Wet cleaning, i.e., flushing with water, is very expensive and requires a lot of equipment; in addition, the line must be dried, and the wastewater must be disposed of.

In general, bulk material lines are piggable with special pigs. The propellant and the energy source (air compressor) for driving the pig are already present in most cases.

The propellant for the bulk material and for the pig is mostly compressed air. The use of inert gases like CO₂, N₂, or argon is required in hazard areas to avoid dust explosions or to avoid oxidation of the bulk product.

There are probably several thousand different bulk materials that are pneumatically conveyed.

Some examples of common bulk materials follow:

Plastics	Polyester pellets (PET) Polystyrene (PS) Polyethylene granules (PE) Polypropylene (PP) Polyamide (PA)
Chemicals	Nitrates, phosphate, carbon black
Foodstuffs	Wheat, barley, corn, rice, soybeans, rape, milk powder, coffee, cocoa, sugar, malt, semolina, flour, baking powder
Wood	Sawdust, saw flour
Cement	Cement, stone powder
Animal feed	Fish meal, grain, grist
Paper	Paper pulp, kaolin
Minerals	Oxides, mineral salts, coal dust, alum clay, aluminum hydroxide

18.2

Structure of Pneumatic Conveying Systems

18.2.1

Basic Structure of Pneumatic Conveying Systems

A pneumatic system for bulk material conveying is shown schematically in Figure 18–1.

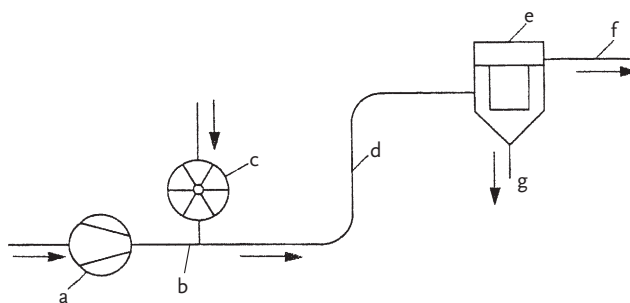


Fig. 18–1. Basic structure of a pneumatic conveying system.

- a) Propellant supply,
- b) Propellant line,
- c) Bulk material feeding (rotary valve),
- d) Pneumatic conveying line,
- e) Separator,
- f) Exhaust-gas line,
- g) Bulk material outlet.

Propellant Supply

The following equipment has proved suitable for pneumatic conveying:

Low pressure	Fan	up to 0.15 bar g
Medium pressure	Rotary blower	up to 1 bar g
High pressure	Compressor	up to 6 bar g

Generally the air must meet the following requirements: clean at the inlet of the blower, below a maximum temperature (sometimes a heat exchanger is needed), limited residual moisture content, no water (condensate), oil-free. The dew point must not be attained in the course of the system. Air flow rate is controlled by a gauge orifice or a Laval nozzle.

Propellant Supply Line

The propellant supply line is the connecting line between the blower unit and the bulk product feeder. Often the compressor is located outside of the process building (noise control), so this line can be quite long.

Bulk Transfer into the Pneumatic Conveying Line

Usually the bulk material is under ambient (atmospheric) pressure before and after conveying. During conveying the pressure in the line will be higher (pressure system) or lower (vacuum system). To transfer the bulk product into the conveying line a specially designed device, is needed (e.g., feed shoe or rotary valve).

Modes of Pneumatic Conveyance

Pneumatic conveying system can be classified as positive-pressure and negative-pressure (vacuum) systems, and there are two basic modes of conveying.

The *dilute phase* is the classic mode of pneumatic conveying. A high-velocity air stream (ca. 20–30 m/s) distributes the bulk product as a suspension almost uniformly over the pipe's cross section. The free-fall velocity of a single particle is less than 10 m/s. The pressure drop in dilute-phase flow is similar to that of a pure air stream.

In *dense-phase* conveying the bulk material moves as a bed along the bottom of the pipe (plug, dune, or slug flow).

The transition between these two phases is an unsteady state.

Conveying Line

The materials for pneumatic conveying lines are carbon steel, stainless steel or aluminum.

The diameters are specified by ISO; usually outer diameters are 60, 76, 88, 101, 114, 139, 168 mm, with wall thicknesses of about 2.6 and 6 mm, the gauge pressure is up to 6 bar (see Table 18–1).

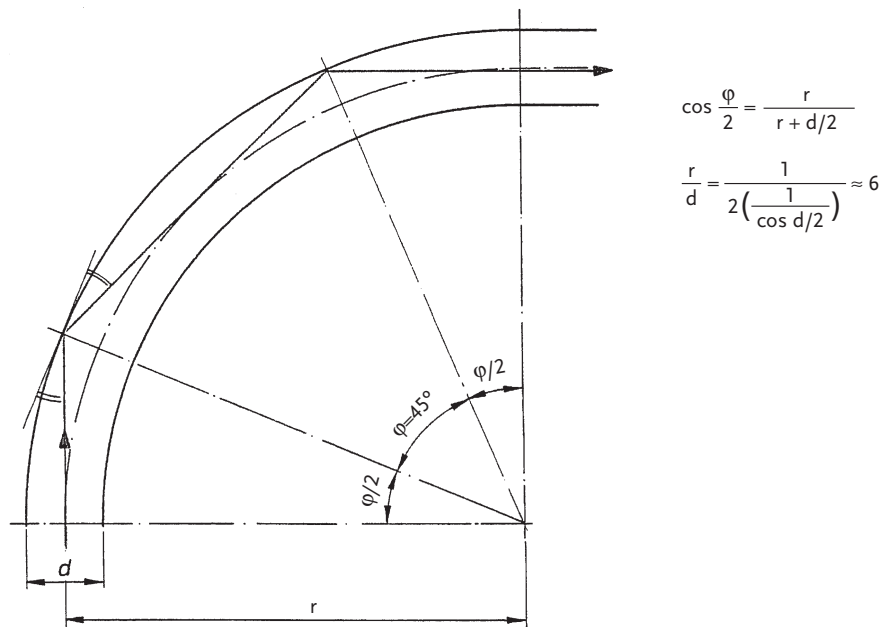
Table 18–1. Dimensions of pneumatic conveying lines

Outside diameter, mm	Inside diameter, mm	Wall thickness, mm
48.3	43.1	2.6
60.3	54.5	2.9
76.1	70.3	2.9
88.9	82.5	3.2
101.6	94.4	3.6
114.3	107.1	3.6
139.7	131.7	4.0
168.3	159.3	4.5

Pipe Bends

The bending radius to diameter ratio (r/d ratio, see Section 5.3.1) must not be less than 6.

While the bend geometry is not usually a problem in dense-phase conveying, in dilute-phase conveying this ratio is important. Consider a particle impinging on the inner pipe and acting as an idealized elastic body. Since the angle of incidence is equal to the angle of reflection, for two points of impact $r/d=6$ (see Fig. 18–2).

**Fig. 18–2.** Theoretical calculation of the minimum r/d ratio

Often pipe bends are installed with bending radii of 500, 1000, 1500, and 2000 mm; they all result in ratios greater than 6 in most cases. With polymer pellets, which form threads on sliding along the pipe inner wall, which can melt pellet corners, large bending radii are less favorable.

Flanges

For optimized pneumatic conveying, the pipe must be as smooth as possible. Inappropriate circumferential welding seams and disoriented flange connections would damage the bulk product and lead to wear of the pipe. Therefore, the pipes are connected with centered flanges. The welded lap joint has the benefit that the pipe sections are turnable and installable in any order one against the other.

Figure 18–3 shows a positive-centering flange according to DIN 2248 (welding flange) or with a lapped joint.

Both flange types produce a gap with a depth equal to the pipe wall thickness and the width of the compressed gasket.

The gaps at the flanges must be kept as narrow as possible by special dead-volume free design, so that the dust cannot settle into the gaps and cannot be removed by the pig. Fig. 18–4 shows such flange, which was used successfully in a plant.

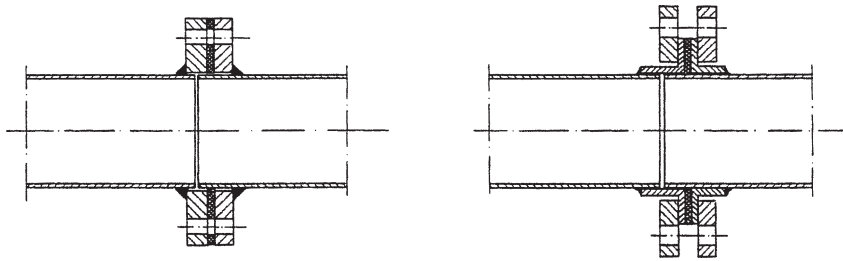


Fig. 18–3. Flanges for conveying lines

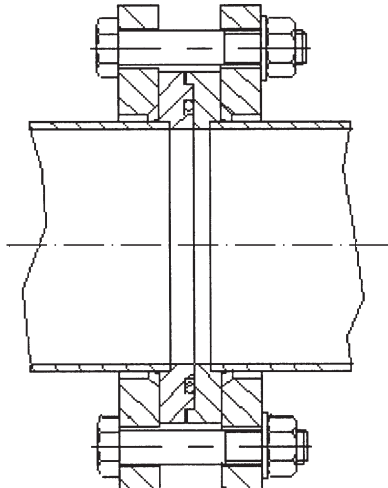


Fig. 18–4. Centered flange (with a short stub end) and an O-ring seal

Conveying Pipe Switches

Similar to piggable lines for liquids pneumatic bulk conveyor lines needs diverter valves at branches. Their design the principle is shown in Fig. 18–5.

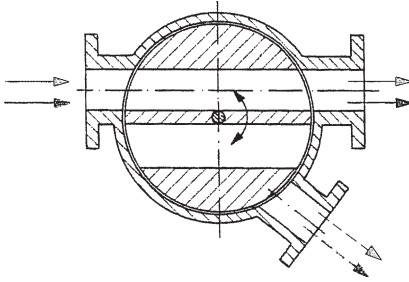


Fig. 18–5. Diverter valve

Here the turnable plug has two eccentric, parallel holes; inlet and outlet are angular, like a segmental elbow. The actuator turns the plug by 35° to connect the incoming pipe with the outgoing pipe. Distribution over several outgoing lines is possible by serial connection of several switches.

Manifolds (modular and rotary types) are also available for pneumatic conveyor lines.

In contrast to normal pigging systems the switches in pneumatic conveying lines usually have a pipe knee in the branching line (Fig. 18–6). This region is well cleaned by the flexible pig since the shape of the pig adapts to the pipe. Also, the flexible pig easily passes this valve.

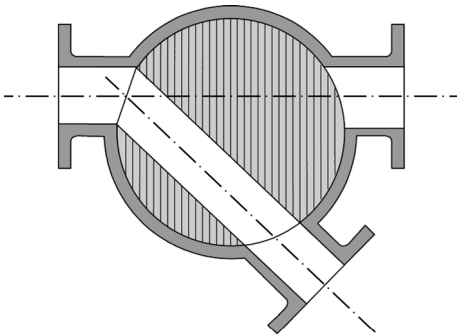


Fig. 18–6. Switches for bulk material conveying lines

A special design is a 90° switch, which can be installed directly on a silo. Thus the lines which cannot be pigged can be kept very short in a design with a pig receiving station. Such a concept makes sense if only one color is stored in each silo and the colors change to lighter tones with increasing number of traversed switches.

Bulk Product – Propellant Separation

At the end of the pneumatic conveying line the bulk product must be separated from the propellant in order to feed only the bulk material to its destination (silo,

hopper, car or ship) and discharge the air to the atmosphere (air vent line). Therefore, a separator or a dust trap is needed, e.g., a cyclone or a separator with a filtering element.

18.2.2

Structure of a Pigging System for Bulk Conveying Lines

In addition to an inlet and one or more outlets a pigging system for a bulk materials conveying line needs launching and receiving stations for cleaning the pipeline (Fig. 18–7).

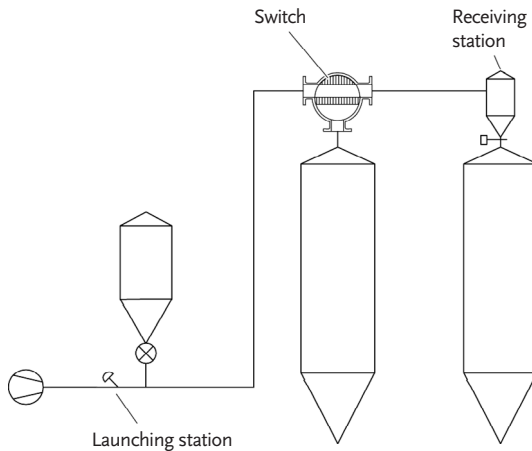


Fig. 18–7. Basic structure of a piggable bulk materials handling system

The cleaning requirements determine the location of the pig launching station at the beginning of the conveying line. If the launching station is located before the feed shoe under the rotary valve, then the pig must pass through the feed shoe, which is a wider pipe section. Hence, complete cleaning of the feed shoe is not possible. This part of the system is then cleaned by hand.

The positioning of the receiving station (simply a tank) on the last silo as in Fig. 18–7 represents one possible design of a piggable system. Several receiving stations are also conceivable, if each color is assigned to a certain silo and the conveying line must be cleaned up to the silo inlet. The pig receiving station can also be located at the base of the silo, in order to avoid long paths in the plant.

As propellant compressed air is used. With dilute-phase conveyance compressors up to 4 bar are used. The available pressure for the transport of the pig is then max. 3.5 bar. Due to the pig design this is sufficient to transport the pig over long distances. For longer distances the necessary air pressure rises accordingly. Then an air supply with higher pressure is necessary for pigging.

The pig launching station is installed before or after the product feed, which is usually a rotary valve (Fig. 18–8).

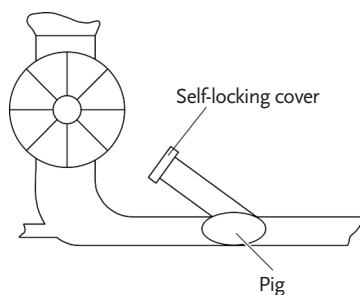


Fig. 18–8. Pig launching station

The pig feeding pipe is designed to avoid backflow of product during conveying. After opening the cover in the pressure-relieved condition the pig is pushed into the line. After closing the cover the air blower is switched on and the pig run starts. For safety reasons the cover is designed in such a way that it cannot be opened if the system is under pressure. The section before the piggable line is cleaned manually.

The receiving station for the pig can be of two different types (see Fig. 18–9):

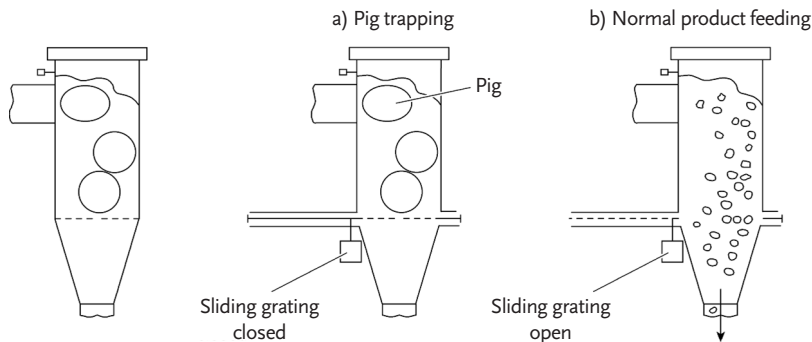


Fig. 18–9. Structure and function of different receiving stations

The simplest solution is a fixed grating to trap the pig in the receiving station. This design is suitable for bulk materials that do not form fluff or threads during conveying. The other design has a sliding grating which is pulled out of the receiving tank during normal conveying. During the pigging procedure, the grating is pushed into the receiving tank. In both cases the cover of the receiving tank is provided with a safety device, so that it can be opened only in the pressure-relieved state. A detector can be used to switch off the blower automatically after arrival of the pig in the receiving station. The pipe is then relieved. If several pig travels are necessary for cleaning, then the next pig can be inserted into the line. After the last cleaning step the pig can be unloaded from the receiving station.

To reduce noise and the forces on arrival of the pig in the receiving tank, the pipe is attached tangentially to the tank. This arrangement also results in lower stress on the product on arrival in the receiving tank.

18.3

Cleaning of Pneumatic Conveying Lines

18.3.1

Purging

When pneumatic conveying stops the pipeline usually has a residual content of several kilograms per meter. High-velocity air purging, also known as blowing clean, is the most common method for coarse cleaning of the line. The air velocity is about 25–30 m/s.

If the case of dilute-phase conveying, purging is straight forward, and a purging time of several minutes is sufficient. With dense-phase conveying, a larger amount of air is needed to achieve the required air velocity, and in some cases an additional compressor is needed. The time required for the purge procedure depends on the total length of the line; usually a time of 10 min per 100 m is sufficient.

18.3.2

Cleaning Pellets

This method, purging with a cleaning product, is similar to shot blasting and is often used on plastic pellet conveying systems between batches of different color. A quantity of “neutral” product is conveyed at a higher than normal velocity in order to abrade material from the inner wall of the pipe. Although fast, this method is not effective in the dead areas and it is expensive due to the waste material that is generated. Cleaning can be made more complete by extending the cleaning period but lost production time and increased waste add to the cost.

A variation on this method is not to use neutral pellets but to sacrifice some of the initial product after a color change until the contamination drops to an acceptable level. This method is not economical due to the need to recycle the waste.

18.3.3

Wet Cleaning

Wet cleaning means washing the conveying lines and all connected valves and silos. The pipeline is spray-washed using a mixture of water and compressed air. The cleaning effect is very good but the line must then be dried with hot air, which is very time consuming and adds to the energy costs. A quick change of products is not possible with this method and the components of the system (e.g. diverter valves) must be watertight. In cold climates the cost is increased greatly due to need for insulation to prevent freezing. A further disadvantage is that the wastewater may be classified as “contaminated” by local regulations and thus require expensive downstream treatment.

18.4

Pigs for Pneumatic Conveying Lines

18.4.1

Soft Pigs

A soft plastic ball or cylinder is conveyed down the pipe using the purge cycle airstream. The ball dusts the inside of the pipe as it travels along at high velocity and pushes loose material ahead of it to a trap at the end of the system. This method is good for loose dust and is particularly effective at the start of the system, but the cleaning effect declines further along the pipe as the ball becomes laden with material. As a result it may take many balls to thoroughly clean the pipe. The soft ball approach is also ineffective for removing pellets from dead areas and has a risk of contamination, as the soft plastic of the ball can leave residues in the pipe.

Another method of a dry cleaning is using a pig which wipes the dust from the pipe wall. The pig for such applications consists of a soft flexible interior body and a covering of a filter-cloth-like material. The flexible interior body can be a foamed elastomer or a flexible hollow ball. The mass of the pig is deliberately kept low so that the compressors which are used for the pneumatic conveying can also be used for the pig run. As a compressible propellant air accelerates the pig in straight sections to high speeds, which are braked in the elbows. With hard pigs this normally entails substantial forces, which can even destroy the pipe. A flexible pig takes up part of these forces and therefore reduces considerably the loads on the piping. A further advantage of the flexible body is the adjustment of the pig to unevenness in the pipe or to larger diameter pipe sections, such as occur in pneumatic conveying lines. Fig. 18–10 shows such a pig before and after a cleaning procedure.



Fig. 18–10. Soft pigs (Coperion- Waeschle, Weingarten, Germany) before (left) and after travel

When product conveying is complete residual product is removed by air purging. Then, the pig is inserted into the pressure-relieved conveying line and driven by the blower air through the line. By using an air flow control unit the air speed is kept to 8–10 m/s. In the pipe only one pig runs at a time, since otherwise the driving pressure would exceed the maximum pressure of the air blower of 4 bar. As soon as the pig arrives in the receiving station, the next pig can be pushed through the line. Depending on product the procedure is repeated 3 to 4 times.

Test results and feedback from installed systems show that dry cleaning with a pig functions reliably. Residual dust is wiped off from the pipe walls, and granulate still in the pipe is removed.

18.4.2

Turbo Pig

With the introduction of the new Turbo-Molch system, all types of material can be removed from the pipeline, quickly and effectively, without the need for water washing. The Turbo-Molch is a pig that combines a modular brush system combined with a pneumatic purge. The brushes are mounted in ring sections that can be configured in different shapes, hardnesses, and quantities (and therefore lengths) to suit the material and system they are used on. The brush diameter is slightly greater than the inside diameter of the pipe to ensure that the bristles can reach the material in dead areas missed by other dry-cleaning systems.

The pig on which the brushes are mounted incorporates an air-distribution system that serves several functions. A portion of the conveying air is used to give the Turbo-Molch forward momentum, and another portion causes the brushes to rotate, making it especially good for removing dust and threads stuck to the inner walls of the pipe.

For complete cleaning it is essential that the material swept out by the brushes is rapidly carried away in front of the pig, which otherwise could slip over the product and leave it behind, as happens with a soft ball. The pig itself, however, must travel at a low velocity to allow the rotating brushes time to thoroughly clean the pipeline. Too fast and the cleaning effect is reduced.

The air management system combined with the air distribution design of the pig itself allows the Turbo-Molch to travel along the pipe at a controlled speed (2 m/s), while giving a gas velocity of 12–18 m/s ahead of it. The brushing and conveying effect combine to give effective dry cleaning of the pipeline in a fraction of the time needed for wet cleaning.

The complete system includes pig loading, pig removal, material separation and air management. Depending on the frequency of material change the unloading and removal process can be manual or automated. The automated design can give savings in reduced manpower and downtime especially on silo farms where the system has a very short payback period.

The modular design of the Turbo-Molch (see Fig. 18–11) means it is easily adapted and can be configured for most existing pipelines with only minor modifications.

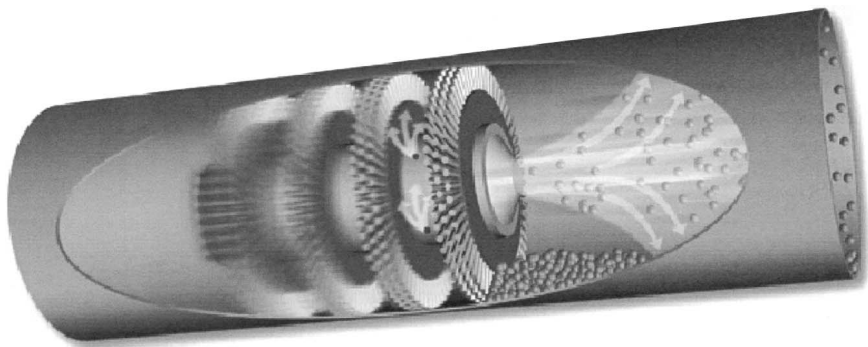


Fig. 18–11. Turbo Pig (Motan Materials Handling, Weingarten, Germany; patent pending)

18.4.3

Notch Pigs

Bulk materials that tend to aggregate and consolidate in a pipe are pigged with compressed air as propellant. Via the notches of the notch pig (see Fig. 18–12) compressed air is introduced into the product ahead of the pig. The propellant thus loosens the material and facilitates its transport without clumping. If the pig sticks nevertheless, then the propellant can still flow over the notches in the pig and loosen up the bulk material sufficiently that the pig can be driven again by the propellant.

Notch pigs are used, e.g., in the food industry for emptying and cleaning of pipes filled e.g. with cocoa powder, baking powder or flour. In notch pigs –permanent magnets can be installed.

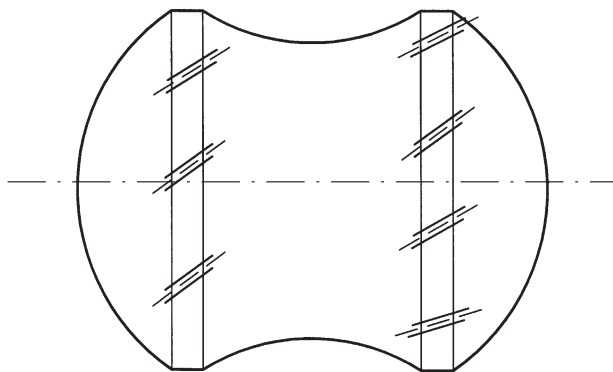


Fig. 18–12. Notch Pig (I.S.T., Hamburg, Germany)

18.4.4

Jet Pigs

The jet pig is a further development of the notch pig. The notch pig is a reliable means of transport for the pigging of granulates and powder lines. In the closed system of an automated plant the return trip of the notch pig can however be problematic, since this pig is suitable only for unidirectional travel.

The jet pig is bidirectional (see Figs. 18–13 and 18–14) and operates like the notch pig, but it has an integrated check valve for the propellant. In forward pigging this valve lets the propellant flow into the product, and in reverse pigging the valve closes the passage for the compressed air. Thus, the jet pig has a wider range of application than the notch pig.

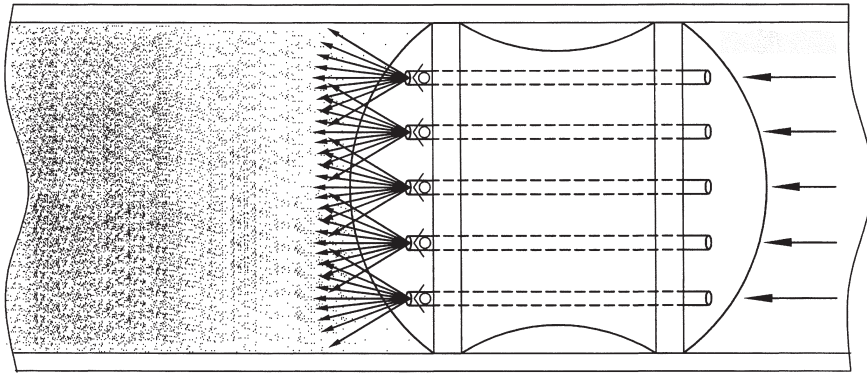


Fig. 18–13. Jet pig with check valves, forward pigging with bulk material of filled pipe (I.S.T., Hamburg, Germany).

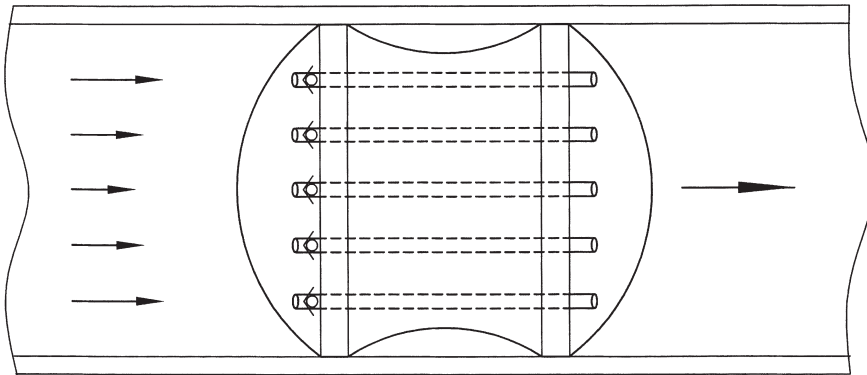


Fig. 18–14. Jet pig, backwards pigging, check valve closed (I.S.T., Hamburg, Germany).

IV

Law and Regulation

19

Legal Requirements

19.1

Laws, Regulations, and Guidelines

Pigging systems in the legal sense are piping systems for conveying combustible or noncombustible, water-endangering liquids or gases, by using the pressure of a propellant. For the design, installation, and operation of pigging systems there are various laws, regulations, and guidelines. In most countries the legal requirements for prevention of accidents, hazards, and ground water contamination are regulated by the respective government. However, the risks due to running a pigging system are more or less the same, independent of national laws.

- Laws and regulations concerning hazards due to gas-pressure or explosions-hazard areas. In Europe the most important are:
 - Pressure Equipment Directive (PED) 97/23/EC
 - Machinery Directive 89/392/EC
 - Directive for equipment for use in potentially explosive atmosphere (ATEX 100a 94/9/EC)

Each guideline is transposed into national regulations, which must be obeyed when a plant is operated by a company. These regulations require that the plants be inspected by experts at defined intervals, with documentation. The responsibility for the documentation is delegated to the plant manager and covers both permission and inspection. The inspections which are necessary are documented in the permission document. The nature and extent of the inspection is specified by the officially certified experts of the local surveillance organisations.

- Laws and regulations concerning the protection of ground water
Directive establishing a framework for community action in the field of water policy 2000/60/EC. In Germany the European Directive is transposed into national law as the Federal Water Act of May 3, 2000 (Wasserhaushaltsgesetz: WHG).
- In addition there are various guidelines prepared by national expert committees, in Germany; for example:
Regulations for the prevention of accidents of BG Chemie:

VBG 15 Welding, cutting and related procedures

VBG 16 Compressors

VBG 61 Gases

The guidelines of the BG Chemie

ZH 1/10 Guideline for the avoidance of dangers due to combustible atmosphere

ZH 1/200 Guideline for the avoidance of danger of ignition due to electrostatic charging

The guideline of the VDMA:

VDMA 24169 Guideline for blowers for the transportation of combustible gas or atmosphere

Each national government is responsible for the transformation of international or national published rules. As far as the authors know, the permission and test obligation of certain components do not differ substantially in the individual regulations.

19.2

Required Permissions and Examinations

Pressure vessels and pipes, require permission and inspection, if there is a particular risk based on their operating time. In most countries the criteria for the risk are product, compressive load, and volume. In the European community regulations concerning pressure equipment are laid down in the PED (Pressure Equipment Directive), which describes the standards for procurement and construction of pressure equipment. Permission is not necessary for operating the pressure equipment, but skilled and trained personnel are required to run this equipment. The manager is responsible for selection and training of the production personnel. He has the duty to provide annual trainee programs and has to document the training method and the participants. For pressure equipment there are two important examinations: inspection before start-up and regular inspections. The extent and intervals of the inspections are regulated in the national guidelines. In addition to the requirements due to pressure hazard (in Germany: TRB), further demands may result from water protection law (in Germany: WHG) or guidelines concerning combustible liquids (in Germany: TRbF).

19.2.1

Pressure Hazard

The Pressure Equipment Directive (PED) applies to pressurised components with a permissible pressure exceeding 0.5 bar (gauge), which are been classified into different categories according to conveyed fluid and parameters like pressure, and nominal size volume in accordance with appendix II of the guideline. Fluids which are handled in pigging systems generally do not have vapor pressures greater than

500 mbar at operating temperature, so that exemplary limits for the applicability of the guideline can be given here. The nominal size of pipes (DN) is given in millimeters, the nominal pressure (PN) in bar g, and the volume in liters (L). Depending on the medium used, the guideline applies if the volume of the vessel or nominal size of the pipe is greater than the value in Table 19–1.

Table 19–1. Scope Pressure Equipment Directive (PED)

Vessels	Fluid Group 1	PN 10	Volume > 20 L
		PN 16	Volume > 12.5 L
	Fluid Group 2	PN 10	Volume > 1000 L
		PN 16	Volume > 625 L
Pipes	Fluid Group 1	PN 10	Nominal Size > 200 mm 8"
		PN 16	Nominal size > 125 mm 5"
	Fluid Group 2	PN 10	Nominal size > 500 mm 20"
		PN 16	Nominal size > 300 mm 12"

Group 1 fluids are classified as follows: explosive, highly inflammable, readily inflammable, inflammable, highly toxic, toxic, fire-supporting. Group 2 consists of all fluids not in group 1.

If a multipurpose pigging system for all fluids is planned, all vessels and pipelines must be suitable for group 1.

Since PN 16 is recommended for vessels, only vessels with volumes greater than 625 L are subject to the requirements of the guideline if neither combustible nor toxic fluids are pigged (group 2).

Industrial pigging units of conventional design do not generally have nominal sizes greater than DN 250, so that for fluids of group 2 the guideline is also not applicable to pipelines. Hence, these components are only designed and manufactured according to good engineering practice (GMP), as valid in the respective manufacturing country, and no CE-label is required. Defining inspection periods and obligations is left to the member states, and in Germany governed by the BetrSichV (Betriebssicherheitsverordnung). This guideline defines additional inspection if the plant causes any hazard that is independent of the scope in the table. In that case the plant manager is responsible for taking measures to prevent hazardous failures.

19.2.2

Ground Water Contamination

Each plant must be designed, erected and operated with regard to protection of the soil and groundwater in the case of damage or leakage. Therefore, consolidation of the soil with materials which prevent wetting when hazardous liquids are liberated is of great importance. Depending on the type and amount of liquid in the plant,

permission and inspection may be necessary. However, pigging units are not run alone, but in cooperation with, for example, a production or storage plant. In most cases it is sufficient to regard the pigging unit in connection with these plants. For more information please contact the experts of the local surveillance organizations.

19.2.3

Explosion-Hazard Areas

The equipment used in explosion hazard areas must be specially designed. The regulations for such equipment vary slightly in different parts of Europe and the world. In Germany, for example a pigging unit is regarded as a piping system and therefore, because the hold-up over 24 h is not so large, no permissions or inspections are necessary. The technical rules laid down in the TRbF must be obeyed for designing and operating the unit. The components of the unit, such as equipment and protective systems, intended for use in explosive atmospheres, show a wide range of variety. If there is any possibility that a potentially explosive atmosphere can occur in the operating range, equipment which is not capable of causing ignition should be used. In each case the plant manager has the obligation to evaluate the risk of using the equipment and is responsible for safety as a whole.

20

Safety and Occupation Health

Every plant must be dimensioned and operated according to the valid rules of technology in such a way that employees and third parties are not endangered. A summary of the laws, technical rules, regulations and guidelines to be observed here is given in Chap. 19. The three main causes and sources of danger are:

- Kinetic energy of the moving pig
- Pressures and/or pressure peaks caused by the propellant
- Explosive vapor air mixtures occurring while pigging combustible liquids with air

20.1

Kinetic Energy of the Pig

Due to their high speeds, pigs have a high kinetic energy. If they strike an obstacle without braking or if they shoot out of an open part of the plant, significant damage can result. Especially with open ends, very high speeds can be reached (according to calculations, ca. 100 m/s). However, open ends occur only in the testing mode or for maintenance and then are specially secured. Due to the relatively large mass, the kinetic energy is approximately 1–2 times that of a rifle bullet.

During pigging of combustible liquids with air, the pipe must be closed during removal of the pig. The vapor–air mixture possibly emerging from the outlet must not endanger the staff and third parties. The strength of the pipes and valves must be sufficiently high to exclude permanent deformations. Due to the high hazard potential the pig must be driven in a closed system and removed only by means of special valves. Open pipes are not permissible; they must be secured by valves, blind flanges, couplings, safety locks, etc. Particularly in the designing the loading and unloading stations, the high kinetic energy must be taken into account.

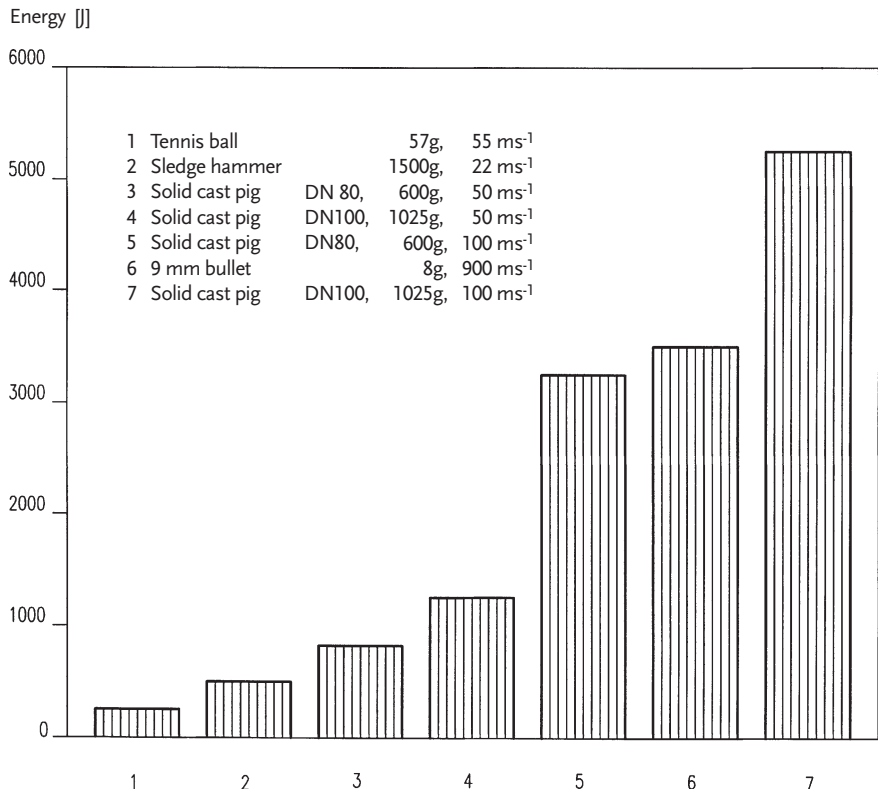


Fig. 20-1. Comparison of kinetic energies

20.2

Energy of the Propellant

The pipeline components, fittings, and components are generally dimensioned, for reasons of erosion resistance and dimensional stability, such that they can also bear the pressures generated by the propellant medium. Working pressures of 4–5 bar (gauge) are used with gaseous propellants. Since these pressures are usually achieved by reduction of a higher pressure stage, it must be ensured that, during failure of the reduction device, the system is not inadmissibly loaded. This may require the application of a safety valve, if a pressure-relief path is not constantly open. Note, that pigs, due to their over-size and their shape can act as effective pressure locks. *Parts of the plant that are possibly under pressure should not be opened without pressure relief.* This plays a role in the regular inspection of exhaust air systems, when products are handled which can lead to sticking or sealing of pipes, especially when the exhaust air system is provided, for example, for reasons of cleaning with a stop valve, which can interrupt the open connection to the pressureless environment. The case of the failure of the reduction station must also be considered.

With liquid propellants, pressures substantially higher than the 5–6 bar with gases can occur. This can be due to the more strongly dimensioned pumps or the incompressible nature of liquids. An enclosed liquid causes a much larger pressure increase than a gas when the temperature rises. However, the most important but often greatly underestimated consequences of the incompressibility of liquids is the pressure peak (water hammer) that occurs during sudden braking of the moving liquid, e.g., by closing a valve. Joukowsky (1847–1921) first found an analytical solution for the case of frictionless flow in an infinitely long pipe and impact on a closed end, which today bears his name. In pigging systems, pressure peaks of this kind can essentially occur with two operating conditions:

1. A liquid propellant drives a pig against a valve that lets product through but stops pigs.
2. An emergency shut-off valve, as is used with loading, for example, of tanks or ships, closes while product is being conveyed or pigged.

Flowing liquids have kinetic energy due to the moving mass. If the liquid in the pipe is decelerated to approximately zero, a pressure peak builds up due to the mass forces. Since the deceleration, due to the finite closing times, does not take place immediately, and both the liquid and the pipe wall show elastic behavior, the pressure peak is not infinitely high. However, the pressure can reach a value high enough to destroy pipes or valves. The following example shows the orders of magnitude that can be expected:

Example:

In a 2" austenitic pipeline (DN 50) with a pipe wall thickness of 2.6 mm oil is pumped over a distance of 200 m, at a speed of 7 m/s (corresponds to a flow rate of 60 m³/h). An emergency shut-off valve interrupts the filling in the case of unintentional displacement of the transport vehicle.

The maximum pressure reached is 75 bar after Joukowsky, and the maximum final pressure is independent of the length of the pipeline. The pressure of the shock wave is thus remarkably high. With a speed of sound of 1200 m/s, the shock wave needs only 160 ms to pass through the 200 m long pipe. After this short time, the whole pipe is under pressure. Since the closing time of the valve of ca. 100 ms lies below this value it essentially does not lower the value of the maximum pressure. With longer closing times, the pressure can dissipate more readily by transformation of kinetic energy, as in a throttle, and the pressure is thereby reduced. Figure 20–2 shows the final pressure as a function of closing time for above example.

$$K \quad \text{Compressibility modulus of the Fluid} \quad = \quad 1.5 \cdot 10^9 \text{ N/m}^2$$

$$K_2 \quad \begin{array}{l} \text{Compressibility modulus of the system} \\ \text{Fluid/wall considering the elasticity} \\ \text{of steel} \end{array} \quad = \quad \frac{K}{\left[1 + \frac{K \cdot D}{E \cdot s}\right]} = 1.3 \cdot 10^9 \text{ N/m}^2$$

$$E \quad \text{Modulus of elasticity in tension} \quad = \quad 200\,000 \text{ N/mm}^2$$

Peak pressure [bar]

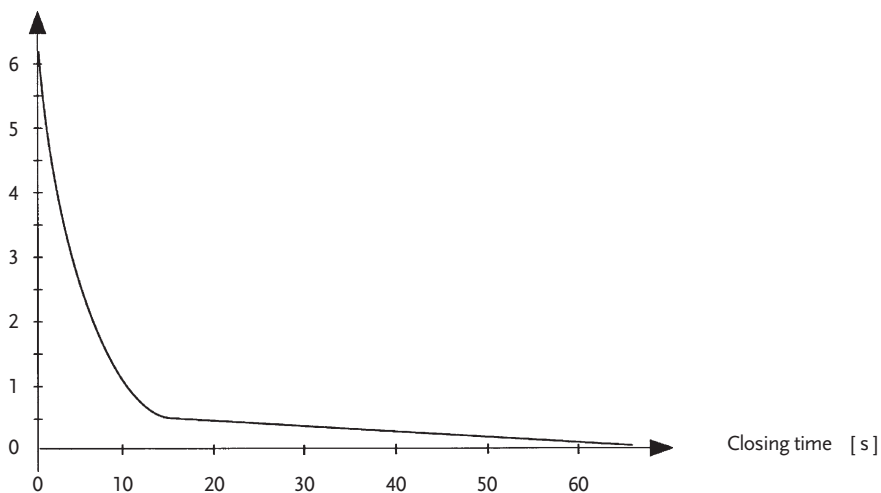


Fig. 20-2. Peak pressure as a function of valve closing time

D inside diameter of pipeline = 55.1 mm

s wall thickness of pipe = 2.6 mm

a shock wave velocity = $\sqrt{\frac{K_2}{\rho}} = 1199 \text{ m/s}$

ρ fluid density = 900 kg/m^3

p_J Joukowski pressure = $v \cdot a \cdot \rho = 75.5 \text{ bar}$

v flow velocity = 7 m/s

For a pipeline dimensioned in nominal pressure PN 10, as recommended in Section 5.3.1, the nominal pressure in this example would be greatly exceeded and damage to be expected. That this is not so is shown by the so-called boiler formula used for dimensioning cylindrical hollow bodies (Eq. 20-1)

$$s = \frac{(D + 2 \cdot s) \cdot p}{20 \cdot K / S + p} \quad \text{where} \quad \begin{array}{l} K = 235 \text{ N/mm}^2 \text{ (steel)} \\ S = 1.5 \end{array} \quad (20-1)$$

D [mm]

s [mm]

p [bar]

A pipe of the considered dimensions would therefore withstand a pressure of 110 bar. Independently, the maximum pressure must be clarified with the manufacturer. In particular, attention must also be paid to flange connections and gaskets since in the case of a pressure peak, leakage is most likely there.

20.3

Definition of Explosion Hazard Terms

20.3.1

Ignitibility and Ignition Temperature

Ignitibility

Apart from the presence of oxygen, the criterion for the formation of explosive mixtures is primarily the flash point. Only when a liquid is heated near the flashpoint can sufficient amounts of combustible vapors develop. In unheated plants, this applies to all materials with flash points below 25 °C. If pipes can be heated by the sun, this temperature difference must also be considered. The flash point is specific to each liquid and can be looked up in safety data sheets. Flash points of common solvents are given in the appendix. For the development of vapors, it is not significant whether the liquid is water-soluble or not. In the following, each liquid is to be regarded as combustible whose temperature is near the flash point, particularly if the pipeline is heat-traced. Temperatures at least 5 K below the flash point are regarded as harmless.

Ignition Temperature

In the presence of oxygen, when the ignition temperature is achieved, the mixture catches fire spontaneously. Ignition temperatures are not achieved under normal operating conditions. However, when welding product-filled pipelines, it must be ensured that the ignition temperature is not reached. The ignition temperature can be achieved in gas-filled systems without an outside ignition source. This is the case, if due to a closed valve, the vapor air mixture is compressed. Since, due to the low volume, compression occurs very quickly, a process without calorific loss (adiabatic change of state) can be assumed. If an explosive vapor air mixture is in a pipeline and can be compressed, e.g., by the ambient pressure to a final pressure of 4 bar (absolute), the temperature may rise from 25 °C to 170 °C, assuming ideal gas behavior (see Table 20–1). The temperature of the total system is generally assumed to be 40 °C. If no spraying occurs, vapor air mixtures are not explosive, if the saturated vapor concentration is below the lower explosion limit (LEL). This is generally the case when the product temperature is at least 5 K below the flash point. Depending on the product, the concentration limits vary. Hence the probability of ignition can be limited by suitable choice of the system parameters. For example, for an initial temperature of 40 °C and a pressure of 5 bar, a heptane air mixture would ignite.

Table 20–1. Maximum temperature T_2 starting from 1 bar for two initial test temperatures T_1 and two final pressures p_2

Final pressure p_2	Initial test temperature	
	$T_1 = 298 \text{ K (25 °C)}$	$T_1 = 313 \text{ K (40 °C)}$
$p = 4 \text{ bar g}$	$T_2 = 443 \text{ K (170 °C)}$	$T_2 = 465 \text{ K (192 °C)}$
$p = 5 \text{ bar g}$	$T_2 = 472 \text{ K (199 °C)}$	$T_2 = 496 \text{ K (223 °C)}$

20.3.2

Explosion Protection of Environment and Off-Gas

Around openings in a plant, an area is defined within which special precautions are taken against ignition sources, due to the probability of the occurrence of combustible mixtures. According to TRbF 100 (German regulations for flammable liquids), zone 1 covers ranges, in which explosive atmospheres can be expected to occur occasionally. Equipment plants and components in which the occurrence of ignition sources is to be expected must be designed explosion-proof. Zone 2 covers ranges in which explosive atmospheres occur rarely and then only for short times. Zone 2 covers ranges in which explosive atmospheres occur rarely and then only for short times. For example, for valves in buildings, zone 2 extends horizontally 3 m towards the floor. With regard to explosion protection, it must always be considered whether cleaning procedures with combustible solvents are carried out, even if otherwise no combustible liquids are handled. The waste-gas system is not usually considered in as much detail in the total plan as the components of the piggable pipelines. Waste gas includes vapor in piggable pipes, which is driven out of the pipes by the pressure of the propellant. The exhaust gas must be removed safely. If subsequent treatment of the exhaust gases is required, the risk of ignition in the waste-gas system must be considered. Vessels and machines for the generation of vacuum such as blowers, or for treatment of the exhaust air, such as washers, or thermal afterburning systems, can also be ignition sources. Blowers used in zones 1 and 2 require a certificate in accordance with the guideline for blowers for the transportation of combustible gases and vapors (VDMA 24169, part 1). For the classification of the pipeline explosion zone, the composition of the conveyed mixture is of importance (see Section 20.4.2). If components of the pigging system are exposed to the atmosphere the waste gas system and corresponding vessels that are not explosion proof must be strictly closed. This can be achieved by suitable switching procedures or in individual cases by organizational measures.

20.3.3

Protection against Electrostatic Charging

Wherever two different materials touch and move relatively to each other (friction), separation of charge can occur. It generally leads to a charge surplus on one of the materials. For example, dangerous charges can occur when chargeable liquids flow through conductive or nonconductive pipelines. If both materials are sufficiently conductive, the excess charge is negligibly small, and no hazard is to be expected. Solids, for example, pigs or metals, are termed chargeable if the surface resistance is greater than $10^8 \Omega$ (DIN 5382). Liquids are to be differentiated into single-phase and multiphase. A multiphase liquid is one that carries solid or gaseous components. Electrostatic charging can be caused by friction of the pig on the inner surface of the pipe or by flow processes. In most cases pigs consist of nonconductive synthetic materials, and therefore charging can generally be expected. The decision whether the charges are dangerous depends on the liquid pigged and on the propellant. The main hazard due to electrostatic charging arises when pressurized air drives the pig and flammable liquids are pigged.

20.3.4

Accident Prevention in Explosion-Hazard Plants

Plants in which products which can develop combustible vapors are pigged have to be rinsed before opening, so that no combustible vapor air mixture can develop and employees or third parties are not endangered. Generally, combustible mixtures only develop in pigging units in which pressurized air is used as propellant (Section 20.4). In accordance with VBG 16 § 18 (1) it is also permissible to drive the rinsing procedure with air. In addition measures must be taken for the protection of employees against hazardous materials when components are opened. In each case the design pressure of each section of the overall system must correspond to the maximum pressure which is generated by the propellant supply or other pressure producers. In the following chapter, the above consideration of the presence of vapor air mixtures is treated in more detail. The addressed points are especially to be considered if the pigging unit is submitted to a cleaning procedure. The use of air as propellant applies to over 80 % of pigging systems.

Operational Openings

The opening of valves, pipes or vessels can take place during operation, provided protective measures were met. Operational openings are usually the pig loading or unloading stations, secondly openings for cleaning procedures.

20.4

Ignition Hazard with Compressed Air as Propellant

The use of compressed air for transportation of combustible liquids is not unproblematical. In this case the general safety notes from Sections 20.1 and 20.2 must be observed. If an individual case is studied, combustible liquids can also be pigged with compressed air. The following considerations are to be thus always seen under the aspect of an individual case for the respective total pigging unit. In the following it is assumed that a possibly explosive mixture can be present constantly or for a long-term period in the pipeline. After TRbF 100 3.34 (1) the inside of the pipeline is to be classified as zone 0. Hence, measures must be taken which reliably prevent the occurrence of ignition sources. In zone 0 ignition sources must also be avoided which occur rarely in the case of operational disturbances. The following areas are investigated for the presence of ignition sources:

- Self-ignition due to pressure and temperature
- Actuators and drive units
- Operational openings
- Exhaust-air system
- Electrostatics

The use of nitrogen as driving medium for pigging units is not unproblematical because of the associated danger of oxygen displacement in the room when leakages occur. Since nitrogen cannot be obtained from the net everywhere, compressed air offers a favorable alternative in terms of availability. The propellant supply must under no circumstances be connected to the control air net for actuated valves and must be equipped with a check valve for safety reason (see Chapter 7.1).

20.4.1

Explosive Mixture Properties

The temperature of the overall system is generally assumed to be 40 °C, unless the product is conveyed with cooling and temperature influences from the outside can be excluded. If no spraying can occur, vapor air mixtures are not explosive if the saturated vapor concentration is at the given temperatures below the lower explosion limit (LEL). This is generally the case if the product temperature is at least 5 K below the flash point. Depending on product the concentration limits are different. So the probability of ignitions can be limited by suitable choice of the system parameters. A method of calculation is given in Section 20.4.2. Furthermore, it must be considered that, depending on the pressure of the propellant, self ignition of the mixture can occur if the temperature after compression reaches the ignition temperature of the mixture. If it is possible to reach the explosive range, it must be ensured, that the temperature before compression is sufficiently low (see Section 20.3.1).

20.4.2

Calculation of the Explosive Composition and Volumetric Concentration in a Pipeline

Whenever combustible liquids are pigged with air as propellant, combustible mixtures can form, for example, mixtures with saturated vapor after prolonged standstill of a partially filled pipe. The concentration depends on the ambient temperature.

To evaluate the explosiveness of the mixture it is decisive whether the vapor concentration lies within the explosion limits of the product. The vapor concentration like the lower explosion limit (LEL) and the upper explosion limit (UEL) is given in m^3 product per m^3 total volume (volume concentration).

At the back of the pig, compressed air from the propellant supply line flows. Since the pig does not clean the pipeline completely, a product film remains on the wall.

Here a film of ca. $20\text{ }\mu\text{m}$ is assumed; the actual value naturally depends on the erosion of the pig material. The residual product film liberates product by evaporation. The time required for complete evaporation depends, among others, on the vapor pressure of the product and the flow rate of the propellant. The volume concentration in the pipe behind the pig starts at zero and rises proportionally to time. When the pig reaches the receiving station, the compressed air is generally not turned off immediately, but flows for a further defined time interval. The total reservoir is then pressure-relieved. Depending on the size of this time interval the concentration in the exhaust air will increase accordingly. If the concentration is calculated as a function of the system parameters, then the length of time can be calculated until the concentration reaches the LEL, i.e., the time at which an explosive mixture is present. The results of the calculation can serve as the basis for a change in the system parameters, so that the assignment of the exhaust air system to zones can be limited or even eliminated. It has been shown that the concentration strongly depends on system and product parameters, so that there are possibilities to positively influence the explosion zone classification.

An example for two different products shows that the concentration in the exhaust air can be calculated and the order of magnitude in which the concentration and time interval lie.

Calculation of the Volume Concentration

For the calculation a mass balance in the pipe is set up. The material balance follows a mass-transfer model whose simplifications are listed here:

- The pipe is uniformly wet by a thin film after pigging
- The thickness of the film is ca. $20\text{ }\mu\text{m}$ (empirical value)
- The concentration of the vapor air mixture leaving the pigged pipe after pigging is to be calculated
- The concentration does not change in the exhaust air system
- The thin film evaporates uniformly
- For the evaporation a linear kinetic model is used

- The vapor–air mixture flowing in the pigged pipeline does not contain liquid droplets and flows with uniform speed
- The speed of the pig is much greater than the flow velocity of the gaseous propellant u

Determination of the function $C_v(t)$, i.e., volume concentration as a function of time (see Fig. 20–3):

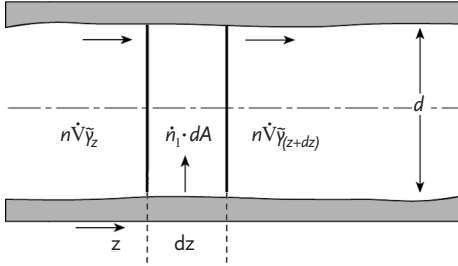


Fig. 20–3. Mass balance in the pipe

d : Inner diameter m

z : Length coordinate m

ν : Kinetic viscosity m^2/s

$\dot{V}$: Volumetric flow rate m^3/s

u : Flow velocity m/s

$C_v(t)$: Volume concentration $\frac{\text{m}^3 \text{ "1" }}{\text{m}^3 \text{ "1" } + \text{m}^3 \text{ air }}$

Re : Reynolds number

Sc : Schmidt number

Sh : Sherwood number

$\tilde{Y}_z$: Molar loading $\frac{\text{mol "1" }}{\text{mol air }}$

$\tilde{y}_z$: Molar fraction $\frac{\text{mol "1" }}{\text{mol "1" } + \text{mol air }}$

Balance for solvent 1 (Eq. 20–2)

$$n \cdot \dot{V} \cdot \tilde{Y}_z + \dot{n}_1 dA - n \cdot \dot{V} \cdot \tilde{Y}_{(z+dz)} = 0 \quad (20-2)$$

Kinetics of mass transfer (Eq. 20–3)

$$\dot{n}_1 = n\beta (\tilde{Y}^* - \tilde{Y}) \quad (20-3)$$

For small loadings Equation 20–4 applies:

$$\tilde{Y} = \tilde{y} \quad (20-4)$$

Relative humidity (Eq. 20-5).

$$\varphi = \frac{p_1}{p_1^*} = \frac{\tilde{y}_{\text{out}}}{\tilde{y}^*} \quad \varphi(z) = 1 - \exp\left[-\frac{4Sh}{Re \cdot Sc \cdot d/z}\right] \quad (20-5)$$

The volume concentration is the ratio of vapor densities (Eq. 20-6).

$$C_v(z) = \frac{\varrho_1}{\varrho_D} \quad \begin{array}{ll} M_1: & \text{molar mass of 1 kg/kmol} \\ p_1^*: & \text{saturation vapor pressure of 1 mbar} \\ R: & \text{universal gas constant kJ/kmol/K} \\ P_1: & \text{vapor density of 1 mbar} \\ T: & \text{system temperature K} \end{array} \quad (20-6)$$

where

$$\varrho_1 = \frac{P_1}{R_1 \cdot T \cdot 10} \quad (20-7)$$

At low concentrations, the vapor can be regarded as an ideal gas. Thus Equation (20-8) follows:

$$C_v(z) = \varphi(z) \cdot p_1^* \cdot \frac{M_1}{\varrho_D \cdot T \cdot R \cdot 10} \left[\frac{\text{m}^3 \text{ of 1}}{\text{m}^3 \text{ air} + \text{m}^3 \text{ of 1}} \right] \quad (20-8)$$

For constant speed u of the gas air mixture, the approximation of Equation (20-9) applies.

$$\varphi(z) \rightarrow \varphi(t) \quad (20-9)$$

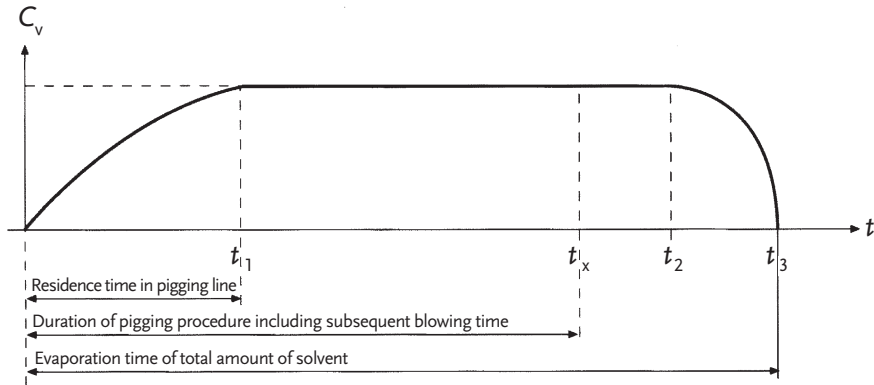


Fig. 20-4. Volume concentration in the exhaust-air pipe

If the total amount of evaporated material 1 is known, the course of the concentration with time can be determined whereby the length of time is considered during which the total solvent film evaporated. The course of concentration with time is shown in Fig. 20-4. It can now be determined whether and for how long the concen-

tration lies within the explosion limits. On this basis preventive measures can be taken. If the saturated vapor concentration at the given temperature is below the LEL, there is no danger of ignition.

Figures 20–5 and 20–6 show the dependence of volume concentration on time, with air as propellant for the common solvents isobutanol and acetone, respectively, for nominal size 4" at an average speed of 3.3 m/s, and a temperature of 25 °C. The concentration of isobutanol in the exhaust air system always lies below the LEL and is thus always in the nonexplosive range. With acetone, the vapor air mixture is within the range in which ignition is possible over a long time interval. The ignition probability could be achieved here by an increase in gas speed or temperature.

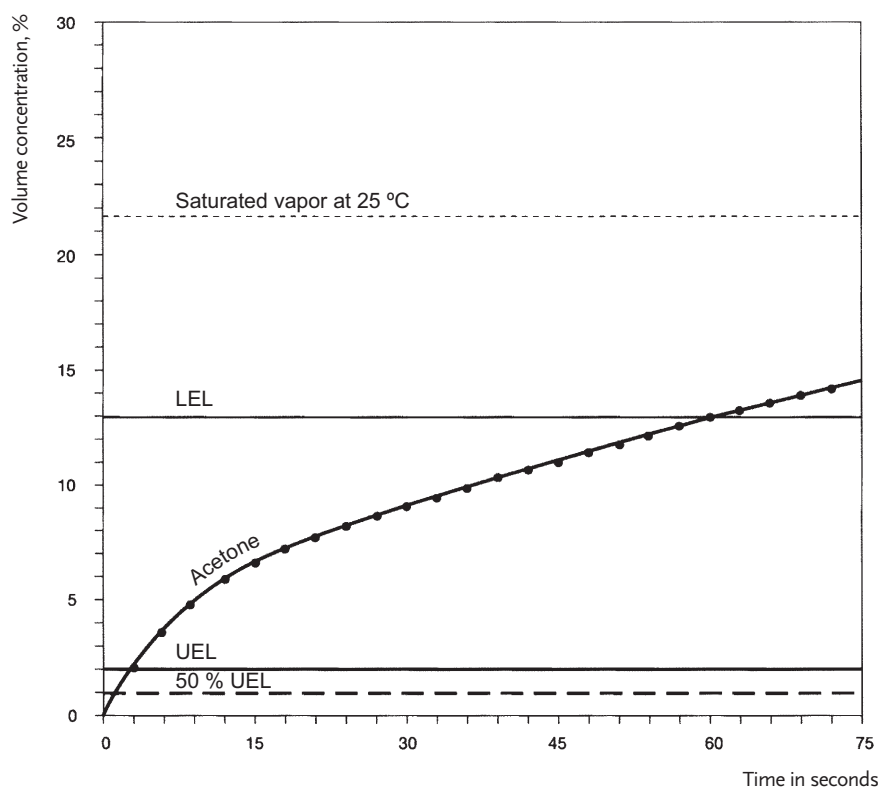


Fig. 20–5. Volume concentration for acetone

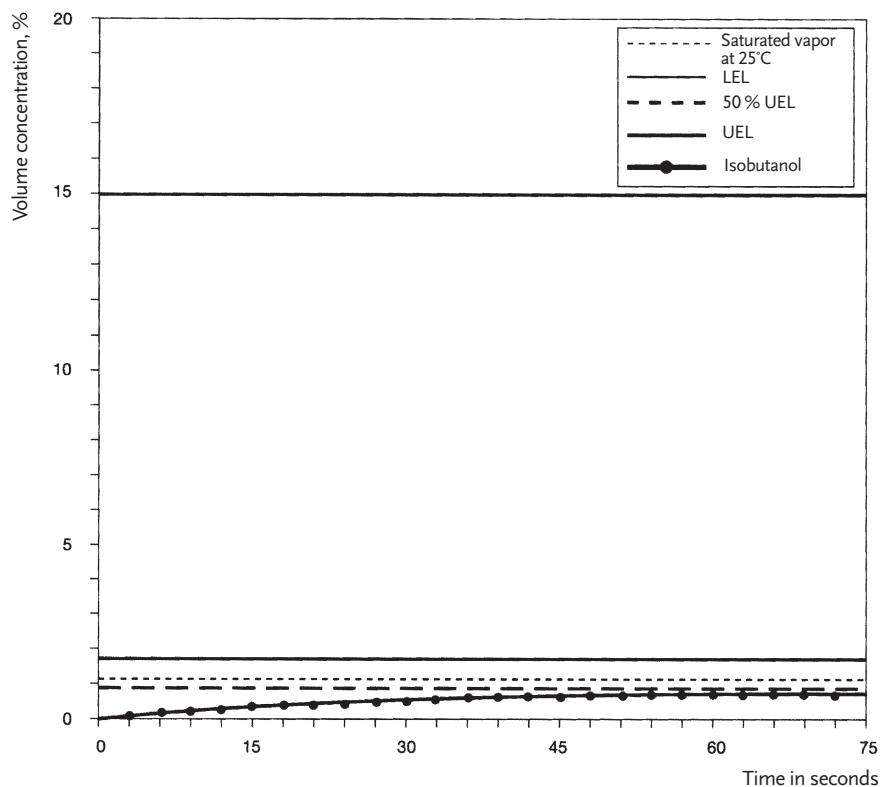


Fig. 20-6. Volume concentration for isobutanol

20.4.3

Electrostatic Charge

The topic of electrostatics was already addressed in Section 20.3.3. With grounded metallic pipes, charging is possible for the following pairs:

- chargeable pig–conducting, combustible liquid
- conducting pig–chargeable, combustible liquid
- chargeable pig–chargeable, combustible liquid

Despite partial wetting the chargeable area of a pig is sufficiently large that it is greater than 25 cm^2 , the size above which measures must be taken according to the guideline ZH 1/200.

Chargeable Pig–Conducting, Combustible Liquid

The application of a chargeable pig in a pigging system driven with compressed air is possible only if the pig itself cannot act as ignition source, i.e., it cannot become charged. This is ensured if the pig drives the conducting liquid before itself and it is

moistened by this liquid. Since the sealing rims are never so tight that the pipe wall is totally dry after cleaning by the pig, the surface of the pig is moistened with conducting liquid and it does not become charged.

Conducting Pig—Chargeable, Combustible Liquid

The layer thickness of residual product on the surface of moistened pig is typically well below 100 µm (see Chap. 10). For liquids of the explosion groups IIA and IIB ignition is generally not expected according to ZH 1/200 7.1.15. The Physikalisch Technische Bundesanstalt in Braunschweig (PTB) evaluates the hazard potential at the product-moistened face as low and recommends the unloading of the pig from the station only with a decoupled system. In the case of doubt consideration of the individual case is suggested.

Chargeable Pig—Chargeable, Combustible Liquid

For this system each case must be examined individually. Materials of explosion group IIC (e.g., carbon disulfide) must not be pigged with air as propellant. The possible ignition sources were discussed above. Apart from the presence of ignition sources, explosiveness of the mixture is of crucial importance. Hence, a method should be sought for calculating the concentration in the pipeline.

20.4.4

Accident Prevention for Equipment

Control Valves and their Actuators

Given the variety of designs and manufacturing companies, the classification of non-electrical equipment (e.g., valves) into classes of ignition probability must be performed in individual cases.

Exhaust-Air System

Equipment especially machines for the generation of vacuum, (e.g., blowers) and treatment of exhaust air, (e.g., washers and thermal afterburning units) can also be ignition sources. TRbF 100, Table 1, defines the number of measures taken against flame breakthrough, according to the explosion zone classification of the pipeline. Blowers used in zones 1 or 2 require a certificate according to the guideline VDMA 24169 (transportation of combustible gas or atmosphere). For the classification of the pipeline into an explosion zone the composition of the conveyed mixture is of importance (see Section of 20.4.2). During pigging with open exhaust air path, valves connected to nonshockproof vessels such as storage tanks or filling stations must always be kept closed. During the opening of piggable valves, the path to the exhaust air system and the connected vessels must be kept closed. This can be achieved by suitable interlocks or, in individual cases, by organizational measures.

20.4.5

Remedial Measures for Hazardous Operating Conditions

If the process cannot be modified to eliminate the explosiveness of the vapor air mixture and ignition sources cannot be excluded, then the air propellant must be replaced by nitrogen. If this is not possible for reasons of supply and economy, then the total pigging system must be examined for resistance to explosion shock.

A system is shockproof if it can withstand an internal explosion without breaking; permanent deformations are permissible. The explosion pressure is material-specific and dependent on the initial pressure at which the ignition takes place in the pipeline or fitting. For an initial pressure of 1 bar (atmospheric pressure) the maximum explosion pressure of liquids or gases can be obtained from relevant tabular data collections (e.g., K. Nabert / G. Schoen, Safety-Relevant Characteristic Data of Combustible Gases and Vapors). It is also permissible to set the maximum final pressure to 10 bar. The highest occurring final pressure arises as a result of multiplication of the explosion pressure by the initial pressure as factor. The exhaust air system (initial pressure $p=1$ bar) is regarded as shockproof when dimensioned to 10 bar (TRbF 120 enclosure 1). If parts of the exhaust air system are not accordingly constructed they must be set up in such a way that in the event of ignition employees or third parties cannot be endangered. The mounting of pressure-relief openings may be required. Pipes used for pigging units are generally shockproof due to their wall thickness. The Physikalisch Technische Bundesanstalt (PTB) in Braunschweig determined on 29 November 1989, that valves from the company I.S.T., up to nominal size 4" are considered to be shockproof if designed for nominal pressure PN 16. For the proof of the pressure strength for larger nominal sizes or fittings from other companies data from the manufacturer is required. According to the PTB, elastic solid cast pigs with a sealing function can act as barriers to an expanding explosion. Other designs, for example lip pigs, do not possess this characteristic, so that in these cases an individual investigation must be carried out. The following section gives a summary of the hazard sources and remedial measures, with regard to inspection of a pigging system by certified experts of local surveillance organizations.

20.5

Evaluation of Operation Safety and Explosion Hazard Classification

The possibilities for hazard elimination listed under "Measures" are to be understood as a starting point for more far-reaching considerations, which in each case are to be coordinated with the responsible expert of the surveillance organization. For example the conductivity of pig material can be changed by admixture of carbon black if the pigged product permits this. In the case of inspection of the plant by experts, the concept can be used for making further decisions (see Fig. 20–7).

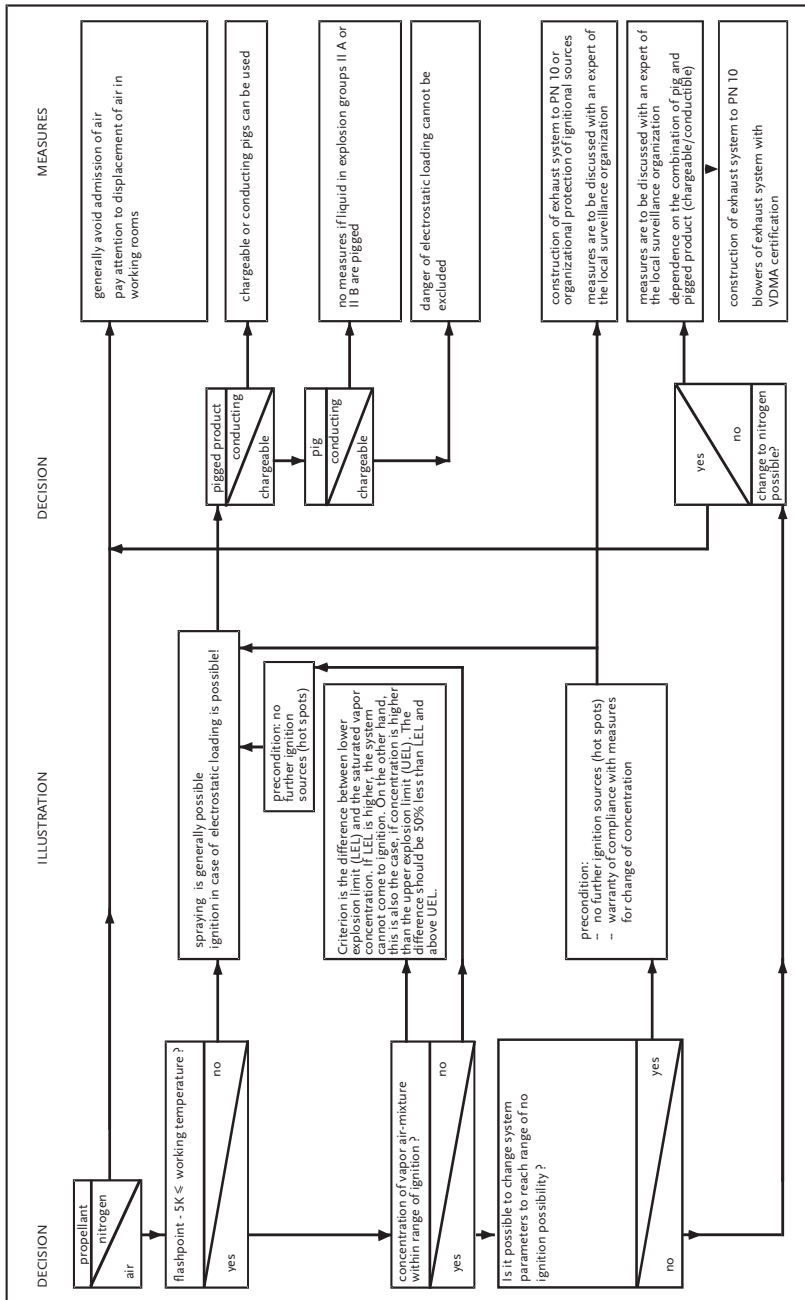


Fig. 20-7. Concept for the evaluation of the operational reliability and explosion-hazard classification of pigging system; hazards due to pressurized gas and combustible vapor air mixtures

V
Appendix

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Chap. 9

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List of Chemical Resistances*

The details given in the following tables have been acquired and gathered from tests of Freudenberg, from the recommendations of their suppliers, as well as from reports of customers' experiences.

In spite of this, these details can only suffice to give a general picture. They are not directly applicable to all working conditions.

Among the various factors applicable to seals and moulded parts, chemical resistance of course plays a very important role although it is only one factor in the overall operating conditions.

If no special recommendation is given in the tables, then normal purity, concentration, and room temperature is to be presumed for the relevant medium.

The elastomers set out in the tables are given with their chemical names as well as with the abbreviated codes laid down in ASTM 1418-80.

Chemical names, common names, or trade names are used for the media.

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Description of Material Codes

NBR	Acrylonitrile Butadiene Rubber
HNBR	Hydrogenated Rubber
CR	Chlorobutadiene Rubber
ACM	Acrylate Rubber
VMQ	Silicone Rubber
FVMQ	Fluorosilicone Rubber
FPM	Fluoro Rubber
FFPM	Perfluoro Rubber
AU	Polyurethane
NR	Natural Rubber
SBR	Styrene Butadiene Rubber
EPDM	Ethylene Propylene Diene Rubber
IIR	Butyl Rubber
CSM	Chlorosulphonated Polyethylene
PTFE	Polytetrafluorethylene

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
Accumulator acid (sulphuric acid)	60	○	○	○	○	○	○	●	●	○	○	●	●	●	●	●
Acetaldehyde, with acetic acid, 90/10%	20	○	○	○	○	○	○	○	●	○	○	●	●	●	●	●
Acetamide	20	⊕	⊕	○	○	○	⊕	○	●	○	○	○	⊕	⊕	⊕	●
Acetic acid, aqueous, 25 to 60%	60	○	○	○	○	○	○	○	●	○	○	○	●	●	●	●
Acetic acid, aqueous, 85%	100	○	○	○	○	○	○	○	●	○	○	○	⊕	⊕	⊕	●
Acetic acid, glacial	60	○	○	○	○	○	○	○	●	○	○	○	●	●	●	●
Acetic anhydride	20	○	○	●	○	○	○	○	●	○	○	●	●	●	●	●
Acetic anhydride	80	○	○	●	○	○	○	○	●	○	○	●	⊕	⊕	⊕	●
Acetone	20	○	○	○	○	○	○	○	●	○	○	○	●	●	⊕	●
Acetophenone	20	○	○	○	○	○	○	○	●	○	○	○	⊕	⊕	⊕	●
Acetylene	60	●	●	●	●	●	●	●	●	⊕	●	●	●	●	●	●
Acrylic acid, ethyl ester	20	○	○	○	○	○	○	○	●	○	○	○	⊕	●	○	●
Acrylonitrile	60	○	○	○	○	○	○	○	●	○	○	○	⊕	○	○	●
Adipic acid, aqueous	20	●	●	●	⊕	⊕	⊕	●	●	⊕	●	●	●	●	●	●
Aero-engine fuels JP3 (MIL-J 5624)	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Aero-engine fuels JP4 (MIL-J-5624)	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Aero-engine fuels JP5 (MIL-J-5624)	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Aero-engine fuels JP6 (MIL-J 25656)	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Air, oil-containing	80	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●
Air, pure	80	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●
Allyl alcohol	80	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Alum, aqueous	60	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
Alum, aqueous	100	●	●	○	○	⊕	⊕	○	○	○	○	○	○	○	○	○
Aluminium sulphate, aqueous	60	●	●	○	○	⊕	⊕	○	○	○	○	○	○	○	○	○
Aluminium sulphate, aqueous	100	●	●	○	○	⊕	⊕	○	○	○	○	○	○	○	○	○
Ammonia, 100%	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Ammonia, aqueous	40	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Ammonium acetate, aqueous	60	●	●	○	○	⊕	⊕	○	○	○	○	○	○	○	○	○

● = Little or no attack

⊕ = No data available; probably suitable; test before use.

○ = Weak to moderate attack

○ = No data available; probably not suitable.

○ = Strong attack to complete destruction

☆ = Special composition of the blend required.

¹⁾ Testing temperature in °C

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTE
Ammonium carbonate	60	●	●	○	○	⊕	⊕	○	●	○	○	●	●	●	●	●
Ammonium chloride, aqueous	60	●	●	○	○	⊕	⊕	●	○	○	○	●	●	●	●	●
Ammonium fluoride, aqueous	20	●	●	○	○	○	●	●	○	○	○	●	●	●	●	●
Ammonium fluoride, aqueous	100	●	●	○	○	⊕	⊕	○	●	○	○	●	●	●	●	●
Ammonium nitrate, aqueous	60	●	●	○	○	⊕	⊕	●	○	○	○	●	●	●	●	●
Ammonium nitrate, aqueous	100	●	●	○	○	⊕	⊕	●	○	○	○	●	●	●	●	●
Ammonium phosphate, aqueous	60	●	●	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●
Ammonium sulphate	60	●	●	○	○	⊕	⊕	●	○	○	○	●	●	●	●	●
Ammonium sulphate	100	●	●	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●
Ammonium sulphide, aqueous	60	●	●	○	○	⊕	⊕	●	○	○	○	●	●	●	●	●
Ammonium sulphide, aqueous	100	●	●	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●
Amyl acetate	20	○	○	○	○	○	○	○	○	●	○	○	●	●	⊕	●
Amyl alcohol	60	●	●	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●
Aniline	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Aniline hydrochloride	20	●	●	○	○	○	⊕	●	○	○	○	○	○	○	○	●
Aniline hydrochloride	100	○	○	⊕	○	○	○	○	○	○	○	○	○	○	○	●
Anisole	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Anthraquinone sulphonic acid, aqueous	30	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Antifreeze (motor vehicle)	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Antimony chloride, aqueous	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Antimony trichloride, anhydrous	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Aqua regia	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Arsenic acid, aqueous	60	●	●	○	⊕	⊕	⊕	●	○	○	○	○	○	○	○	●
Arsenic acid, aqueous	100	●	●	○	⊕	⊕	○	○	○	○	○	○	○	○	○	●
Asphalt	100	○	○	○	⊕	○	○	⊕	○	○	○	○	○	○	○	●
ASTM fuel A	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
ASTM fuel B	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
ASTM fuel C	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●

● = Little or no attack

⊕ = No data available; probably suitable; test before use.

● = Weak to moderate attack

○ = No data available; probably not suitable.

○ = Strong attack to complete destruction

☆ = Special composition of the blend required.

¹⁾ Testing temperature in C°

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	PVMQ	FFPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
ASTM oil No.1	100	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●
ASTM oil No.2	100	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●
ASTM oil No.3	100	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●
ATE brake fluid	100	○	○	○	○	●	●	○	⊕	○	●	●	●	●	○	●
ATF oil	100	●	●	○	○	●	●	●	●	●	○	○	○	○	○	●
Barium hydroxide, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Barium salts, aqueous	60	●	●	○	○	●	●	●	●	○	●	●	●	●	●	●
Beef tallow emulsion, sulphonated	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Beer	20	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Benzaldehyde, aqueous	60	○	○	○	○	○	○	●	●	○	●	○	○	○	○	●
Benzene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Benzoic acid, aqueous	60	●	●	○	○	●	●	●	●	○	●	●	●	●	●	●
Benzyl alcohol	60	○	○	○	○	○	○	○	○	⊕	⊕	⊕	⊕	⊕	⊕	●
Bisulphite lye	50	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bitumen	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Black lye	100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Blast furnace gas	100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bleaching lye	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bone oil	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Borax, aqueous	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Boric acid, aqueous	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Brake fluids (glycoether)	80	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bromine water, saturated cold	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bromine, liquid	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bromine, vapour	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bromobenzene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Bunker oil	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Butadiene	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●

● = Little or no attack	⊕ = No data available; probably suitable; test before use.
○ = Weak to moderate attack	○ = No data available; probably not suitable.
○ = Strong attack to complete destruction	☆ = Special composition of the blend required.

¹⁾ Testing temperature in °C

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FFPM	FFPM	AU	NR	SR	EPDM	IIR	CSM	PTE
Butane, gaseous	20	●	●	●	○	⊕	●	●	●	○	○	○	○	○	○	●
Butanediol, aqueous	20	●	●	●	○	⊕	⊕	●	⊕	●	●	●	●	●	●	●
Butanediol, aqueous	60	●	●	●	○	⊕	⊕	⊕	⊕	○	●	●	●	●	●	●
Butanol, aqueous	20	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●
Butanol, aqueous	60	○	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●	●
Butter	20	●	●	●	⊕	●	●	●	●	○	○	○	○	○	○	●
Butter	80	●	●	●	⊕	⊕	⊕	●	⊕	○	○	○	○	○	○	●
Butyl acetate	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Butyl alcohol	60	○	○	○	○	⊕	⊕	○	○	○	○	○	○	○	○	●
Butyl phenol	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Butylene glycol	60	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
Butylene, liquid	20	●	●	●	⊕	⊕	●	●	●	○	○	○	○	○	○	●
Butyne diol	20	●	●	○	○	⊕	⊕	●	●	○	○	○	○	○	○	●
Butyraldehyde	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Butyric acid, aqueous	20	●	●	○	⊕	⊕	●	●	⊕	○	⊕	⊕	⊕	⊕	⊕	●
Calcium bisulphite, aqueous	20	●	●	○	⊕	⊕	●	●	●	○	○	○	○	○	○	●
Calcium chloride, aqueous	100	●	●	○	○	●	●	●	○	○	○	○	○	○	○	●
Calcium hydroxide, aqueous	20	●	●	○	○	●	●	●	○	○	○	○	○	○	○	●
Calcium hypochlorite, aqueous	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Calcium nitrate, aqueous	40	●	●	○	○	●	●	●	○	○	○	○	○	○	○	●
Calcium phosphate, aqueous	20	●	●	○	○	●	●	●	⊕	○	○	○	○	○	○	●
Camphor	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Camphorated oil	20	●	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Carbolineum	80	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Carbolineum	60	○	○	○	○	○	⊕	⊕	○	○	○	○	○	○	○	●
Carbon dioxide, dry	60	●	●	●	●	●	●	●	○	○	○	○	○	○	○	●
Carbon disulphide	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Carbon monoxide, dry	60	●	●	●	●	●	●	●	○	○	○	○	○	○	○	●

● = Little or no attack

⊕ = No data available; probably suitable; test before use.

● = Weak to moderate attack

○ = No data available; probably not suitable.

○ = Strong attack to complete destruction

☆ = Special composition of the blend required.

¹⁾ Testing temperature in C°

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FFPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
Carbon monoxide, moist	20	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●
Carbon tetrachloride	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Caustic potash, 50 %	60	●	●	●	○	○	○	○	○	○	●	●	●	●	●	●
Caustic soda	20	●	●	●	○	○	○	○	○	○	●	●	●	●	●	●
Cellosolve	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Chloral hydrate, aqueous	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Chloramine, aqueous	20	●	●	●	⊕	⊕	⊕	○	○	⊕	●	●	●	●	●	●
Chlorethanol	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Chloric acid, aqueous	80	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Chloride of lime, aqueous	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Chlorine water, saturated	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Chlorine, dry gaseous	20	○	○	○	○	○	○	●	○	⊕	○	○	○	○	○	●
Chlorine, liquid	20	○	○	○	○	○	○	●	○	○	○	○	○	○	○	●
Chlorine, moist gaseous	20	○	○	○	○	○	○	●	○	○	○	○	○	○	○	●
Chlorobenzene	20	○	○	○	○	○	○	●	○	⊕	○	○	○	○	○	●
Chlorobromomethane	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Chloroform	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Chlorsulphonic acid	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Chromic acid, aqueous	60	○	○	○	○	○	○	●	●	○	○	○	⊕	⊕	●	●
Chromic acid/ sulphuric acid/ water 50/15/35%	40	○	○	○	○	○	○	●	●	○	○	○	⊕	⊕	●	●
Citric acid, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Clophen T 64	100	○	○	○	⊕	○	⊕	●	●	○	○	○	○	○	○	●
Clophen-A types	100	○	○	○	⊕	●	●	●	●	○	○	○	○	○	○	●
Coconut fat	80	●	●	○	●	●	●	●	●	○	○	○	○	○	○	●
Coconut fatty alcohol	20	●	●	○	⊕	⊕	⊕	●	○	○	○	○	○	○	○	●
Coconut oil	60	●	●	○	●	●	●	●	●	○	○	○	○	○	○	●
Coconut oil	80	●	●	○	⊕	⊕	⊕	●	○	⊕	○	○	○	○	○	●
Cod-liver oil	20	●	●	○	●	●	●	●	●	○	○	○	○	○	○	●

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⊕ = No data available; probably suitable; test before use.

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Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FFPM	FFPM	AU	NR	SR	EPDM	IIR	CSM	PTE
Coking-oven gas	80	○	○	○	⊕	⊕	●	●	○	○	○	○	○	○	○	●
Copper fluoride, aqueous	50	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Copper nitrate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Copper sulphate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Copper(I) chloride, aqueous	20	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●
Cottonseed oil	20	●	●	●	⊕	⊕	⊕	●	●	●	●	●	●	●	●	●
Cresol, aqueous	45	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Crotonaldehyde	20	○	○	○	○	○	○	○	⊕	⊕	○	○	○	○	○	●
Cyclohexane	20	●	●	○	●	●	●	●	●	○	○	○	○	○	○	●
Cyclohexanol	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Cyclohexanone	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Cyclohexylamine	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Decahydronaphthalene (Decalin)	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Decahydronaphthalene (Decalin)	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Desmodur T	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Desmophen 2000	80	●	●	⊕	⊕	⊕	⊕	⊕	⊕	⊕	○	○	⊕	⊕	⊕	●
Detergent, synthetic	60	●	●	●	○	⊕	⊕	●	○	⊕	●	●	●	●	●	●
Detergents	100	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Dextrin, aqueous	60	●	●	●	○	●	●	●	○	○	○	○	○	○	○	●
Diacetone alcohol	20	●	●	●	○	⊕	⊕	○	○	⊕	●	●	●	●	●	●
Dibenzyl ether	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dibutyl ether	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dibutyl phthalate	20	○	○	○	○	●	●	●	○	○	○	○	⊕	⊕	⊕	●
Dibutyl phthalate	60	○	○	○	○	●	●	○	○	⊕	○	○	⊕	⊕	⊕	●
Dibutyl sebacate	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dichloroacetic acid	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dichlorethane	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dichlorethylene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●

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Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FFPM	FFPM	AU	NR	SR	EPDM	IIR	CSM	PTFE
Dichlorobenzene	20	○	○	○	○	○	●	●	●	○	○	○	○	○	○	●
Dichlorobutylene	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Dichloromethane	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Diesel fuel	60	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●
Diethyl ether	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Diethyl sebacate	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Diethylamine	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Diethylene glycol	20	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Diglycolic acid, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	○	○	○	○	○	●
Dihexyl phthalate	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Diisobutyl ketone	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dimethyl ether	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dimethylamine	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dimethylformamide	60	○	○	○	⊕	○	⊕	○	○	○	○	○	○	○	○	●
Dinonyl phthalate	30	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dioctyl phthalate	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dioctyl sebacate	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Dioxane	60	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Dipentene	20	●	●	○	⊕	⊕	⊕	●	●	⊕	○	○	○	○	○	●
Diphenyl	20	○	○	○	○	○	○	○	○	⊕	○	○	○	○	○	●
Diphenyl oxide	100	○	○	○	○	○	○	○	○	⊕	○	○	○	○	○	●
Engine oils	100	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●
Epichlorhydrin	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Essential oils	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Ethane	20	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●
Ethanol	20	●	●	○	○	○	⊕	☆	○	○	○	○	○	○	○	●
Ethanol	80	○	○	○	○	⊕	⊕	○	○	○	○	○	○	○	○	●
Ethanol with acetic acid (fermentation mixture)	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●

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Medium	°C ¹⁾	NR	HNR	CR	ACM	VMQ	FVMQ	FPM	FFPM	AU	NR	SR	EPDM	IIR	CSM	PTE
Ethanol with acetic acid (fermentation mixture)	60	○	○	○	○	○	○	●	●	○	●	●	●	●	●	●
Ethyl acetate	60	○	○	○	○	○	○	◐	○	○	○	○	○	○	○	●
Ethyl acrylate	20	○	○	○	○	○	○	◐	○	○	○	○	⊕	◐	○	●
Ethyl benzene	20	○	○	○	○	○	◐	◐	⊕	○	○	○	○	○	○	●
Ethyl chloride	20	◐	◐	○	○	○	○	◐	●	○	◐	◐	◐	◐	⊕	●
Ethyl ether	20	○	○	○	○	○	○	○	●	○	○	○	◐	◐	○	●
Ethylene chloride	20	◐	◐	○	○	○	○	◐	●	○	◐	◐	◐	◐	⊕	●
Ethylene diamine	60	○	○	○	○	○	○	○	◐	○	○	◐	●	●	⊕	●
Ethylene glycol	100	●	●	◐	○	◐	⊕	●	○	○	○	●	●	●	⊕	●
Ethylene trichloride	20	○	○	○	○	○	⊕	◐	○	○	○	○	○	○	○	●
Exhaust gases, containing carbon dioxide	60	●	●	●	●	●	●	●	●	⊕	●	●	●	●	●	●
Exhaust gases, containing carbon monoxide	60	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Exhaust gases, containing hydrogen chloride	60	◐	◐	○	○	⊕	⊕	●	○	○	○	●	●	●	●	●
Exhaust gases, containing hydrogen fluoride, traces	60	●	●	●	⊕	⊕	⊕	●	○	○	●	●	●	●	●	●
Exhaust gases, containing nitrous gases, traces	60	⊕	⊕	●	○	○	◐	●	○	○	⊕	●	◐	●	●	●
Exhaust gases, containing nitrous gases, traces	80	⊕	⊕	●	○	○	◐	●	○	○	⊕	●	◐	●	●	●
Exhaust gases, containing sulphur dioxide	60	◐	◐	○	○	⊕	⊕	●	○	○	◐	◐	●	●	●	●
Exhaust gases, containing sulphuric acid	60	◐	◐	○	○	⊕	⊕	●	○	○	◐	◐	●	●	●	●
Exhaust gases, containing sulphuric acid	80	○	○	◐	⊕	⊕	●	○	○	○	◐	◐	●	●	●	●
FAM test fuels DIN 51 604-A	20	●	◐	○	○	○	●	●	●	○	○	○	○	○	○	●
FAM test fuels DIN 51 604-C	20	○	○	○	○	○	◐	☆	●	○	○	○	○	○	○	●
Fats; mineral, animal or vegetable	80	●	●	◐	●	●	●	●	●	○	○	○	○	○	◐	●
Fatty acids	100	◐	◐	○	○	○	○	●	○	○	○	○	○	○	◐	●
Fatty alcohol	20	●	●	●	●	●	⊕	●	○	○	◐	◐	◐	◐	◐	●
Fertiliser salt, aqueous	60	●	●	◐	○	●	●	●	○	○	●	●	●	●	●	●
Fish oil	20	●	●	●	●	●	●	●	○	⊕	◐	◐	◐	◐	◐	●
Fluorine, dry	60	○	○	○	○	○	○	⊕	○	○	○	○	○	○	○	●
Fluorobenzene	20	○	○	○	○	○	○	◐	●	○	○	○	○	○	○	●

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Fluorocarbon oils	100	⊕	⊕	⊕	⊕	●	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	●
Fluorosilicic acid	100	⊕	⊕	⊕	○	⊕	⊕	⊕	⊕	○	○	⊕	⊕	⊕	⊕	●
Fluorosilicic acid, aqueous	60	●	●	●	○	○	○	●	●	○	●	●	●	●	●	●
Formaldehyde, aqueous	60	●	●	●	○	⊕	⊕	○	○	○	●	●	●	●	●	●
Formamide	60	○	○	○	○	○	○	●	●	○	○	⊕	●	●	●	●
Formic acid, aqueous	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 11	20	●	●	●	○	○	⊕	●	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 113	20	●	●	●	○	○	⊕	●	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 114	20	●	●	●	○	○	⊕	○	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 12	20	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 13	20	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 134a	20	●	●	●	○	○	⊕	○	○	○	○	○	○	○	○	●
Freon according to DIN 8962 R 22	20	○	○	●	○	○	⊕	○	○	○	○	○	○	○	○	●
Fruit juice	100	●	●	●	○	●	⊕	●	●	○	○	○	○	○	○	●
Furane	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Furfural	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Furfuryl alcohol	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Furnace gas, dry	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Gas liquor	40	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Gas oil	80	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Gasohol	20	○	○	○	○	○	○	☆	○	○	○	○	○	○	○	●
Gelatine, aqueous	40	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Glaubers salt, aqueous (sodium sulphate)	20	●	●	●	○	⊕	⊕	○	○	○	○	○	○	○	○	●
Glucose, aqueous	80	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Glue (size)	20	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Glycerol chlorhydrin	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Glycerol, aqueous	100	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●
Glycine, aqueous, 10%	40	●	●	●	○	⊕	⊕	○	○	○	○	○	○	○	○	●

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Glycol, aqueous	100	●	●	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●
Glycolic acid, aqueous, 37%	20	●	●	○	○	●	●	●	○	○	●	●	●	●	●	●
Grape sugar, aqueous	80	●	●	○	○	●	●	●	○	○	○	●	●	●	●	●
Heating oil, mineral-oil based	60	●	●	○	○	⊕	⊕	○	○	○	○	○	○	○	○	●
Henkel P3 solution	100	●	●	○	○	⊕	⊕	○	○	○	○	●	●	●	●	●
Heptane	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Hexachlorobutadiene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hexachlorocyclohexane	20	○	○	○	○	○	⊕	○	○	○	○	○	○	○	○	●
Hexaldehyde	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hexane	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Hexane triol	20	●	●	○	○	○	○	○	○	⊕	⊕	○	○	○	○	●
Hexene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydraulic fluids, hydraulic oils DIN 51 524	80	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydraulic fluids, oil-in-water emulsions HFA	55	●	●	○	○	⊕	⊕	○	○	○	○	○	○	○	○	●
Hydraulic fluids, phosphoric acid ester HFD	80	○	○	○	○	○	○	☆	○	○	○	○	☆	☆	○	●
Hydraulic fluids, polyglycol-water emulsions	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydraulic fluids, water-in-oil emulsions HFB	60	☆	☆	○	○	⊕	⊕	○	○	○	○	○	○	○	○	●
Hydrazine hydrate	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrobromic acid, aqueous	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrochloric acid, concentrated	80	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrochloric acid, concentrated	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrochloric acid, dilute	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrofluoric acid, concentrated	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrogen	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrogen chloride gas	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrogen peroxide, aqueous	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrogen sulphide, aqueous	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Hydrogen sulphide, dry	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●

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¹⁾ Testing temperature in °C

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	PPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
Hydroquinone, aqueous	20	●	●	◐	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Hydrosulphite, aqueous	40	◐	◐	◐	○	⊕	⊕	○	◐	○	●	●	●	●	●	●
Hydroxylamine sulphate, aqueous	35	●	●	◐	○	●	●	○	◐	○	●	●	●	●	●	●
Ink	20	●	◐	●	●	●	●	●	●	○	●	●	●	●	●	●
Iodine, tincture	20	●	●	◐	○	◐	◐	●	●	○	●	●	●	●	●	●
Iodoform	20	○	○	○	○	○	○	●	●	○	○	○	●	●	○	●
Iron(III) chloride, aqueous	40	●	●	○	○	⊕	⊕	●	●	⊕	●	●	●	●	●	●
Isobutanol	20	◐	◐	●	○	◐	◐	●	●	○	●	●	●	●	●	●
Isooctane	20	●	●	◐	●	◐	●	●	●	○	○	○	○	○	○	●
Isophorone	20	⊕	⊕	⊕	⊕	⊕	⊕	⊕	◐	◐	⊕	⊕	●	●	⊕	●
Isopropanol	60	◐	◐	◐	○	●	●	◐	☆	○	○	●	●	●	●	●
Isopropyl acetate	80	○	○	○	○	○	○	○	◐	○	○	○	◐	◐	◐	●
Isopropyl chloride	20	○	○	○	○	○	◐	●	●	○	○	○	○	○	○	●
Isopropyl ether	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Kerosene	20	●	◐	○	●	◐	●	●	●	○	○	○	○	○	○	●
Lactam	80	○	○	○	○	○	○	○	◐	○	○	○	○	○	○	●
Lactic acid, aqueous	40	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Lanolin (wool fat)	60	●	●	◐	●	●	●	●	●	●	●	◐	○	○	◐	●
Laughing gas (nitrous oxide)	20	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Lauryl alcohol	20	●	●	⊕	⊕	⊕	●	●	⊕	◐	◐	◐	◐	◐	◐	●
Lavender oil	20	◐	◐	○	◐	◐	◐	●	●	⊕	○	○	○	○	○	●
Lead acetate, aqueous	60	●	◐	◐	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Lead acetate, aqueous	100	●	◐	◐	○	⊕	⊕	○	●	○	○	●	●	●	●	●
Lead nitrate, aqueous	20	●	●	◐	⊕	⊕	⊕	●	●	○	●	●	●	●	●	●
Lemon juice, undiluted	20	●	●	◐	○	●	⊕	⊕	●	⊕	●	●	⊕	⊕	⊕	●
Linoleic acid	20	◐	◐	○	○	◐	⊕	◐	●	⊕	○	○	○	○	○	●
Linseed oil	60	●	●	●	⊕	⊕	⊕	●	●	◐	◐	◐	◐	◐	◐	●
Liqueurs	20	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

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Lithium bromide, aqueous	20	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
Lithium chloride, aqueous	20	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
Machine oil, mineral	80	●	●	●	○	●	●	●	●	●	○	○	○	○	○	●
Magnesium chloride, aqueous	100	●	●	●	○	⊕	⊕	●	○	○	●	●	●	●	●	●
Magnesium sulphate, aqueous	100	●	●	●	○	⊕	⊕	●	○	○	●	●	●	●	●	●
Maize oil (corn oil)	60	●	●	●	⊕	⊕	⊕	●	●	⊕	○	○	○	○	○	●
Maleic acid, aqueous	100	●	●	●	○	⊕	⊕	●	○	○	○	○	●	●	●	●
Maleic anhydride	60	○	○	○	○	○	⊕	●	●	○	○	○	○	○	○	●
Margarine	80	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●
Marsh gas (methane)	20	●	●	●	●	●	●	●	●	⊕	●	●	●	●	●	●
Menthol	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Mercury	60	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Mercury salts, aqueous	60	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●
Mesityl oxide	20	⊕	⊕	○	○	○	⊕	⊕	⊕	⊕	○	○	●	●	○	●
Methane	20	●	●	●	●	●	●	●	●	⊕	●	●	●	●	●	●
Methanol	60	●	●	○	○	●	●	☆	●	○	○	●	●	●	●	●
Methoxy butanol	60	●	●	●	○	⊕	⊕	●	○	⊕	○	○	●	●	●	●
Methyl acrylate	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Methyl bromide	20	○	○	○	○	○	⊕	●	●	○	○	○	○	○	○	●
Methyl chloride	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Methyl ethyl ketone	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Methyl isobutyl ketone	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Methyl methacrylate	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Methylamine, aqueous	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Methylene chloride	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Milk	20	●	●	●	○	●	●	●	●	●	○	○	○	○	○	●
Milk of lime	80	○	○	●	○	○	○	●	●	○	○	○	⊕	⊕	⊕	●
Mineral oil	100	●	●	○	●	●	●	●	●	○	○	○	○	○	○	●

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Mineral water	60	●	●	◐	○	●	●	●	●	⊕	●	●	●	●	●	●
Mixed acid I (sulphuric acid/nitric acid/water)	20	○	○	◐	○	○	○	●	●	○	○	○	●	●	●	●
Mixed acid II (sulphuric acid/phosphoric acid/wa	40	○	○	○	○	○	○	●	●	○	○	◐	●	●	●	●
Molasses	100	●	●	◐	○	⊕	⊕	●	●	○	○	○	◐	◐	◐	●
Monobromobenzene	20	○	○	○	○	○	○	◐	●	○	○	○	○	○	○	●
Monochloroacetic acid	60	◐	◐	◐	○	○	○	○	◐	○	○	○	●	●	●	●
Monochloroacetic acid, ethyl ester	60	○	○	○	○	○	○	◐	●	○	○	○	◐	◐	◐	●
Monochloroacetic acid, methyl ester	60	○	○	○	○	○	○	◐	●	○	○	○	●	●	○	●
Morpholine	60	○	○	○	○	⊕	⊕	○	⊕	○	○	○	◐	◐	◐	●
Myristyl alcohol	20	●	●	●	●	⊕	⊕	●	●	⊕	●	●	●	●	●	●
n-Propanol	60	◐	◐	◐	○	●	●	◐	●	○	●	●	●	●	●	●
Naftolen ZD	20	◐	◐	○	⊕	⊕	⊕	●	●	○	○	○	○	○	○	●
Naphtha	20	○	○	○	◐	○	◐	●	●	○	○	○	○	○	○	●
Naphthalene	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Naphthoic acid	20	◐	◐	⊕	○	○	○	●	●	○	○	○	○	○	○	●
Natural gas	20	●	●	●	⊕	○	○	●	●	◐	○	○	○	○	●	●
Natural gas, crude	20	●	●	●	●	●	●	●	●	●	●	◐	◐	◐	◐	●
Nickel acetate, aqueous	20	●	●	◐	○	⊕	⊕	⊕	○	○	●	●	●	●	●	●
Nickel chloride, aqueous	20	●	●	◐	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Nickel sulphate, aqueous	60	●	●	◐	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Nitric acid, dilute	80	◐	◐	◐	○	○	○	●	●	○	○	◐	◐	◐	●	●
Nitric acid, fuming	60	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Nitric, concentrated	80	○	○	○	○	○	○	○	⊕	○	○	○	○	○	●	●
Nitrobenzene	60	○	○	○	○	○	○	○	◐	○	○	○	○	○	○	●
Nitrogen	20	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Nitrogen dioxide	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Nitroglycerine	20	○	○	○	○	○	○	●	●	○	○	◐	●	●	●	●
Nitroglycol, aqueous	20	○	○	◐	○	⊕	⊕	●	●	⊕	⊕	⊕	●	●	●	●

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Nitromethane	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Nitropropane	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Nitrous gases (oxides of nitrogen)	20	○	○	○	○	○	○	●	●	○	○	○	●	●	●	●
o-Nitrotoluene	60	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Octane	20	⊕	⊕	○	○	○	○	○	○	○	○	○	○	○	○	●
Octyl alcohol	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Octyl cresol	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Oil, crude	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Oleum, 10 %	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Oleyl alcohol	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Olive oil	60	●	●	○	○	○	○	○	○	⊕	○	○	○	○	○	●
Oxalic acid, aqueous	100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Ozone	20	○	○	○	○	○	○	○	○	⊕	○	○	○	○	○	●
Palm kernel fatty acid	60	●	●	○	⊕	⊕	⊕	○	○	⊕	○	○	○	○	○	●
Palmitic acid	60	○	○	○	⊕	⊕	⊕	○	○	⊕	○	○	○	○	○	●
Paraffin	60	●	●	○	⊕	⊕	⊕	○	○	⊕	○	○	○	○	○	●
Paraffin emulsions	40	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Paraffin oil	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Pectin	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Pentachlorodiphenyl	60	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Pentane	20	●	●	○	⊕	⊕	⊕	○	○	⊕	○	○	○	○	○	●
Peracetic acid < 1%	40	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Peracetic acid < 10%	40	○	○	○	○	○	○	☆	○	○	○	○	○	○	○	●
Perchlorethylene	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Perchloric acid	100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Petrol	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Petrol/benzene mixture, 50/50%	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Petrol/benzene mixture, 60/40%	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●

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Petrol/benzene mixture, 70/30%	20	●	○	○	○	○	●	●	●	●	○	○	○	○	○	●
Petrol/benzene mixture, 80/20%	20	●	○	○	○	○	●	●	●	●	○	○	○	○	○	●
Petrol/benzene/ethanol, 50/30/20%	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Petroleum	60	●	●	○	○	○	●	●	●	○	○	○	○	○	○	●
Petroleum ether	60	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenol, aqueous, up to 90 %	80	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenyl benzene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenyl ethyl ether	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenyl hydrazine	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenylhydrazine chlorhydrate, aqueous	80	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phosgene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phosphine	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phosphoric acid, aqueous	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phosphorus oxychloride	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phosphorus trichloride	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Photographic developer	40	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Photographic emulsions	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Photographic fixing baths	40	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Phthalic acid, aqueous	60	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Pickling solution (leather)	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Picric acid	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Picric acid, aqueous	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Pine needle oil	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Pine needle oil	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Pinene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Piperidine	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Potash, aqueous	40	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Potassium acetate, aqueous	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

● = Little or no attack	⊕ = No data available; probably suitable; test before use.
○ = Weak to moderate attack	○ = No data available; probably not suitable.
○ = Strong attack to complete destruction	☆ = Special composition of the blend required.

¹⁾ Testing temperature in °C

Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FFPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
Potassium bisulphate, aqueous	40	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium borate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium bromate, 10 %	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium bromide, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium carbonate, aqueous	40	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●
Potassium chlorate, aqueous	60	○	○	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium chloride, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium chromate, aqueous	20	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium cyanide, aqueous	40	●	●	○	○	●	●	●	●	⊕	●	●	●	●	●	●
Potassium cyanide, aqueous	80	●	●	○	○	●	●	●	●	○	○	○	●	●	●	●
Potassium dichromate, aqueous 40 %	20	●	●	○	○	⊕	⊕	●	●	○	○	●	●	●	●	●
Potassium iodide, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium nitrate, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Potassium perchlorate, aqueous	80	○	○	○	○	⊕	⊕	●	●	○	○	○	●	●	●	●
Potassium permanganate, aqueous	40	○	○	○	○	○	○	●	●	○	○	●	●	●	●	●
Potassium persulphate, aqueous	60	○	○	○	○	○	○	●	●	○	○	●	●	●	●	●
Potassium sulphate, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Propane, liquid, gaseous	20	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●
Propargyl alcohol, aqueous	60	●	●	○	○	⊕	⊕	●	●	○	●	⊕	●	●	●	●
Propionic acid, aqueous	60	●	●	○	○	○	○	●	●	○	○	⊕	⊕	⊕	⊕	●
Propylene glycol	60	●	●	○	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Propylene oxide	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Prussic acid (hydrocyanic acid)	20	⊕	⊕	○	○	●	⊕	⊕	●	○	⊕	⊕	⊕	●	●	●
Pyridine	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Pyrrole	20	○	○	○	○	○	○	⊕	⊕	○	○	○	○	○	○	●
Rapeseed oil	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Refrigerant according to DIN 8962 R 11	20	●	●	○	○	○	⊕	○	○	○	○	○	○	○	○	●
Refrigerant according to DIN 8962 R 113	20	●	●	○	○	○	⊕	○	○	○	○	○	○	○	○	●

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Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
Refrigerant according to DIN 8962 R 114	20	●	●	●	○	○	⊕	⊕	○	●	●	●	●	●	●	●
Refrigerant according to DIN 8962 R 12	20	●	●	●	○	○	○	○	○	●	●	●	●	●	●	●
Refrigerant according to DIN 8962 R 13	20	●	●	●	○	○	○	○	○	●	○	●	●	●	●	●
Refrigerant according to DIN 8962 R 134a	20	●	●	●	○	⊕	○	○	○	○	○	○	●	○	○	●
Refrigerant according to DIN 8962 R 22	20	○	○	●	○	⊕	○	○	○	●	●	●	●	●	●	●
Sagrotan	20	●	●	●	○	●	●	●	○	●	●	●	●	●	●	●
Salicylic acid	20	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●
Salt water	20	●	●	●	○	○	○	●	●	○	●	●	●	●	●	●
Sea water	20	●	●	●	○	●	●	●	○	●	●	●	●	●	●	●
Silicic acid, aqueous	60	●	●	●	○	○	○	●	●	○	●	●	●	●	●	●
Silicone grease	20	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●
Silicone oil	20	●	●	●	○	○	○	●	●	○	○	●	●	●	●	●
Silver nitrate, aqueous	100	●	●	●	○	⊕	⊕	●	●	○	○	●	●	●	●	●
Silver salts, aqueous	60	●	●	●	○	●	●	●	○	○	○	●	●	●	●	●
Skydrol	20	○	○	○	○	○	○	○	⊕	○	○	○	○	⊕	○	●
Soap solution, aqueous	20	●	●	●	○	⊕	⊕	●	●	●	●	●	●	●	●	●
Soda, aqueous	60	●	●	●	○	○	○	●	●	○	●	●	●	●	●	●
Sodium benzoate, aqueous	40	●	●	●	○	⊕	⊕	●	●	⊕	●	●	●	●	●	●
Sodium bicarbonate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Sodium bisulphite, aqueous	100	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Sodium chlorate	20	○	○	○	○	⊕	⊕	●	●	○	○	○	●	●	●	●
Sodium chloride	100	●	●	●	○	⊕	⊕	●	●	○	○	●	●	●	●	●
Sodium hypochlorite, aqueous	20	●	●	●	○	⊕	⊕	●	●	○	○	○	●	●	●	●
Sodium nitrate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Sodium nitrite	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Sodium phosphate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Sodium silicate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Sodium sulphate, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●

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Medium	°C ¹⁾	NBR	HNBR	CR	ACM	VMQ	FVMQ	FFM	FFPM	AlU	NR	SBR	EPDM	IIR	CSM	PTFE
Sodium sulphide	40	●	●	◐	◐	⊕	⊕	●	●	◐	●	●	●	●	●	●
Sodium thiosulphate	60	○	○	●	⊕	⊕	⊕	●	●	◐	●	●	●	●	●	●
Spermaceti	20	●	●	◐	⊕	⊕	⊕	●	●	⊕	○	○	○	○	○	●
Spindle oil	60	●	●	◐	●	●	●	●	●	○	○	○	○	○	○	●
Starch syrup	60	●	●	●	◐	⊕	⊕	●	●	◐	●	●	●	●	●	●
Starch, aqueous	60	●	●	●	◐	●	●	●	●	◐	●	●	●	●	●	●
Steam	130	○	○	○	◐	○	○	☆	○	○	○	○	●	●	●	●
Stearic acid	60	●	●	◐	●	●	●	●	●	○	○	●	●	●	●	●
Stoddard solvent	20	●	●	○	●	◐	●	●	●	○	○	○	○	○	○	●
Styrene	20	○	○	○	◐	○	◐	◐	⊕	○	○	○	○	○	○	●
Succinic acid, aqueous	60	●	●	◐	◐	⊕	⊕	●	●	○	●	●	●	●	●	●
Sugar syrup	60	●	●	○	◐	⊕	⊕	●	●	◐	●	⊕	●	●	●	●
Sulphur	60	◐	◐	◐	◐	⊕	⊕	●	●	⊕	◐	◐	●	●	●	●
Sulphur chloride	20	○	○	○	◐	◐	●	●	●	○	○	◐	◐	◐	◐	●
Sulphur dioxide, aqueous	60	○	○	○	◐	◐	◐	●	●	◐	○	◐	●	●	●	●
Sulphur dioxide, dry	80	○	○	○	◐	⊕	⊕	●	●	○	○	◐	●	●	●	●
Sulphur dioxide, liquid	60	○	○	○	◐	◐	◐	●	●	○	○	◐	●	●	●	●
Sulphur hexafluoride	20	●	●	●	⊕	●	●	●	●	⊕	⊕	●	●	●	●	●
Sulphuric acid, concentrated	50	○	○	○	◐	○	○	●	●	○	○	◐	●	●	●	●
Sulphuric acid, dilute	20	◐	◐	○	◐	◐	◐	●	●	◐	◐	◐	●	●	●	●
Sulphuryl chloride	20	○	○	○	◐	◐	◐	●	●	○	◐	◐	◐	◐	◐	●
Tallow	60	●	●	◐	⊕	⊕	⊕	●	●	○	○	○	○	○	○	●
Tannic acid	60	●	●	◐	◐	●	●	●	●	◐	●	●	●	●	●	●
Tannin	40	◐	◐	○	◐	⊕	⊕	●	●	●	●	●	●	●	●	●
Tanning extract	20	●	●	◐	◐	●	●	●	●	◐	●	●	●	●	●	●
Tar	20	○	○	○	◐	◐	◐	⊕	●	○	○	○	○	○	○	●
Tar oil	20	○	○	○	◐	◐	◐	⊕	●	○	○	○	○	○	○	●
Tartaric acid, aqueous	60	●	●	◐	◐	●	●	●	●	○	●	●	●	●	●	●

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¹⁾ Testing temperature in °C

Medium	°C ¹⁾	NR	HNR	CR	ACM	VMQ	FVMQ	FFPM	FFPM	AU	NR	SBR	EPDM	IIR	CSM	PTFE
Test media ASTM oil No.1	100	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●
Test media ASTM oil No.2	100	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●
Test media ASTM oil No.3	100	●	●	○	●	●	●	●	●	●	○	○	○	○	○	●
Tetrachlorethane	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Tetrachlorethylene	60	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Tetraethyl lead	20	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Tetrahydrofuran	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Tetrahydronaphthalene (tetralin)	20	○	○	○	○	○	⊕	●	●	○	○	○	○	○	○	●
Thionyl chloride	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Thiophene	60	○	○	○	○	○	○	⊕	○	○	○	○	○	○	○	●
Tin(II) chloride, aqueous	80	●	●	○	○	⊕	⊕	●	●	○	○	○	○	○	○	●
Titanium tetrachloride	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Toluene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Town gas, benzene free	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Transformer oil	60	●	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Transmission fluid, Type A	20	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Triacetin	20	●	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Tributoxyethyl phosphate	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Tributyl phosphate	60	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Trichloroacetic acid, aqueous	60	●	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Trichlorethyl phosphate	20	○	○	○	○	○	○	○	⊕	○	○	○	○	○	○	●
Trichlorethylene	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Tricresyl phosphate	60	○	○	○	○	○	⊕	○	⊕	○	○	○	○	○	○	●
Triethanolamine	20	○	○	○	○	○	○	○	⊕	○	○	⊕	○	○	○	●
Triethyl aluminium	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Triethyl borane	20	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Triglycol	20	●	●	○	○	○	⊕	○	○	○	○	○	○	○	○	●
Trimethylol propane, aqueous	100	○	○	○	○	○	⊕	○	○	○	○	○	○	○	○	●

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Trinitrotoluene	20	○	○	●	○	○	●	●	●	○	○	○	○	○	●	●
Trioctyl phosphate	60	○	○	○	○	○	⊕	●	●	○	○	○	●	●	●	●
Trisodium phosphate	20	●	●	○	○	●	●	●	●	⊕	●	●	●	●	●	●
Turpentine	60	●	●	○	⊕	○	○	●	●	○	○	○	○	○	○	●
Turpentine, oil of	20	●	●	○	⊕	○	○	●	●	○	○	○	○	○	○	●
Urea, aqueous	60	●	●	●	○	⊕	⊕	●	●	○	●	●	●	●	●	●
Vaseline	60	●	●	●	●	●	●	●	●	⊕	○	○	○	○	●	●
Vaseline oil	60	●	●	●	●	●	●	●	●	⊕	○	○	○	○	●	●
Vinyl acetate	20	○	○	○	○	○	○	○	●	○	○	○	○	○	○	●
Vinyl chloride, liquid	20	○	○	○	○	○	○	○	●	○	○	○	○	○	○	●
Water	100	●	●	●	○	●	⊕	●	●	○	●	●	●	●	●	●
Wax alcohol	60	●	●	○	⊕	⊕	⊕	●	●	⊕	○	○	○	○	○	●
Whisky	20	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●
White lye	100	●	●	○	○	○	○	○	●	○	○	●	●	●	●	●
White oil	20	●	●	●	●	●	●	●	●	⊕	○	○	○	○	●	●
White spirit	60	●	●	○	⊕	⊕	●	●	●	⊕	○	○	○	○	○	●
Wine	20	●	●	●	⊕	●	●	●	●	●	●	●	●	●	●	●
Xylamon (wood preservatives)	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Xylene	20	○	○	○	○	○	○	●	●	○	○	○	○	○	○	●
Yeast, aqueous	20	●	●	○	○	●	●	●	●	⊕	●	●	●	●	●	●
Zeolites	20	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Zinc acetate	20	●	●	○	○	●	●	●	●	●	○	○	●	●	●	●

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Properties of Solvents

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Solvent	Molar mass kg/kmol	Rel. Vapor density Air = 1	Vapor pressure at 20 °C mbar	Liquid density kg/m ³	Flash point °C	LEL %	UEL %	Ignition temperature °C	Temperature group	Explosion group	Conductivity at 25 °C pS/m	Charge- able
Acetone	58,10	2	233	0,79	-19	2,3	13	540	T1	II A	490 000	no
Gasoline	95,00	4	87	0,71	-10	0,8	6,5	220	T3	II A	0,1	yes
Benzole	78,11	2,7	100	0,88	-11	1,2	8	555	T1	II A	0,0001	yes
Butanol-1	74,12	2,56	5,6	0,81	35	1,4	11,3	340	T2	II A	910 000	no
Cyclohexan	84,20	2,9	104	0,78	-18	1,2	8,3	260	T3	II A	1 500	no
Cyclohexanon	98,10	3,4	4,7	0,95	43	1,1	9,4	430	T2	II A	0,0005	yes
DMF	73,10	2,5	4	0,95	58	2,2	16	440	T2	II A	6 · 10 ⁶	no
Ethanol	46,10	1,59	77	0,79	12	3,4	15	425	T2	II A/B	140 000	no
Heptan-1	100,20	3,6	48	0,68	-4	1	6,7	215	T3	II A/B	<100	yes
Hexan-1	86,20	2,97	190	0,65	-20	1	7,5	260	T3	II A	1,9	yes
Isobutanol	74,10	2,6	11,7	0,8	27	1,7	15	430	T2	II A	1,6 · 10 ⁶	no
Isopropanol	60,10	2,08	43	0,79	12	2	12	425	T2	II A	5,8 · 10 ⁶	no
Methanol	32,04	1,1	128	0,79	11	5,5	31	455	T1	II A	150 000	no
Methylformiat	60,10	2,1	640	0,97	-20	5	23	450	T2	II A	1,9 · 10 ⁸	no
Propanol-1	60,10	2,07	18,7	0,8	22	2,1	13,5	405	T2	II A/B	9,2 · 10 ⁸	no
Styrene	104,20	3,6	6	0,91	32	1,1	8	490	T1	II A	–	yes
THF	72,11	2,49	200	0,89	-20	2	12,4	230	T3	II B	120 000	no
Toluene	92,14	3,2	29	0,87	6	1,2	7	535	T1	II A	<1	yes
Xylene	106,20	3,7	8,8	0,87	25	1	7,6	460	T1	II A	0,1	yes

Buyer's Guide *

	IP U, Design	Pigs	Piggable valves	Recycling valves	Piggable pipes	Construction, piping	Pigs for pipelines	Control systems	Pig indicators	Piggable hoses	Pumps	Loading valves	Mass flow meters	Pipe bends	Test pigging systems	Smart pigs	Pigs for bulk material	Hygienic design
3 P Services							×											
AbK		×																
Allweiler											×							
Archinger																	×	
Avesta					×													
Berghöfer									×									
Beta Sensorik								×										
Bornemann											×							
Butting					×									×				
Coperion/Waeschle																	×	
EHR						×								×				
Endress+Hauser													×					
Feige												×						
FMC		×	×	×														
H. Rosen Engineering							×									×		
Hartmann & Braun								×										
Honeywell								×										
I. S. T.		×	×	×														×
IMO						×												
Kiesel		×	×	×														×
Kieselmann		×	×	×														×
Kopp							×											
KSB											×							
Lang & Peitler								×										
Markert									×									
Motan Materials Handling																	×	

*) This table is not exhaustive

	IPU, Design	Pigs	Piggable valves	Recycling valves	Piggable pipes	Construction, piping	Pigs for pipelines	Control systems	Pig indicators	Piggable hoses	Pumps	Loading valves	Mass flow meters	Pipe bends	Test pigging systems	Smart pigs	Pigs for bulk material	Hygienic design
Pepperl + Fuchs									x									
Pfeiffer	x	x	x														x	
Pipetronix							x									x		
Probst				x														
Resistoflex									x									
Rohrbogen AG														x				
Roth									x									
RSI						x								x				
Samson								x										
Sandvik					x													
Skibowski															x			
Südmo			x														x	
Tecno Plast									x									
Tuchenhagen	x	x	x														x	
Turck									x									
Weber/Lauer						x								x				

Supplier's Names and Addresses *

Supplier Code	Supplier Name	Products	Street	Town
3P Services	Pipeline, Petroleum & Precision Services GmbH & Co KG	Pigs for pipelines	Industriestraße 7	D – 49744 Geeste/Dalum
A. Hak	A. Hak Industrial Services	Pipecleaning Inline Inspection	Am Heiligenstock 12	D – 61200 Wölfersheim
AbK	AbK Armaturenbau GmbH	Valves	Otto-Hahn-Straße 23	D – 50997 Köln
Anapur	Anapur AG	Control System	Donnersbergweg 1	D – 65059 Ludwigs-hafen
Allweiler	Allweiler AG	Pumps	Hauptstraße 74	D – 63333 Dreieich
Avesta	Avesta Sheffield Rohr & Fittings GmbH	SS-Pipes	Postfach 11 64	D – 76457 Muggen-sturm
Berghöfer	Chr. Berghöfer GmbH	Hoses	Postfach 420 120	D – 34070 Kassel
Beta Sensoric	beta Sensorik	Pig detector	Am Anger 2a	D – 96328 Küps/Ofir.
Bornemann	J. H. Bornemann GmbH & Co KG	Pumps	Bornemannstraße 1	D – 31683 Obernkirchen
Butting	H. Butting GmbH & Co KG	SS-pipes prebent pipesections		D – 29377 Wittingen
Coperion Waeschle	Coperion Waeschle GmbH	Bulk Materials	Niederbiegerstraße 9	D – 88250 Weingarten
EHR	Essener Hochdruck Rohrleitungsbau	Construction	Wohlbeckstraße 25	D – 45329 Essen
Endres+Hauser	Endres + Hauser Meßtechnik GmbH + Co	Mass-Flow Meter	Postfach 22 22	D – 79574 Weil/Rhein
Feige	Feige GmbH Abfüll-technik	Filling Techn.	Postfach 11 61	D – 23831 Bad Oldesloe
FMC	FMC Fluid Transfer Systems GmbH	Industrial Pigging Units	Grunerstraße 43	D – 40239 Düsseldorf
H. Rosen Engineering	H. Rosen Engineering	Pigs for pipelines	Am Seitenkanal 8	D – 49811 Lingen
Hartmann & Braun	Hartmann & Braun AG	Control-System	Gräfststraße 97	D – 60487 Frankfurt
Honeywell	Honeywell Holding AG	Control-System	Kaiserleistraße 39	D – 63067 Offenbach
I.S.T.	I.S.T. Molchtechnik GmbH	Industrial Pigging Units	Albert-Schweitzer-Ring 23	D – 22045 Hamburg
IMO	IMO Bau Hüther GmbH	Construction	Kreuzholzstraße 7	D – 67069 Ludwigs-hafen

*) This table is not exhaustive

Supplier Code	Supplier Name	Products	Street	Town
ITAG	ITAG Hermann von Rautenkranz Internationale Tiefbohr GmbH & Co KG	Pig stations, three way valves	Itagstraße	29221 Celle
Kiesel	G.A. Kiesel GmbH	Pigging Units	Wannenäckerstraße 20	D – 74078 Heilbronn
Kieselmann	Kieselmann Anlagenbau GmbH	Pigging Units	Paul-Kieselmann-Straße 6	D – 75438 Knittlingen
Kopp	Kopp Pipetronix GmbH	Hygienic Design	Friedrich-Ebert-Straße 131	D – 49811 Lingen
KSB	KSB Aktiengesellschaft	Pumps	Johann-Klein-Straße 6	D – 67227 Frankenthal
Lang & Peitler	Lang & Peitler Automation GmbH	Control Systems	Am Herrschaftsweiher 23	D – 67071 Ludwigshafen-Ruchheim
Lauer Ludwigshafen	Alois Lauer Ludwigshafen Stahl- u. Rohrleitungsbau GmbH	Construction	Industriestraße 59	D – 67063 Ludwigshafen
Maihak	Maihak AG Prozess- und Umwelt-Meßtechnik	Leakage Sensors for pipelines	Semperstraße 38	D – 22303 Hamburg
Markert	A. Markert + Co GmbH	Hoses	Gadelanderstraße 135	D – 24539 Neumünster
Motan Materials	Motan Materials Handling GmbH	Bulk Materials	Birkenweg 12	D – 88250 Weingarten
Pepperl + Fuchs	Pepperl + Fuchs GmbH	Magnetic Sensors	Königsberger Allee 87	D – 68307 Mannheim
Pfeiffer	Pfeiffer Chemie-Armaturen GmbH		Hooghe Weg 41	D – 47906 Kempen
Pipetronix	Pipetronix GmbH		Lorenzstraße 10	D – 76297 Stutensee
Probst	H. Probst GmbH Armaturen-Recycling	Valve-Recycling	Robert-Bunsen-Straße 18	D – 67098 Bad Dürkheim
Resistoflex	Resistoflex GmbH	Hoses	Industriestraße 96	D – 75181 Pforzheim
Rohrbogen AG	Rohrbogen Pratteln AG	Prebent Pipe Sections		CH – 4133 Pratteln
Roth	Dieter A. Roth	Hoses	Boschstraße 1-3	D – 75204 Keltern
RSI	RSI GmbH	Construction	Auestraße 37-39	D – 67346 Speyer
Samson	Samson AG	Control Systems	Weismüllerstr. 3	D – 60314 Frankfurt
Sandvik	Sandvik GmbH	SS-Pipes	Heerdter Landstraße 229-243	D – 40035 Düsseldorf
Sewerin	Hermann Sewerin GmbH	Pig Detection	Postfach 2851	D – 33326 Gütersloh
Sterling Fluid Systems	SIHI-Halberg Vertriebsgesellschaft mbH	Pumps	Neustadter Straße 37-39	D – 68309 Mannheim
Skibowski	SJ Technischer Service	Test pigging	Schierenberg 74	D – 22149 Hamburg
Südmo	Südmo Holding GmbH	Hygienic Design	Industriestraße 7	D – 73469 Riesbürg
Techno Pipe	Techno Pipe Gesellschaft für Pipeline- und Anlagentechnik mbH	Pigs for pipelines	Johann-Gutenberg-Straße 5	D – 61271 Wehrheim
Tecno Plast	Tecno Plast Industrie-technik GmbH	Hoses	Willstätter Straße 5	D – 40549 Düsseldorf
Tüchenhagen	Tüchenhagen GmbH	IPU	Am Industriepark 2-10	D – 21514 Büchen
Turck	Hans Turck GmbH & Co KG	Magnetic Sensors	Witlehenstraße 7	D – 45472 Mülheim/Ruhr
Weber/Lauer	Weber/Lauer GmbH	Piping, construction	Dieselstraße 13	D – 50257 Pulheim

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