

Shell flow meter engineering handbook

2nd Edition 1985

Main contributors:

J.S. Battye
G.W.A. Danen
F.H. van der Heul
J.P. Jansen
P.B. Nanning

Edited by:

G.W.A. Danen

ROYAL DUTCH / SHELL GROUP

Mc GRAW-HILL
Book Company (UK) Limited

London • New York • St Louis • San Francisco • Auckland •
Bogotá • Guatemala • Hamburg • Johannesburg • Lisbon •
Madrid • Mexico • Montreal • New Delhi • Panama • Paris •
San Juan • São Paulo • Singapore • Sydney • Tokyo • Toronto

**SHELL
FLOW METER ENGINEERING
HANDBOOK**

British Library Cataloguing in Publication Data

Shell flow meter engineering handbook. – 2nd ed.

1. Flow meters

I. Battye, J.S. II. Danen, G.W.A.

681'.2 TC177

ISBN 0-07-084798-3

Library of Congress Cataloging-in-Publication Data

Shell flow meter engineering handbook.

Bibliography: p.

Includes index.

1. Flow meters-Handbooks, manuals, etc. I. Battye, J.S.

II. Danen, G.W.A.

III. Koninklijke

Nederlandsche Petroleum Maatschappij.

TJ935.S47 1985 681'.2 85-19918

ISBN 0-07-084798-3

Copyright © 1985 Shell Internationale Petroleum Maatschappij B.V. The Hague, the Netherlands.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior permission of Shell Internationale Petroleum Maatschappij B.V.

RESPONSIBILITY - Though this handbook has been prepared by highly qualified and experienced experts while exerting utmost care and diligence, neither the authors nor the publishers accept any responsibility, financial or other, for the contents of this handbook, whether in terms of correctness, completeness or otherwise. The application, therefore, by the users of this handbook, or any part thereof, is at their own full risk.

Printed and bound in the Netherlands by
Wolters-Noordhoff Grafische Bedrijven bv, Groningen

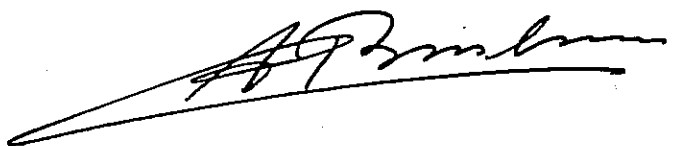
Foreword

The guiding principles for the 2nd edition of this publication are the same as for the previous edition i.e. to provide a systematic compilation of instructions and basic rules for the design and calculation of differential pressure flow meters, so that it forms a convenient handbook for all possible users.

This publication has undergone revisions with regard to the 1st publication in order to:

1. Remain in line with the internationally recognized standard practices, i.e. ISO recommendation 5167 of 1980.
2. Adapt to the changing methods in engineering, where the programmable calculator has become a standard tool.

Shell specialists have critically examined the requirements as defined by the above ISO publication and practical solutions are given for some ISO requirements which are difficult to meet. In this way Shell has endeavoured to make a continued contribution to a more efficient and economic use of these devices in industry and science at large.



Head Instrument Department
Shell Internationale Petroleum
Maatschappij B.V.

Contents

Section	1. General
	1.1 Preface
	1.2 Introduction
	1.3 General nomenclature
Section	2. Flow meter selection
	2.1 General
	2.2 Selection flow charts
	2.3 List of numbered error messages
	2.4 Choice of flow measuring device
Section	3. Square edge orifices
	3.1 Square edge orifice with flange tappings
	3.2 Square edge orifice with corner tappings
	3.3 Square edge orifice with radius tappings
Section	4. Orifices with special entrance forms
	4.1 Quarter of circle orifice
	4.2 Conical entrance orifice
Section	5. Non-concentric orifices
	5.1 Segmental orifices
Section	6. Venturi-type devices
	6.1 Venturi tube (classical)
	6.2 Rectangular Venturi tube
Section	7. Nozzles
	7.1 ISA 1932 nozzle
	7.2 Long radius nozzle
Section	8. Centrifugal force devices
	8.1 Pipe bend (90°)
Section	9. Velocity head devices
	9.1 Pitot tube
Section	10. Special applications
	10.1 Prefabricated orifice meter runs
	10.2 Integral orifices
	10.3 Restriction orifices
	10.4 Special intake devices
	10.5 Flow straighteners
Section	11. Flow meter installation and construction
	11.1 General
	11.2 Pipe orientation and flow direction
	11.3 Orientation of the flow meter in relation to the pipe axis
	11.4 Straight length requirements
	11.5 Locally fabricated orifice meter runs

Section	12. General considerations
	12.1 The principle of differential pressure flow measurement
	12.2 Orifice plate designs
	12.3 Orifice flange designs
	12.4 Specification of pipework upstream and downstream the flow meter
	12.5 Upstream and downstream straight lengths requirements
Section	13. Uncertainties
	13.1 Understanding a differential pressure flow meter's output reading
	13.2 The accuracy of differential pressure flow meters over their meter range
	13.3 The uncertainty of flow measurement
	13.4 Typical uncertainties
	13.5 Guide to the effects of a departure from the standards
Section	14. General data
	14.1 Reynolds Number and viscosity
	14.2 Standard pipe diameters ANSI and DIN
	14.3 Pipe wall roughness
	14.4 Steam quality correction factor

APPENDICES

Appendix A	– Flow meter sizing
Appendix B	– Flow factor calculation
Appendix C	– Computer flow calculation program

Section 1. General

1.1 Preface

1.2 Introduction

1.3 General nomenclature

1.1 PREFACE

The main purpose of this handbook is to provide data for the instrument engineer to select, calculate, design and install flow meters.

Essentially this handbook provides data for differential pressure type flow meters only, except for the guidelines on selection and installation, where a wider range of flow meters has been covered. The reason for this approach is, that the differential pressure type flow meter still has preference over all other types of flow meters in the larger part of the applications, they are reasonably well defined in internationally recognized standards and test results on these types of flow meter are available over a long period. For the other types of flow meter such as turbine, vortex, positive displacement meters, the design data have generally to be obtained from individual suppliers.

In revising this handbook the emphasis has been on making it easy for the engineer to find his way in designing a particular type of flow meter without having to consult other (hand)books or standards, except for obtaining certain physical data, or having to study this book in full detail before the actual design work can start. The engineer using this handbook should have available a (handheld) programmable calculator for the calculations. Tables are included only when no suitable alternative formulae can be given.

Physical data have been given to a limited extent only since these tend to change regularly in details and are normally available to the user.

Some basic principles on the functioning of differential pressure flow meters have been included for completeness.

For the square edge orifice flow meter, which is the type normally used, the ISO recommendation 5167 of 1980 has been followed, however the design has been amended in some details for practical and economic reasons. Therefore clarification and proposed deviations from the above standard together with the approximated consequences on the accuracy of flow measurement have been given where possible. When other standards are followed these are also dealt with in the handbook in the same way as the ISO standard above.

It has taken many manhours to finalize this handbook. In addition to the main contributors listed on the title page, many other engineers and designers, draughtmen, editors and typists have contributed to the book. They are too many to list but their contribution is greatly appreciated.

A special word of thanks to the management of Shell Internationale Petroleum Maatschappij B.V. who have made the preparation and printing of this handbook possible.

Comments are welcomed from all users and should be addressed to:

Shell Internationale Petroleum Maatschappij B.V.

MFEE/4, PO Box 162

2501 AN The Hague – the Netherlands.

1.2 INTRODUCTION

Where cross references are made to (sub)sections in this handbook, the relevant (sub)sections are shown in brackets.

Essentially this handbook can be divided in 4 parts as follows:

- Guidelines on the selection of flow meters (2).
- Guidelines on the design and calculation of flow meters (3) to (10).
- Guidelines on the installation of flow meters (11).
- General information such as uncertainties, background information on the methods of flow meter design, installation and physical data (12) to (14).

The basis for the selection of flow meters (2) are the flow charts (2.2) and related error messages (2.3). In addition, a general flow meter survey is included (2.4.1) together with graphs which indicate the limitation and ranges of application for various flow meters (2.4.2, 2.4.3 and 2.4.4).

The above flow charts with error messages, together with the data given in this handbook for various flow meter designs could form the basis for a flow meter selection and sizing computer program (Appendix C).

ISO recommendation 5167 (1980), further referred to in this document as ISO 5167, forms the basis for the design and calculation of most of the differential pressure type flow meters as indicated in the references of (sub)sections (3) to (10). The same data are also published as BS 1042 of 1981.

BS 1042, part I (1964) still forms the basis for the design of quarter of circle and conical entrance type differential pressure flow meters (4).

For some special applications, reference is made to the ASME codes and in house information.

Special flow devices such as prefabricated orifice meter runs, integral orifices, restriction orifices, special intake devices and flow straighteners are discussed in section (10). Restriction orifices and flow straighteners are added only for completeness.

Standard forms for the sizing and flow factor calculation of various differential pressure type flow meters are included in (Appendix A) and (Appendix B).

The related software programs are included in basic language.

These standard forms present a simple tool for the instrument engineer to size a flow meter or to define its flow factor.

An accurate installation of the flow meter is as essential as the flow meter design itself and guidelines for flow meter installation are therefore given in section (11).

An explanation of differential pressure type flow meters is given in section (12) for those instrument engineers who do not have a background in physics.

In the same section (12) a clarification is given on the differences between the ISO 5167 guidelines and the recommended practices given in this handbook.

These recommendations are given for practical and economic reasons and serve, with regard to a slight increase in the uncertainties, the larger part of flow meter applications.

Based on the design data of the flow meter and the installation, the uncertainties can be assessed, section (13). ISO 5167 forms the basis for defining the uncertainties, however the approximated uncertainties for non-ISO installations as discussed in (12) have also been included.

The essential physical data for the design of flow meters are given in section (14).

Physical data on process fluids have been omitted and are considered to be readily available to the user.

The data given in this handbook are in SI units as far as possible and the nomenclature used is given in (1.3).

1.3 GENERAL NOMENCLATURE

Symbol	Description	Dimension
a_B	total flow coefficient for pipe bends	—
a_p	ratio of average velocity and velocity at the point of measurement (usually the centre) for Pitot and Pitot-Venturi tubes	—
α	linear expansion coefficient of pipe material (α_{pipe}) or orifice material (α_{plate}) or flow meter material (α_{Venturi} , α_{nozzle})	—
β	diameter ratio of orifice or throat and inside diameter of line	—
C	coefficient of discharge	—
D	internal pipe diameter (upstream) at operating temperature	mm
d	orifice or throat diameter at operating temperature	mm
$(\cdot)_{\text{des}}$	at design conditions	—
d_m	orifice or throat diameter measured at temperature T_o	mm
DP	differential pressure transmitter	bar
dp	differential pressure at X (scale reading factor) $dp = DP(X/10)^2$	bar
D_m	internal pipe diameter (upstream) measured at temperature T_o	mm
ϵ	expansibility or expansion factor, a correction required to take into account the effects of expansion as a compressible fluid flows through a restriction	—
F_s	correction factor for the steam quality (moisture content)	—
H	height of upstream conduit (rectangular Venturi)	mm
h	height of throat (rectangular Venturi)	mm
k	absolute roughness = the average peak-to-hollow height	mm
k/D	relative roughness	—
κ	$\frac{C_p}{C_v} = \frac{\text{specific heat at constant pressure}}{\text{specific heat at constant volume}}$	—
L_{U1}	distance between flow meter and first upstream fitting (straight length requirement)	mm
L_{U2}	distance between first upstream fitting and second upstream fitting (straight length requirement)	mm
L_{D1}	distance between flow meter and first downstream fitting (straight length requirement)	mm
M_p	Pitot tube factor (depends on construction of Pitot tube)	—
η	dynamic or absolute viscosity	mPa·s
p	absolute static pressure of the fluid at the upstream pressure tapping (gauge pressure + local barometric pressure)	bar
q_m	mass flow rate	kg/s
r	radius of curvature of the entrance form of a quarter of circle orifice	mm
R	radius of curvature of a pipe bend	mm

Re_d	orifice or throat Reynolds Number	—
Re_D	pipe Reynolds Number	—
ρ	density. This is the mass of a substance per unit volume	kg/m ³
T_o	ambient temperature	°C
T	operating temperature	°C
V_D	mean velocity in pipe	m/s
V_d	mean velocity in orifice throat	m/s
ν	kinematic viscosity	mm ² /s
W	width of upstream conduit (rectangular Venturi)	mm
w	width of throat (rectangular Venturi)	mm
X	scale reading factor	—
y	diameter bleed hole	mm
Z_{ReD}	roughness correction factor corrected with Reynolds Number	—
Z_o	roughness correction factor	—

Section 2. Flow meter selection

- 2.1 General
- 2.2 Selection flow charts
- 2.3 List of numbered error messages
- 2.4 Choice of flow measuring device
 - 2.4.1 Flow meter survey
 - 2.4.2 Lower and upper Re_D limits
 - 2.4.3 Mass flow rate limits
 - 2.4.4 Values of nett pressure losses

2.1 GENERAL

The following flow charts have been developed to provide a means of selecting flow meters. Although primarily concerned with orifice plate flow meters, Venturis and other types are included with recommendations for their application.

The order of preference for differential pressure flow meters is as follows:

1. Orifice flow meters are preferred to any other.
2. Flange tapings are preferred to corner tapings.
3. Square edge plates are preferred to conical entrance plates.
4. Conical entrance plates are preferred to quarter of circle plates.

The discussion on which flow meter is suitable for the given service is largely based on the limitations of use as laid down in ISO 5167 and BS 1042 (1964 and 1981).

The charts consider only pipe size, orifice or throat diameter, beta ratio and Reynolds Number limitations.

Note that for all trial calculations it is sufficient to assume initially that all orifice flow meters have a discharge coefficient of 0.6, Venturi and nozzle meters have a discharge coefficient of 1 and that the expansivity and velocity of approach factors $(1-\beta^4)^{-1/2}$ for all types of meters are 1.0. Thus for a quick approximate calculation to expedite the use of the flow diagram:

$$\text{For orifice flow meters : } d = \sqrt{\frac{q_m \cdot 10^4}{2.1 \sqrt{dp} \sqrt{\rho}}}$$

$$\text{For Venturi flow meters : } d = \sqrt{\frac{q_m \cdot 10^4}{3.5 \sqrt{dp} \sqrt{\rho}}}$$

Where: d = the orifice diameter in millimetres
 q_m = the mass flow rate in kilograms per second
 dp = the differential pressure range in bars and
 ρ = the density of the fluid in kilograms per cubic metre

After selecting the preferred flow instrument, the calculations should be performed as appropriate and further discussed in this handbook.

A further discussion on the choice of flow measuring devices is given in (2.4).

2.2 SELECTION FLOW CHARTS

The flow charts guide the various steps to be taken while selecting flow meters. Each step can be either a calculation, a selection or a test.

Tests can either pass or fail.

For further details on calculations and design of differential pressure type flow meters, see the following sections:

- Section 3. Square edge orifices
- Section 4. Orifices with special entrance forms
- Section 5. Non-concentric orifices
- Section 6. Venturi-type devices
- Section 7. Nozzles
- Section 8. Centrifugal force devices
- Section 9. Velocity head devices
- Section 10. Special applications

Chart (2.0) gives an overall view of the selection, while charts (2.1) to (2.15) incl. provide guidance in selecting a flow meter.

A list of messages as indicated in the flow charts is given in section (2.3).

The recommendations given in the following charts and the related error messages, see section (2.3), may eventually have to be corrected.

For example chart (2.1) suggests that the turndown ratio of a differential pressure transmitter should be limited to 3:1.

Developments on these types of transmitters may result in the acceptance of a higher turndown ratio per transmitter.

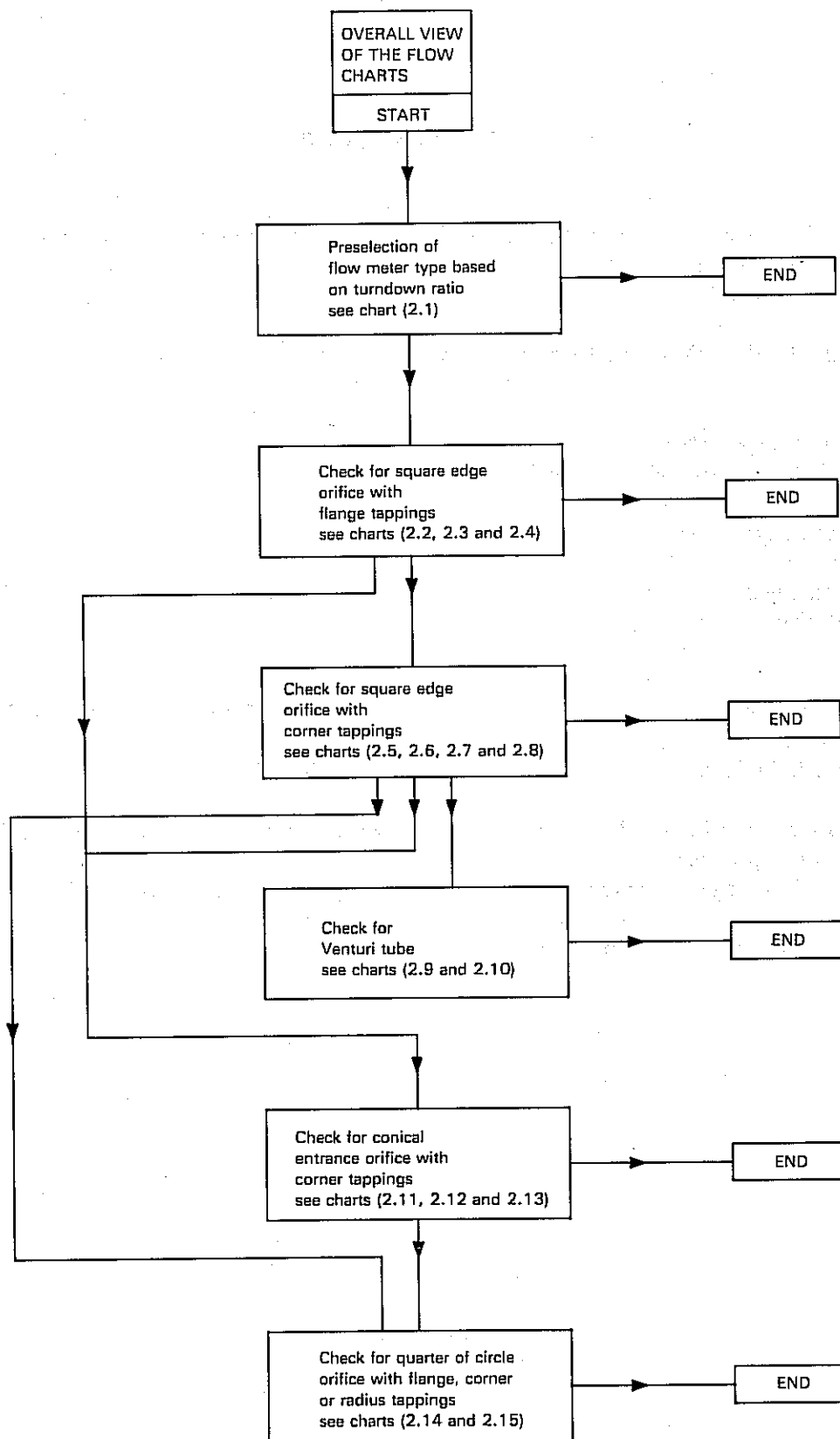


Chart 2.0 Overall view of the flow charts

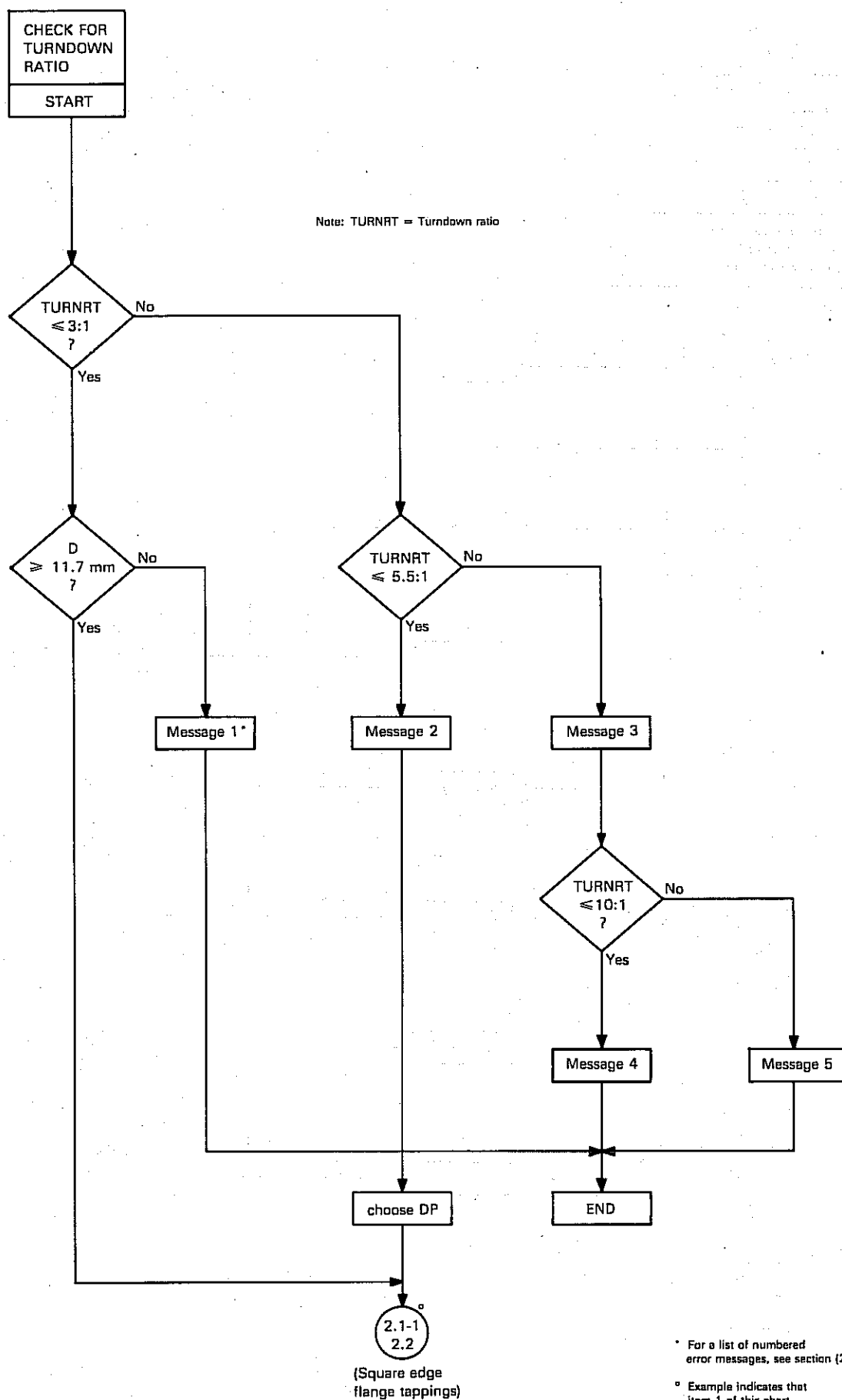


Chart 2.1 Preselection of flow meter type based on turndown ratio

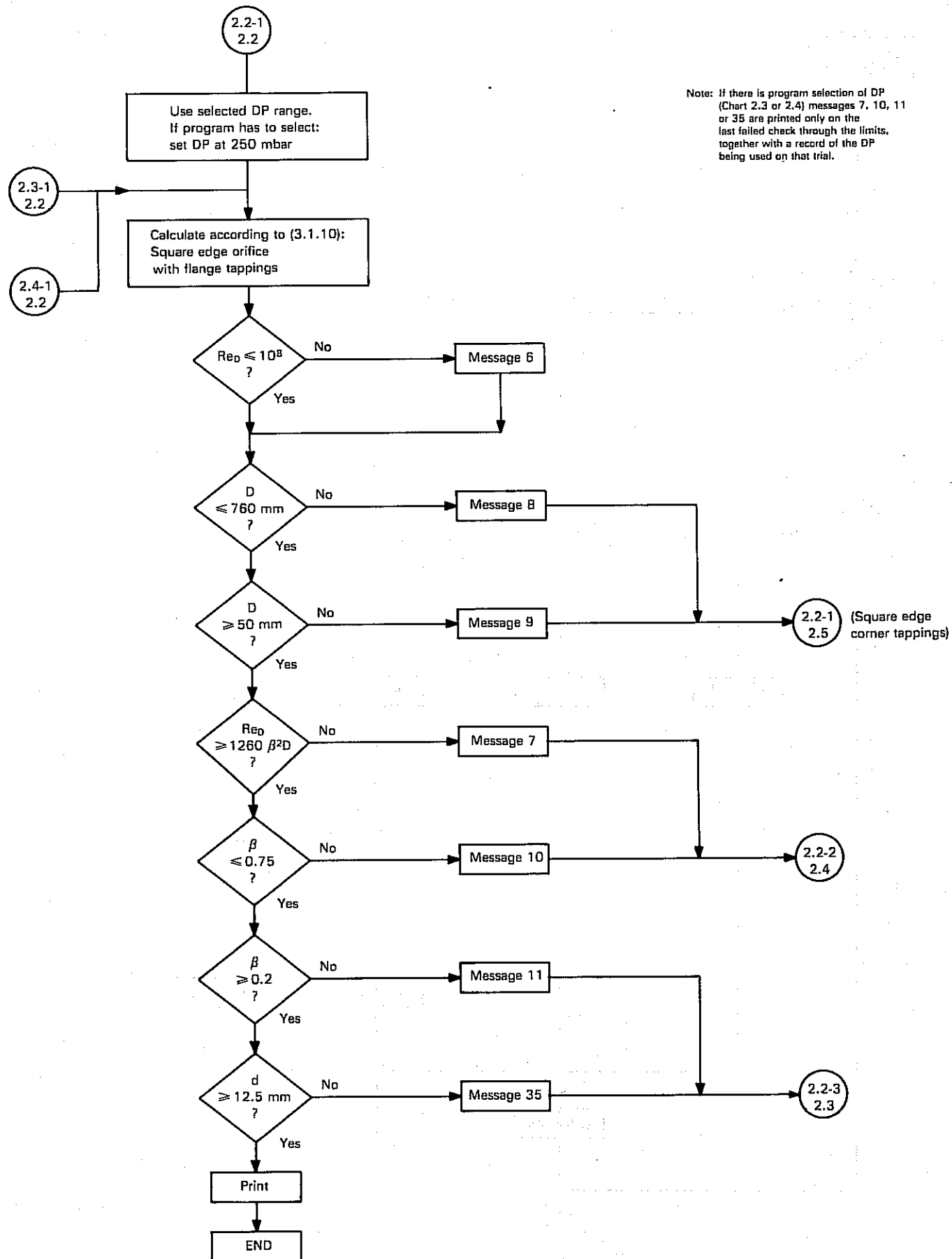


Chart 2.2 Check for square edge orifice with flange tappings

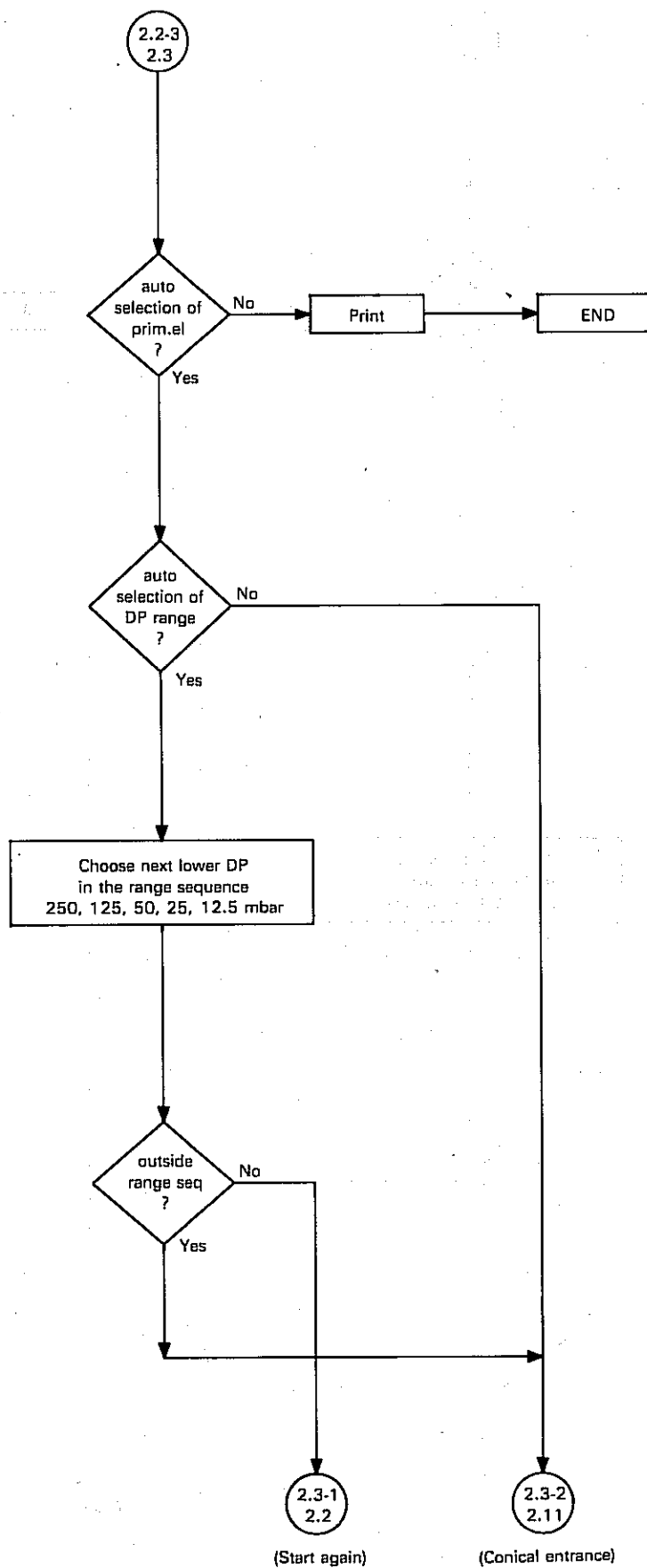


Chart 2.3 Check for square edge orifice with flange tapplings (continued)

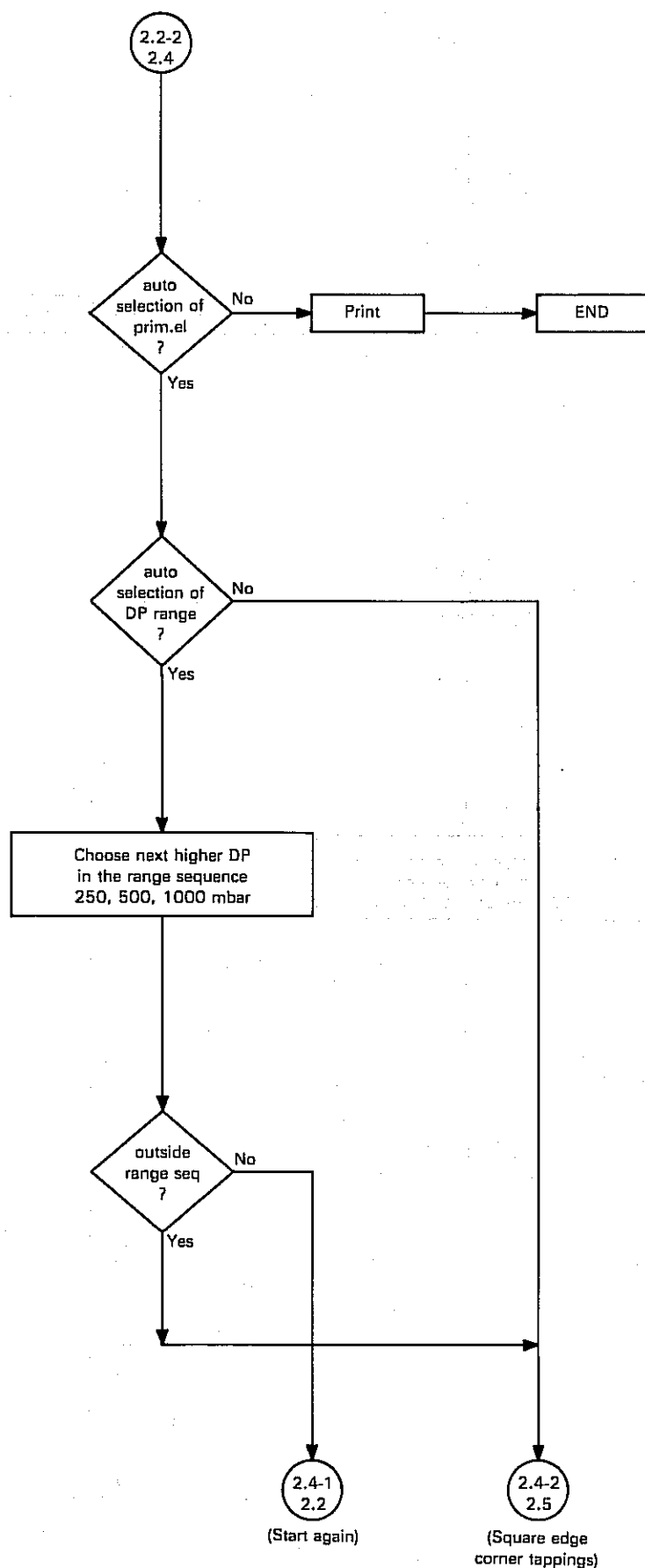


Chart 2.4 Check for square edge orifice with flange tappings (continued)

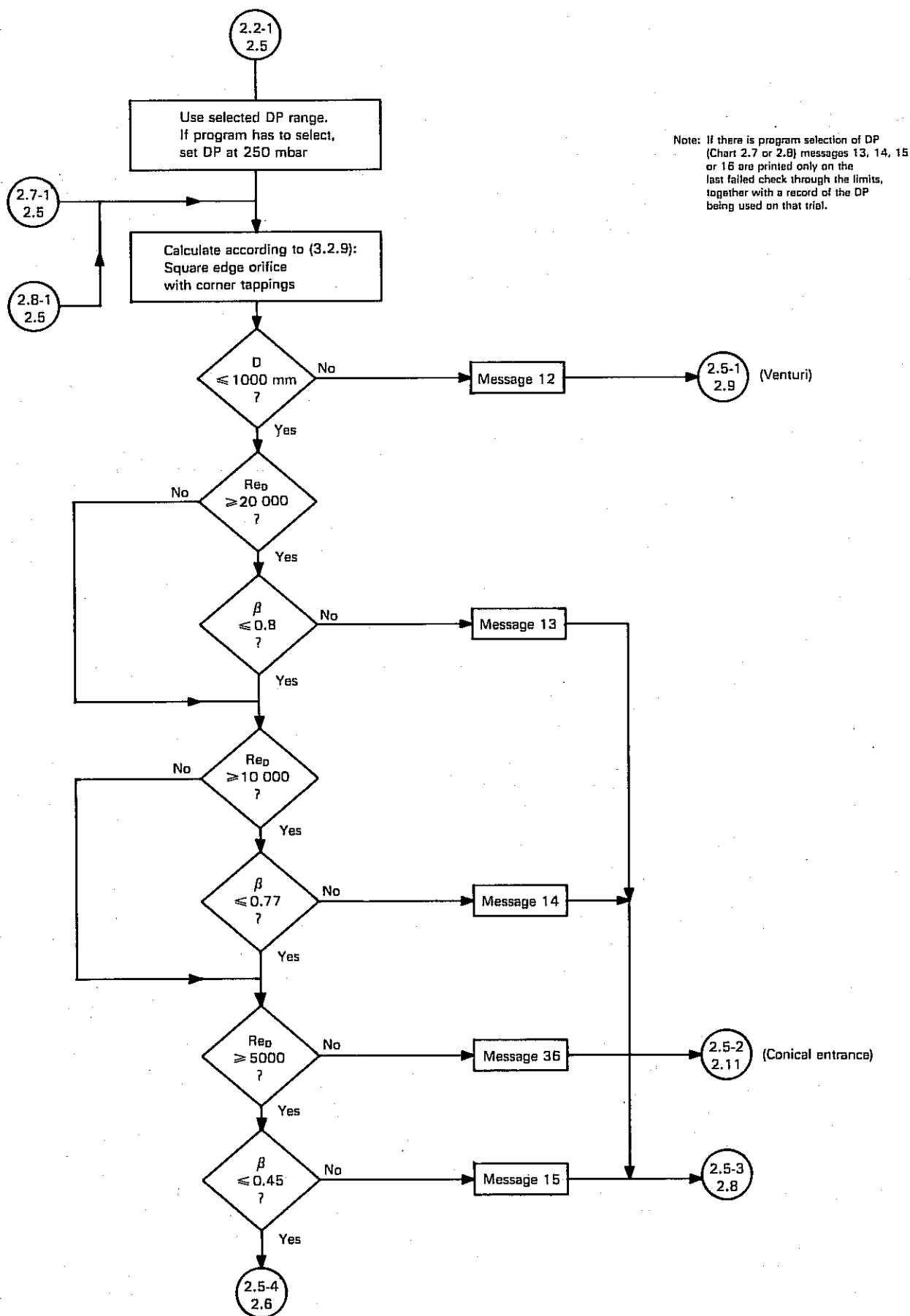


Chart 2.5 Check for square edge orifice with corner tapings

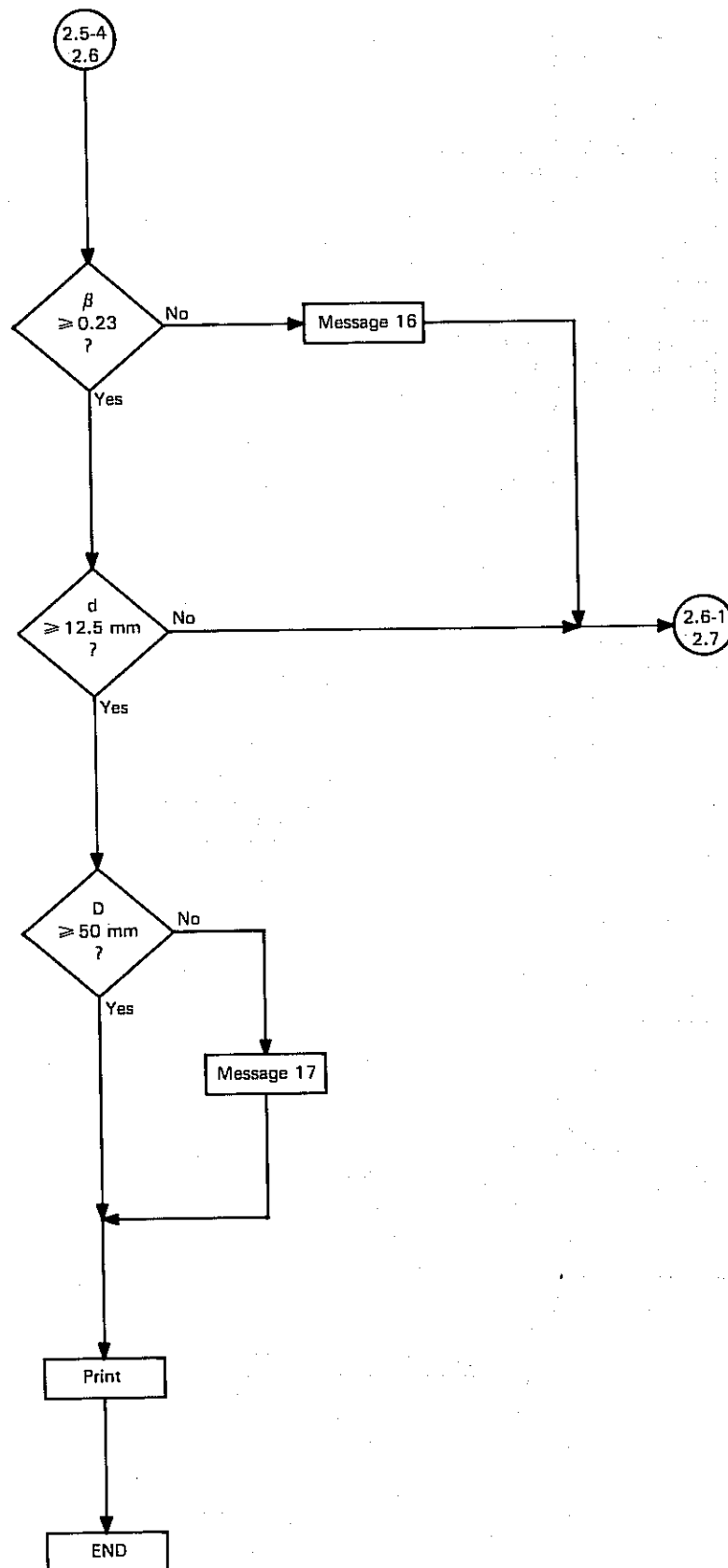


Chart 2.6 Check for square edge orifice with corner tappings (continued)

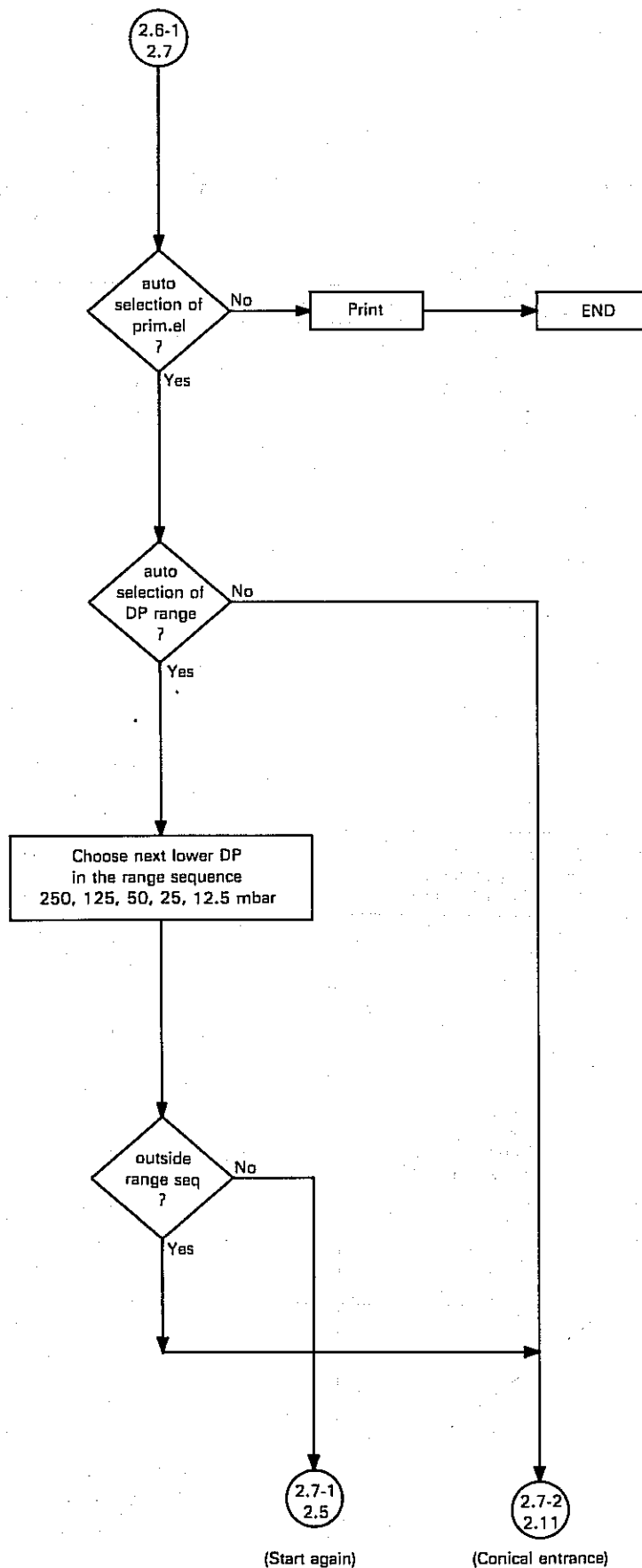


Chart 2.7 Check for square edge orifice with corner tappings (continued)

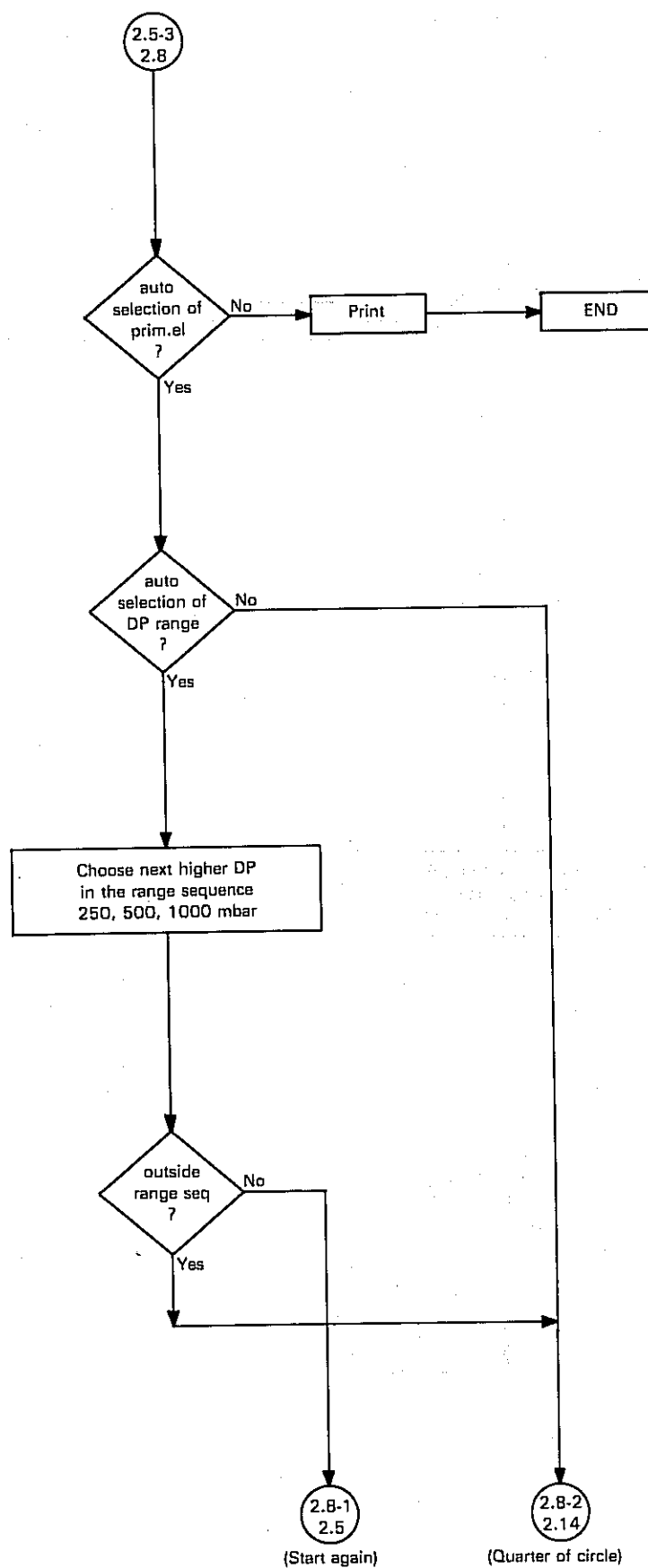
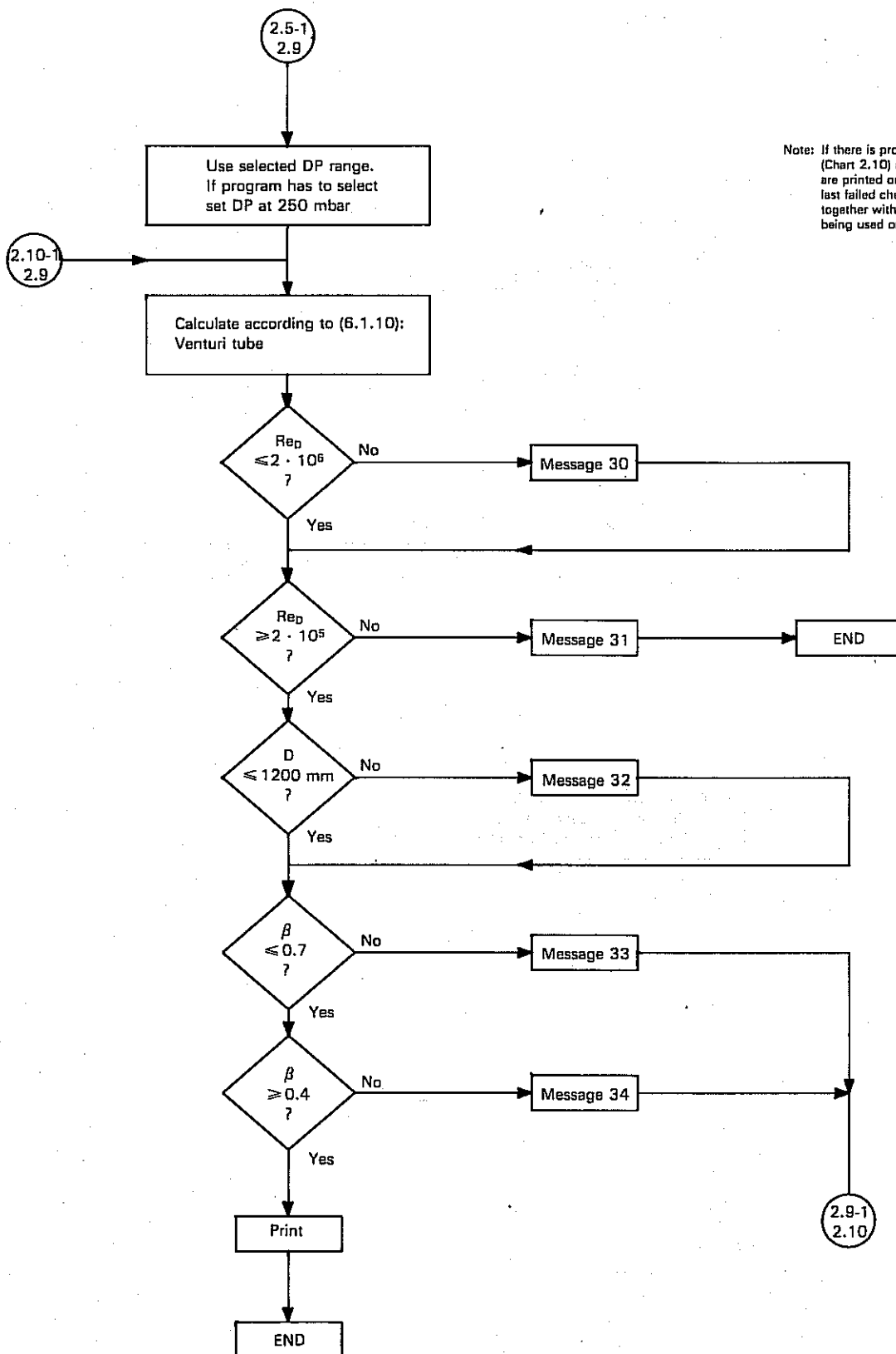


Chart 2.8 Check for square edge orifice with corner tappings (continued)



Note: If there is program selection of DP (Chart 2.10) messages 33, 34 are printed only on the last failed check through the limits, together with a record of the DP being used on that trial.

Chart 2.9 Check for Venturi tube

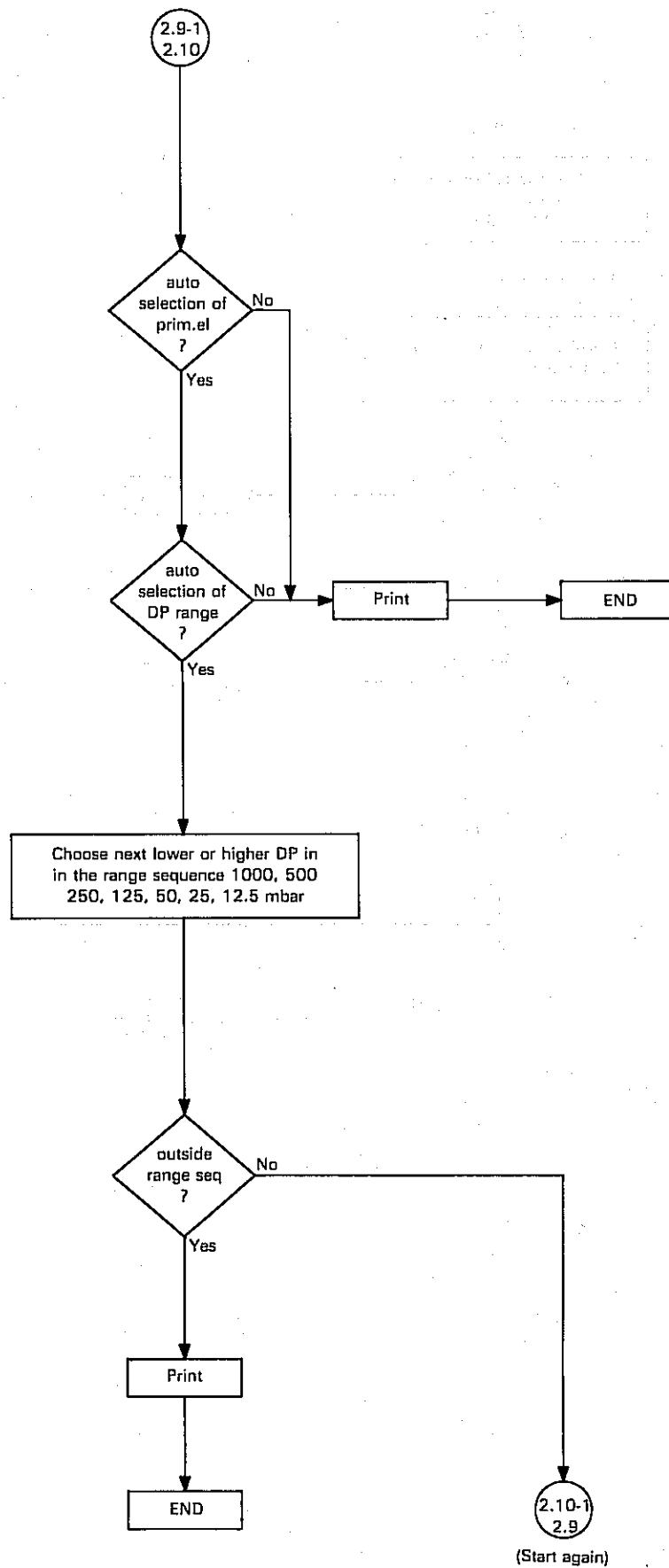


Chart 2.10 Check for Venturi tube (continued)

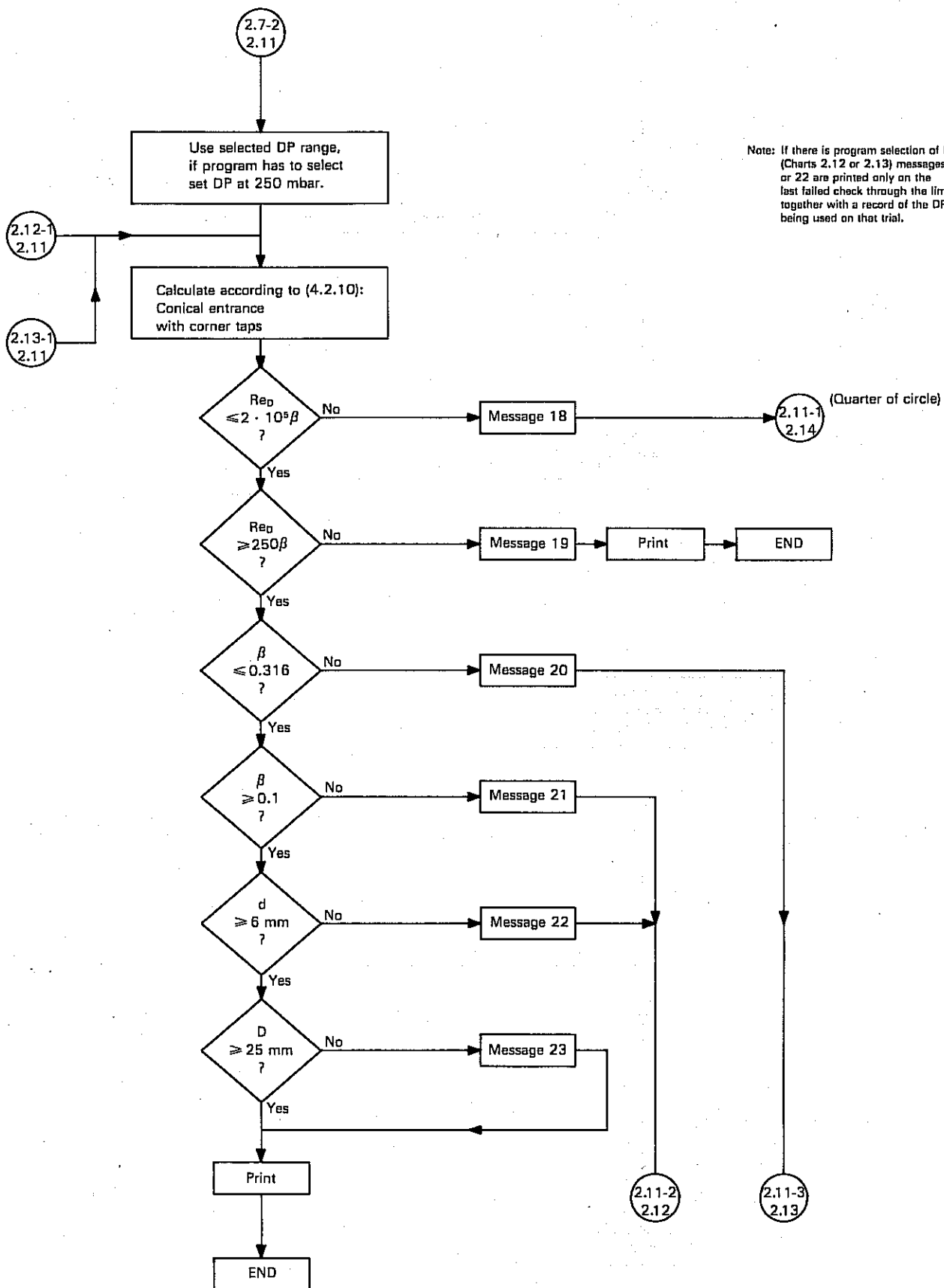


Chart 2.11 Check for conical entrance orifice with corner tappings

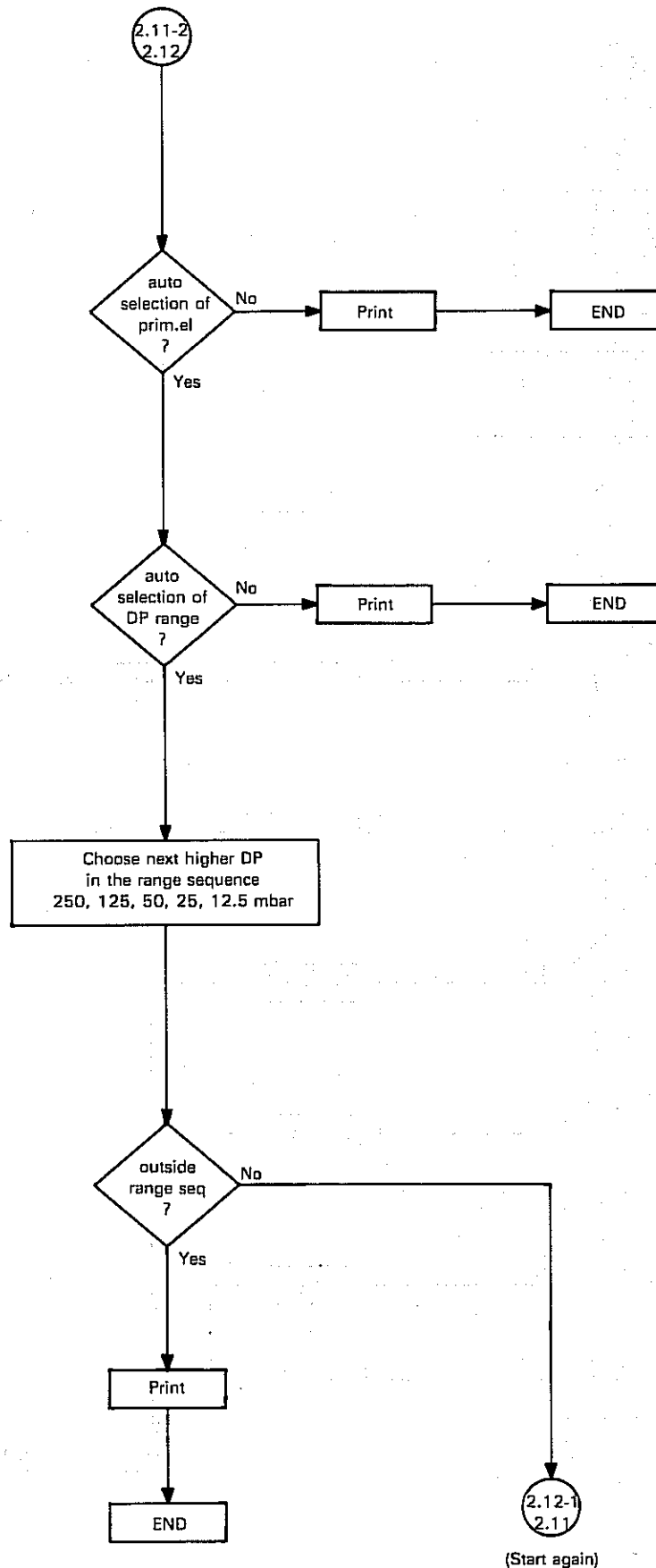


Chart 2.12 Check for conical entrance orifice with corner tappings (continued)

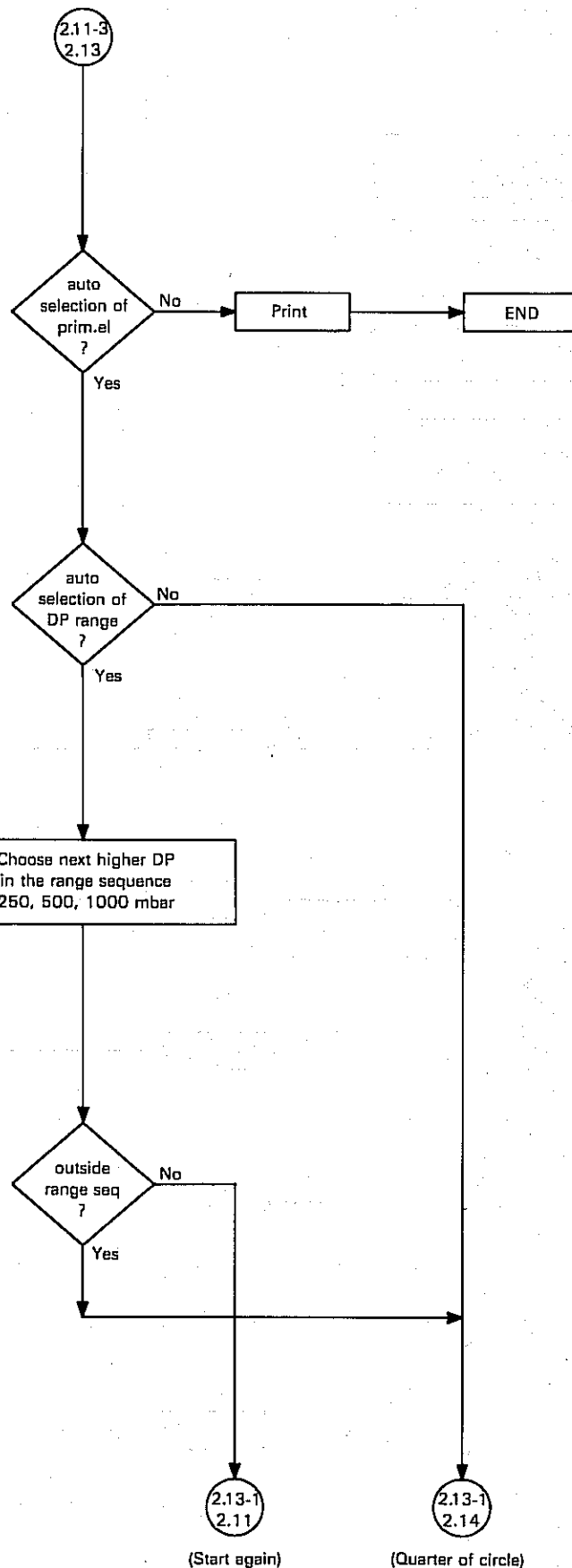
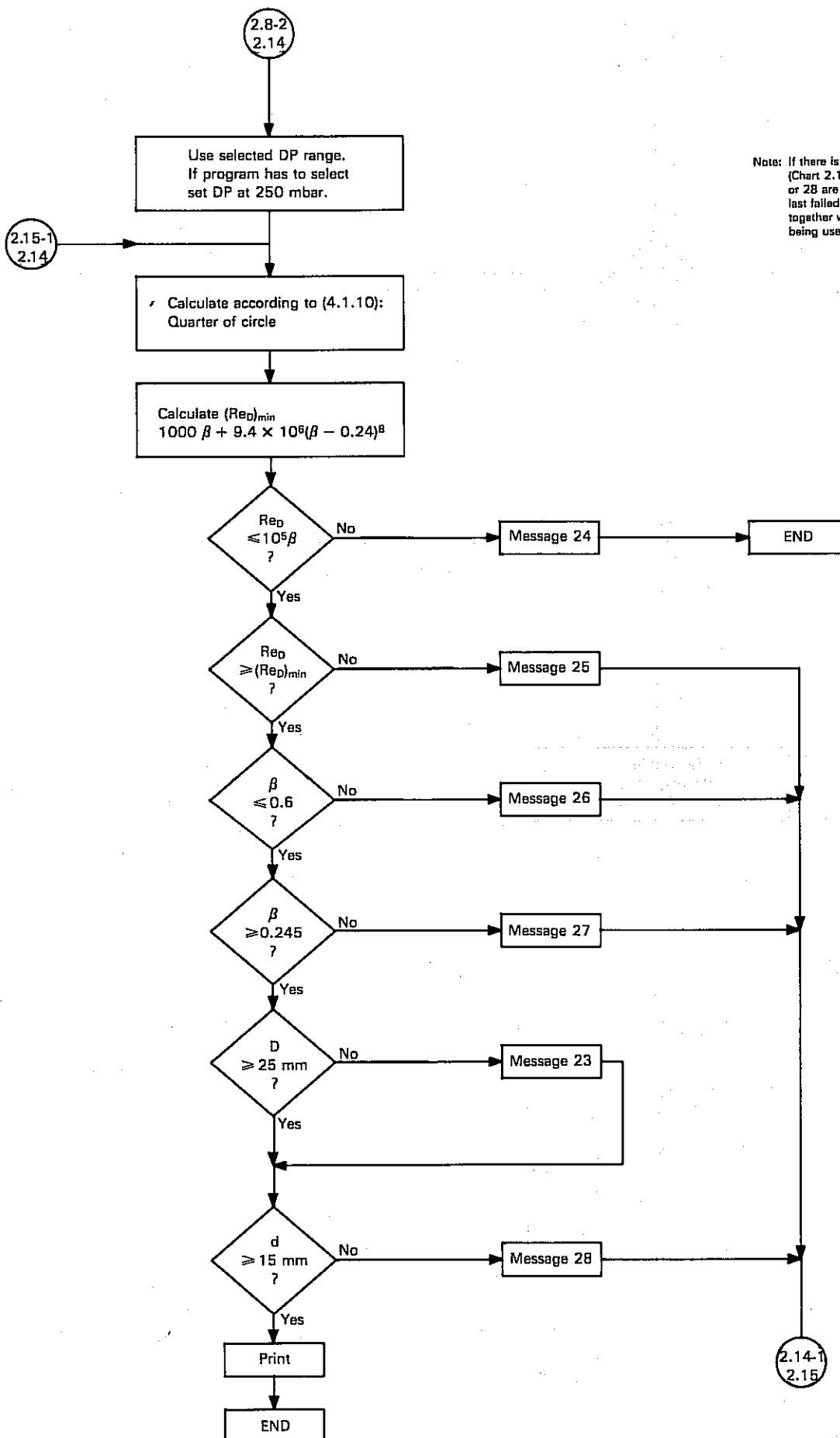
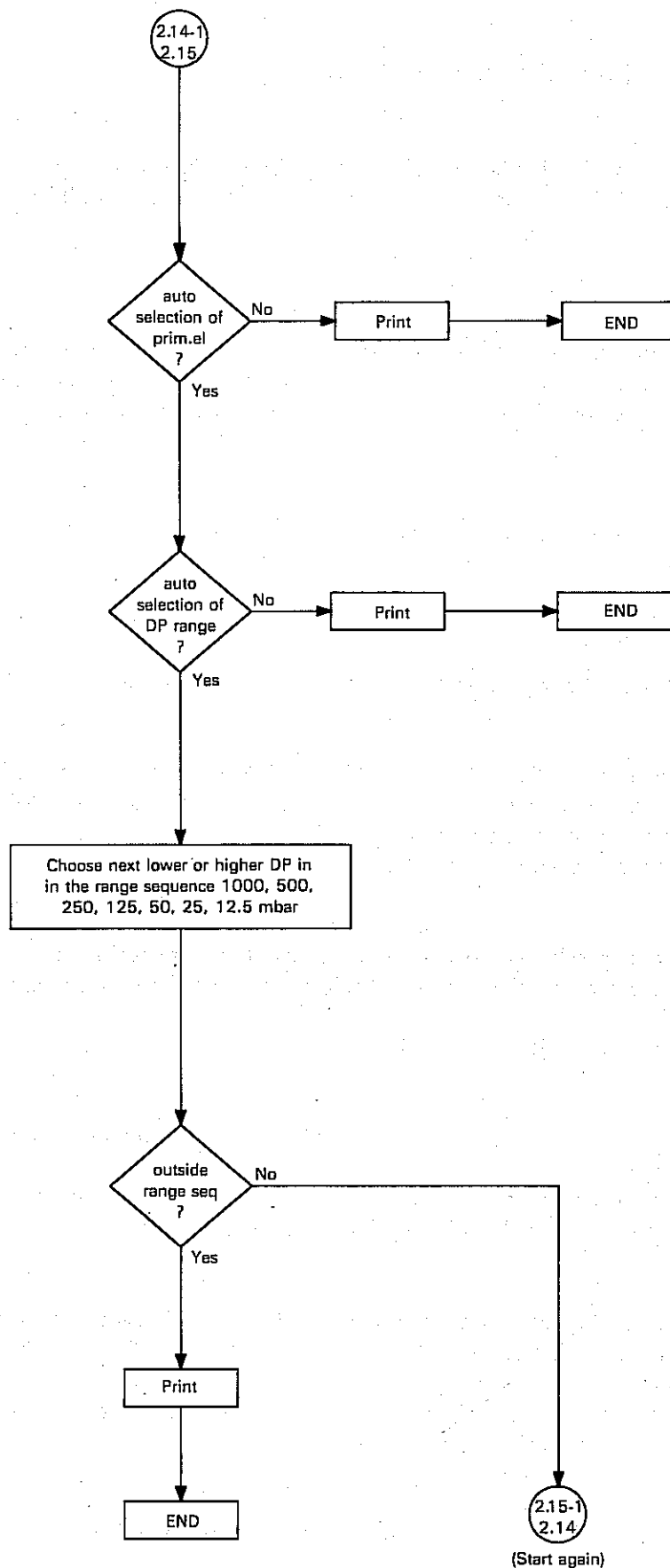


Chart 2.13 Check for conical entrance orifice with corner tappings (continued)



Note: If there is program selection of DP (Chart 2.15) messages 25, 26, 27 or 28 are printed only on the last failed check through the limits, together with a record of the DP being used on that trial.

Chart 2.14 Check for quarter of circle orifice with flange, corner or radius tappings



**Chart 2.15 Check for quarter of circle orifice with flange, corner or radius tappings
(continued)**

2.3 LIST OF NUMBERED ERROR MESSAGES

The messages indicated in the flow charts of section (2.2) are listed below.

A computer which runs a selection procedure as shown in (2.2) should typically produce these messages (See Appendix C).

Note : xxxxx represents case dependent generated output.

Message 1

Orifice plate, Venturi and nozzle not acceptable for small line size. Minimum line size for orifice flow meter is DN 15, nominal. Possible suitable types of flow meter are: integral orifice, variable area, turbine, electromagnetic, micromotion, linear plug. Check details of requirement with manufacturers literature.

Message 2

Range requirement can be met using a flow meter with two differential pressure transmitters (dp cells). Program being continued on the assumption that a flow meter with two dp cells will be used if all other conditions allow.

Message 3

Range requirement cannot be met using a flow meter with less than three dp cells.

Message 4

Large range requirement precludes the use of differential pressure type flow meters.

Consider the use of: electromagnetic, vortex, positive displacement, turbine, variable area, gifflo, hot wire/thermistor or film anemometer, ultrasonic flow meters.

Check details of requirement with manufacturers literature.

Message 5

Large range requirement precludes most common forms of flow metering.

Consider the use of: electromagnetic, vortex, gifflo, hot wire/thermistor or film anemometer, ultrasonic flow meters.

Check details of requirement with manufacturers literature.

Message 6

Reynolds Number of xxxxx is greater than the ISO 5167 limit of 100 000 000 for any type of differential pressure flow metering.

No other type of flow meter known is suitable for such a condition. Check accuracy of input data.

Consider decreasing the Reynolds Number by increasing the line size.

Message 7

Flange tapped, square edge orifice flow meter rejected because the minimum Reynolds Number of xxxxx is lower than the ISO 5167 limit of $1260 * (\beta)^{0.75} * D$, ($\beta = \text{xxxxx}$, $DP = \text{xxxxx mbar}$) for the flange tapped orifice flow meter.

Consider reducing beta by accepting a higher DP range up to 1 bar but check the acceptability of the overall pressure loss. Consider using a smaller line size.

Message 8

Flange tapped, square edge orifice flow meter rejected because the line size is greater than the ISO 5167 limit of 760 mm.

Consider using a smaller line size. If the program is re-run with the same line size specifying flange tappings, the flange tapped orifice calculation will be executed, but the actual uncertainty of flow measurement will be greater than calculated.

Message 9

Flange or radius tapped orifice flow meter rejected because the line size is less than the ISO 5167 limit, DN 50. Consider orifice flange with corner tappings.

Message 10

Flange tapped, square edge orifice flow meter rejected because the calculated beta ratio of xxxxx (DP = xxxxx mbar) is above the ISO 5167 limit of 0.75.

Consider using a higher DP range so that beta ratio ≤ 0.75 , but check the acceptability of the overall pressure loss.

Note: The recommended limit for β is 0.7 in view of standardized piping arrangements.

Message 11

Flange tapped, square edge orifice flow meter rejected because the calculated beta ratio of xxxxx (DP = xxxxx mbar) is below the ISO 5167 limit of 0.2.

Consider using a lower DP range, down to minimum 12.5 mbar, to achieve a larger beta ratio.

Message 12

Corner tapped orifice flow meter rejected because the line size is greater than the ISO 5167 limit of 1000 mm.

Consider using a smaller line size. If program is re-run specifying corner tappings, the corner tapped orifice calculation will be executed but the actual uncertainty of flow measurement will be greater than calculated.

Message 13

Corner tapped, square edge plate orifice flow meter rejected because the calculated beta ratio of xxxxx (DP = xxxxx mbar) is above the ISO 5167 limit of 0.8.

Consider reducing beta by using a higher DP range but check the acceptability of the overall pressure loss.

If the total head loss is too high consider classical Venturi (or the Venturi nozzle, Dall tube).

Message 14

All types of differential pressure flow metering rejected because of the calculated unacceptable combination of low Reynolds Number of xxxxx and high beta ratio xxxxx (DP = xxxxx mbar).

The only possibility for differential pressure type flow metering is the use of a higher DP range so that the beta ratio becomes < 0.77 .

Check the acceptability of the overall pressure loss.

Message 15

All forms of square edge orifice flow metering are rejected because the calculated Reynolds Number of xxxxx is too low and (calculated) beta ratio of xxxxx (DP = xxxxx mbar) too high. The only possibility of using square edge orifices is the use of a higher DP range so that the beta ratio becomes < 0.45 .

Check the acceptability of the overall pressure loss.

Message 16

All types of square edge orifice flow meters rejected because of the unacceptable combination of the calculated low Reynolds Number xxxxx and high beta ratio xxxxx (DP = xxxxx mbar). A square edge orifice could be used if a lower DP range is acceptable (down to min. of 12.5 mbar) so that the beta ratio becomes ≥ 0.23 .

Alternatively, the DP range could be kept the same (or increased) by decreasing the line size.

Message 17

Special corner tapped meter run should be applied for this pipe size. For all pressure ratings up to 2500 lbs the recommended design, see (10.1.9), has within 0.2 mm, a 32 mm bore for the nominally DN 40 flow meter, a 21 mm bore for the nominally DN 25 flow meter, a 17 mm bore for the nominally DN 20 flow meter and a 12 mm bore for the nominally DN 15 flow meter. For these designs a maximum roughness of 0.004, 0.003, 0.002 or 0.001 mm respectively has to be specified. The actual diameters shall be measured after manufacturing.

Message 18

The conical entrance orifice flow meter is rejected because the calculated maximum Reynolds Number of xxxxx is above the BS 1042 (1964) limit of 200 000. Check messages to discover why the use of a square edge orifice was rejected and endeavour to adjust requirements to make use of the square edge orifice plate.

Message 19

The conical entrance orifice flow meter is rejected because the calculated Reynolds Number of xxxxx is below the BS 1042 (1964) lower limit of 250.

If the application is only for control (not mass balance) and other flow meter types are undesirable, then re-run the program specifying a conical entrance orifice flow meter, but the actual uncertainty of the flow measurement will be greater than calculated.

Other flow meters which could be used are: positive displacement, variable area flow meters.

Message 20

The conical entrance orifice flow meter is rejected because the computed beta ratio of xxxxx (DP = xxxxx mbar) is above the BS 1042 (1964) limit of 0.316. Consider using a larger DP range but check the consequent acceptability of flow meter's total head loss. If the application is only for control (not mass balance) and other flow meter types are undesirable, then re-run the program specifying a conical entrance orifice flow meter, but the actual uncertainty of the flow measurement will be greater than calculated.

Message 21

The conical entrance orifice flow meter is rejected because the calculated beta ratio of xxxxx (DP = xxxxx mbar) is below the BS 1042 (1964) limit of 0.1. Consider using a lower DP range, down to a minimum of 12.5 mbar, in order to achieve a larger beta ratio.

Message 22

The conical entrance orifice flow meter is rejected because the calculated orifice diameter of xxxxx is below the BS 1042 (1964) limit of 6 mm. Consider a larger beta ratio by using a lower DP range, down to a minimum of 12.5 mbar.

Message 23

The line size of the meter run is below the BS 1042 (1964) limit of 25 mm.

Message 24

The quarter of circle orifice flow meter rejected because the calculated maximum Reynolds Number of xxxxx is above the BS 1042 (1964) limit of 100 000.

Message 25

The quarter of circle orifice flow meter rejected because the calculated minimum Reynolds Number of xxxxx is below the BS 1042 (1964) limit of xxxxx for the calculated beta ratio of (DP = xxxxx mbar). Consider using a higher DP up to 1 bar to get a smaller beta ratio and so lower the minimum Reynolds Number limit but check acceptability of the overall pressure loss. The lowest Reynolds Number limit allowed by BS 1042 (1964) for small beta ratios is 1000.

Message 26

All types of differential pressure flow metering are rejected because of the unacceptable combination of low Reynolds Number of xxxxx and the calculated high beta ratio of xxxxx (DP = xxxxx mbar). The only possibility for differential pressure type flow metering is to use a higher DP range so that the beta ratio becomes less than or equal to 0.6.

Check for the acceptability of the overall pressure loss. For $\beta = 0.6$, or just less, the only possibility is to use a quarter of circle orifice plate.

Message 27

The quarter of circle orifice flow meter is rejected because the calculated beta ratio of xxxxx (DP = xxxxx mbar) is below the BS 1042 (1964) limit of 0.245.

Consider using a lower DP range down to a minimum of 12.5 mbar.

Message 28

The quarter of circle orifice flow meter is rejected because the calculated orifice diameter of xxxxx (DP = xxxxx mbar) is less than the BS 1042 (1964) limit of 15 mm.

Consider using a lower DP range down to a minimum of 12.5 mbar.

Message 29

Note that the computer automatic selection routine considers a Venturi tube only to meet the ISO 5167 requirements within the line size 1000 mm to 1200 mm.

If a strict ISO 5167 metering or very low total pressure loss is not required, specify a much cheaper orifice flow meter, re-run the program and accept a slightly greater uncertainty in the flow measurement.

Message 30

The calculated maximum Reynolds Number of xxxxx is above the ISO 5167 limit of 2 000 000 but within the BS 1042 (1964) limit.

Consider decreasing the Reynolds Number by increasing the line size.

Venturi tube calculation continued but the uncertainty of flow measurement will be slightly greater than calculated.

Message 31

The Venturi tube is rejected because the calculated minimum Reynolds Number of xxxxx is below the ISO 5167 limit of 200 000. Consider increasing the Reynolds Number by decreasing the line size.

Message 32

The line size is greater than the ISO 5167 limit of 1200 mm, but is within the BS 1042 (1964) limit.

The uncertainty of flow measurement will be slightly greater than calculated.

The calculation based on a Venturi tube is continued.

Message 33

The Venturi tube is rejected because the calculated beta ratio is above the ISO 5167 limit of 0.7.

Consider using a higher DP range up to a maximum of 1 bar.

Message 34

The Venturi tube is rejected because the calculated beta ratio is below the ISO 5167 limit of 0.4.

Consider using a lower DP range up to a minimum of 12.5 mbar.

Message 35

The orifice diameter is outside the ISO 5167 limits.

Check the acceptability for this particular application.

Message 36

The corner tapped square edge orifice is rejected because the calculated minimum Reynolds Number of xxxxx (beta = xxxxx, DP = xxxxx mbar) is lower than the ISO 5167 lower limit of 5000 for corner tapped orifice flow meters. Consider reducing beta by accepting a higher DP range up to a maximum of 1 bar but check the acceptability of overall pressure loss.

Consider using a smaller line size.

Message 37

Too many variables are entered, i.e.: flow rate, differential pressure range and orifice diameter. Two variables should be specified only.

Calculation is completed with the assumption that the flow rate has to be calculated.

Message 38

The pipe roughness is above the ISO 5167 limit.

A correction has been made to allow of the greater roughness.

Message 39

The program forces a scale reading of 10.0 on chart for the calculation. The non-preferred DP range is chosen because the flow rate and the orifice diameter (or beta ratio) are defined. These two quantities should have been defined together only if a second transmitter is wanted, e.g. for recording¹⁾ or trips²⁾. If this is not the case, define only the flow or the beta ratio, not both, and let program choose the preferred DP range.

- ¹⁾ For the recording, choose the next higher preferred DP range. The new flow factor will then be:
 $(\text{above flow factor}) * (\text{above DP range} / \text{preferred DP range})^{**0.5}$.

Note: Errors will be slightly larger than printed above.

- ²⁾ For a trip, choose the next but one higher preferred DP range. Trip point will then be at "p" on 0-10 scale where:

$$p = 10 * (\text{above DP range} / \text{preferred DP range})^{**0.5}$$

In general "p" will always be acceptable for the preferred ranges listed below:

12.5, 25, 50, 125, 250, 500, 1000, 2000 mbar.

Message 40

Check the pipe specification.

The pipe bore is not consistent with the ANSI, DIN or ISO standards. So the program is unable to choose automatically the bleed hole size to match the pipe size. If your pipe is correct, refer to the relevant orifice plate drawings and select the nearest bleed hole size.

Re-run the program with the selected bleed hole.

2.4 CHOICE OF FLOW MEASURING DEVICE

Many factors affect the selection of suitable flow measuring devices. The following tables and graphs are intended for guidance and comparison in this field, although it should be realized that the recommended flow meter for general application remains the square edge orifice with flange tapings.

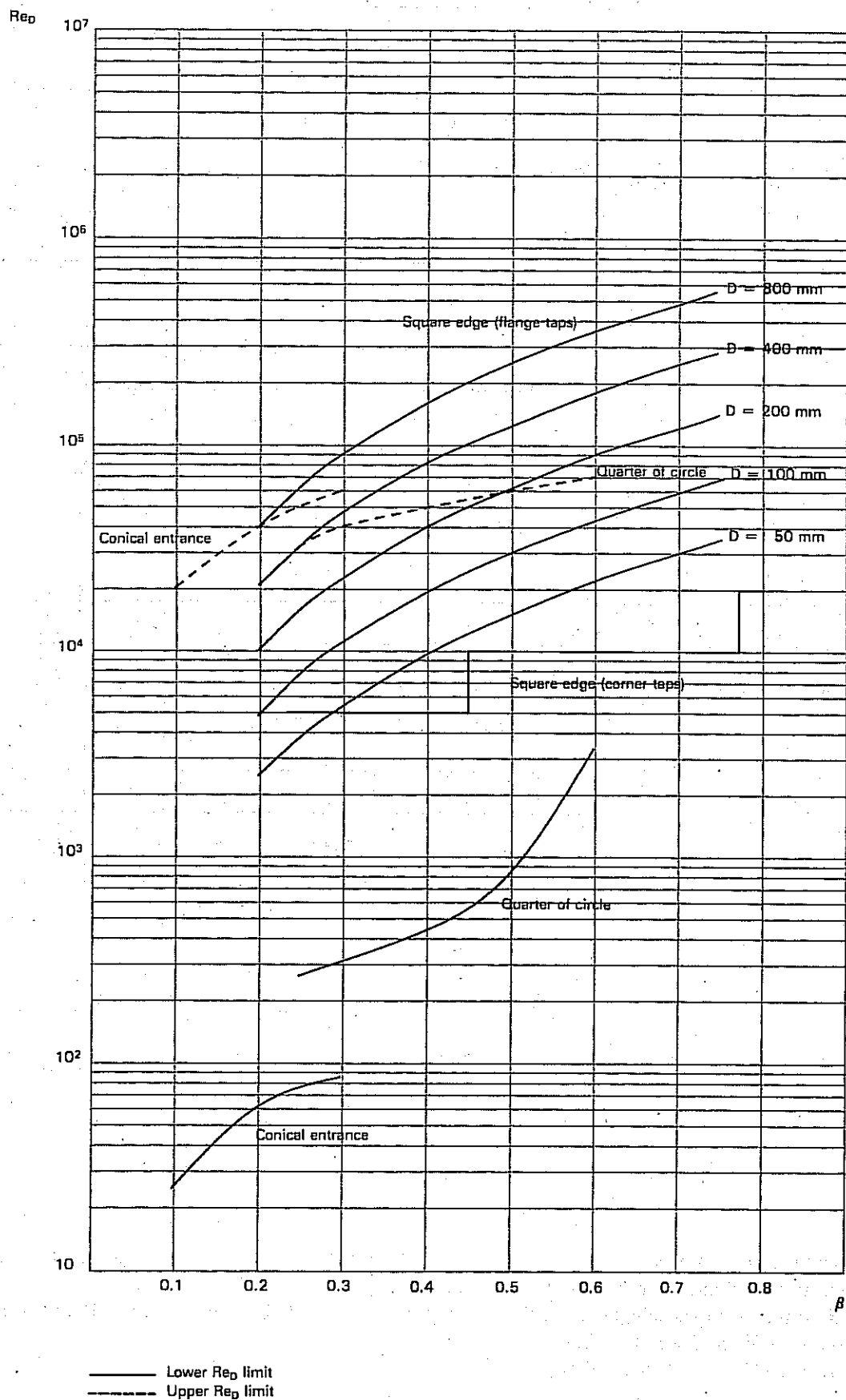
Table 2.4.1 gives a comparison of flow meters and the approximate values of factors and limitations. The differential pressure flow instruments and other flow measuring devices are listed in one table in order to obtain a survey for comparison of the advantages and disadvantages of differential pressure flow instruments. Recommendations for the application of the various flow meters are given in the column "Field of application".

Fig. 2.4.2 gives a comparison of flow meters and the lower and upper Re_D limits.

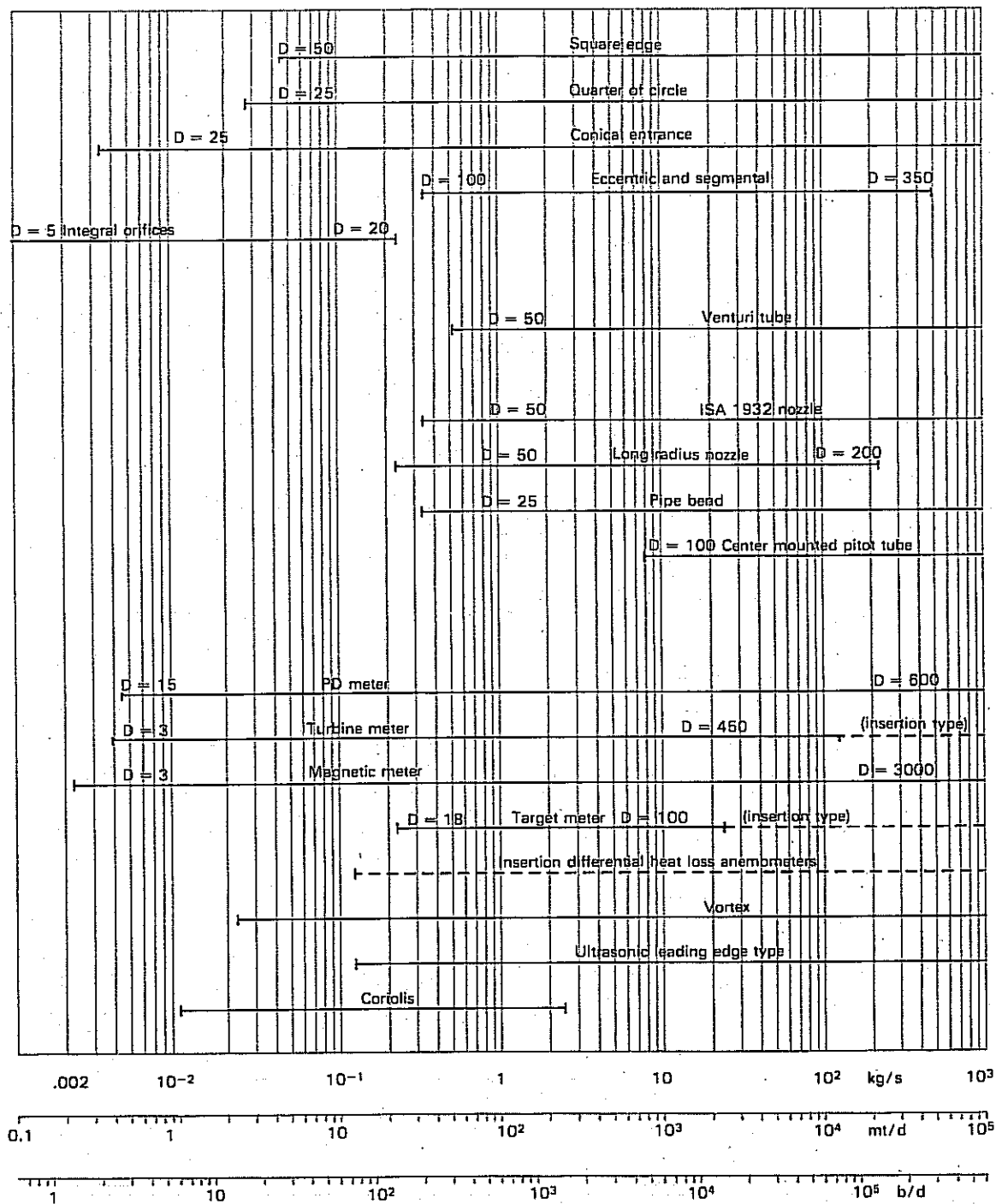
Fig. 2.4.3 gives the mass flow rate limitations for the different flow measuring devices.

Fig. 2.4.4 gives the pressure loss as a function of the differential pressure versus beta ratio for differential flow meters.

Fluid property limitations			Application considerations					Field of application	Line size range (in.)	Fill
Maximum pressure (bar abs.)	Maximum temperature (°C)	Lower Re_D or viscosity (mm ² /s) limit	Meter rangeability	Type of scale	Possible construction materials	Overall approximate error (% full scale value)				
						Un-calibrated	Calibrated			
400	500	> 8000 (500 000)	3:1	Square root	All metals and some plastics	± 1.5	± 0.75	General purpose	> 2	N
400	500	> 5000 (10 000)	3:1	"	"	± 1.5	± 0.75	"	> 2	"
400	500	> 14 000 (200 000)	3:1	"	"	± 1.7	± 0.75	"	> 2	"
400	500	> 6000 (500 000)	3:1	"	"	± 1.4	± 0.75	"	> 2	"
400	500	> 8000 (250 000)	3:1	"	"	± 1.4	± 0.75	"	> 2	"
400	500	> 250 (3300)	3:1	"	"	± 2.2	± 0.75	Low Re_D , viscous fluids	> 1	"
400	500	> 25 (75)	3:1	"	"	± 2.2	± 0.75	Very low Re_D , viscous fluids	> 1	"
400	500	> 10 000	3:1	"	"	± 2.1	± 0.75	Dirty fluids and two-phase flow	4-14	"
400	500	> 10 000	3:1	"	"	± 2.2	± 0.75	"	4-14	"
400	500	Depends on orifice	3:1	"	"	± 1.5	± 0.5	Accurate measurement of small quantities	0.5-1.5	"
400	500	> 200 000	3:1	"	"	± 1.7	± 0.75	Accurate measurement of clean and dirty fluids at low pressure loss. Non-viscous fluids	4-32	"
400	500	> 200 000	3:1	"	"	± 5.0	± 1.0	Rough measurement at low pressure loss and high differential pressure. Non-viscous fluids	Any	"
400	500	> 20 000	3:1	"	"	± 2.2	± 0.75	High velocity measurement of non-viscous fluids	2-30	"
400	500	> 80 000 (190 000)	3:1	"	"	± 4.0	± 0.75	High velocity measurement at low pressure loss of non-viscous fluids	3-20	"
400	500	> 6000	3:1	"	"	± 1.8	± 0.75	High velocity measurement of non-viscous fluids	2-8	"
400	500	> 50 000	3:1	"	"	± 4.0	± 0.75	Rough measurement at low pressure loss of most fluids	> 1	"
400	500	< 2000 or > 10 000	3:1	"	"	± 1.4-4	± 0.75	Large quantities at low pressure loss of clean fluids	> 4	"
400	250	> 10 000	4:1	Near linear	Metals, glass, ceramics, plastics	± 2.0	± 1.0	Local indicators for small quantities of clean fluids	0.25-12	Y
80	250	< 1000 (8000) mm ² /s	10:1	Linear	Bronze, steel, stainless steel	± 0.3 ^b	± 0.1 ^b	Highest accuracy at wide rangeability	0.5-24	"
80	ambient	—	10:1	"	"	± 2.0 ^b	± 1.0 ^b	Wide rangeability	2-10	"
2000	150	< 2-15 mm ² /s	10:1	"	Most metals	± 0.5 ^b	± 0.2 ^b	High accuracy at wide rangeability of clean fluids	0.125-18	"
20-200	180	No limits	10:1 ^b	"	Lined stainless steel	± 1.0	± 0.5	High accuracy and low pressure loss for conductive fluids	0.1-78	N
100	400	< 2000	3:1	Square root	Steel or stainless steel	± 5.0	± 1.0	Viscous fluids	0.75-4	"
100	300	> 10 000 10 mm ² /s	10:1	Linear	Stainless steel	± 1.5	± 0.5	Wide rangeability	1-10	N
400	260	No limits	10:1	"	All metals	± 2.0	± 0.5	Wide rangeability	0.1-118	"
190	200	No limits	10:1	"	Stainless steel	—	± 0.4	Mass flow	0.375-6	"



2.4.2 Lower and upper Re_D limits



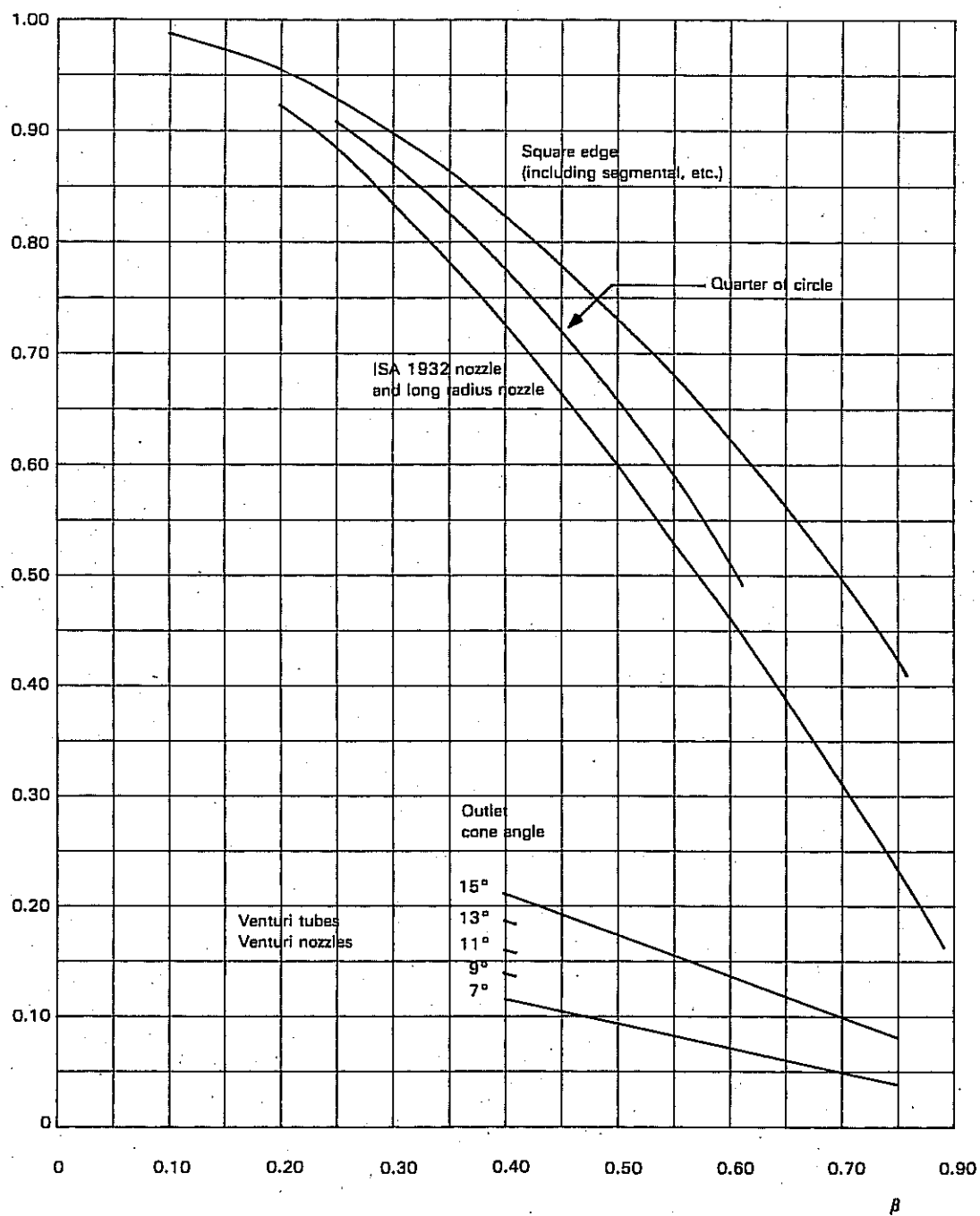
Notes:

The indicated minimum capacity is calculated for the minimum recommended β and D, a Δp of 12.5 mbar at an indication at 50% and water as fluid.

The maximum capacity is calculated for the maximum recommended β and D, a Δp of 1000 mbar at an indication at 100% and water as fluid.

The relative density of water is taken as 1.

2.4.3 Mass flow rate limits



Notes:

The curves marked "Venturi tubes" and "Venturi nozzles" are applicable only to non-truncated types. The nett pressure loss for truncated types may be 25% higher.

A nozzle gives the same pressure loss as an orifice at the same rate of flow in the same size of pipe at the same differential pressure.

2.4.4 Values of nett pressure losses

Section 3. Square edge orifices

- 3.1 Square edge orifice with flange tapplings**
 - 3.1.1 Construction
 - 3.1.2 Application
 - 3.1.3 Limitations
 - 3.1.4 Discharge coefficient
 - 3.1.5 Expansion factor
 - 3.1.6 Calculation
 - 3.1.7 References
 - 3.1.8 Square edge orifice plate for ANSI orifice flanges
 - 3.1.9 ANSI RF orifice flanges with flange tapplings
 - 3.1.10 Calculation of orifice diameter
 - 3.1.11 Calculation of flow rate
- 3.2 Square edge orifice with corner tapplings**
 - 3.2.1 Construction
 - 3.2.2 Application
 - 3.2.3 Limitations
 - 3.2.4 Discharge coefficient
 - 3.2.5 Expansion factor
 - 3.2.6 Roughness correction factor
 - 3.2.7 Calculation
 - 3.2.8 References
 - 3.2.9 ANSI RF orifice flanges with corner tapplings
 - 3.2.10 Calculation of orifice diameter
 - 3.2.11 Calculation of flow rate
- 3.3 Square edge orifice with radius tapplings**
 - 3.3.1 Construction
 - 3.3.2 Application
 - 3.3.3 Limitations
 - 3.3.4 Discharge coefficient
 - 3.3.5 Expansion factor
 - 3.3.6 Calculation
 - 3.3.7 References
 - 3.3.8 Calculation of orifice diameter
 - 3.3.9 Calculation of flow rate

3.1 SQUARE EDGE ORIFICE WITH FLANGE TAPPINGS

3.1.1 Construction

The upstream edge of the orifice shall be sharp, see (3.1.8). The high-pressure tapping is 25 ± 1 mm upstream of the inlet face, and the low-pressure tapping is at the same distance downstream of the outlet face of the orifice plate, see (3.1.9). The orifice flange rating ANSI 300 lb is the recommended standard unless process conditions require a higher rating. The ANSI 150 lb rating, however, is sometimes used, e.g. in the chemical industry for exotic materials.

3.1.2 Application

It is the recommended type for general application in clean fluids, i.e. for gas, steam and liquid. Fabrication is easy and economical.

3.1.3 Limitations

Pipe bore: $50 \leq D \leq 760$ mm

Orifice diameter: $12.5 \leq d \leq 570$ mm

Beta ratio: $0.2 \leq \beta \leq 0.75$

Reynolds Number: $1260 \beta^2 D \leq Re_D \leq 10^8$

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

The upper limits of the relative roughness factor k/D (for a distance of at least $10D$ upstream of the orifice plate) and the orifice plate's β ratio, must be such as to conform to the values in the following table:

β	≤ 0.3	0.32	0.34	0.36	0.38	0.40	0.45	0.50	0.60	0.70	0.75
$k/D \cdot 10^4$	25	18.1	12.9	10	10	10	10	10	10	10	10

If $k/D < 10 \cdot 10^{-4}$ no limitation for β

3.1.4 Discharge coefficient

$$C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)} \right]^{0.75} + \left[\frac{2.286}{D} \right] \beta^4 \cdot (1 - \beta^4)^{-1} - \left[\frac{0.85598}{D} \right] \beta^3$$

If $D < 58.615$ mm use (0.0390) as coefficient of $\beta^4 (1 - \beta^4)^{-1}$

$$\text{Uncertainty: } \frac{\delta C}{C} = \pm 0.6\% \text{ for } \beta \leq 0.6$$

$$\frac{\delta C}{C} = \pm \beta\% \text{ for } \beta > 0.6$$

3.1.5 Expansion factor

$$\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] [X/10]^2 \cdot \kappa^{-1}$$

$$\text{Uncertainty: } \frac{\delta \epsilon}{\epsilon} = \pm 4 \frac{dp}{p} \% \text{ for } 0.2 \leq \beta \leq 0.75$$

(note: dp and p in same units)

3.1.6 Calculation

Limitations, see (3.1.3)

Sizing, see (3.1.10)

Flow rate, see (3.1.11)

Pressure loss, see (2.4.4)

Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

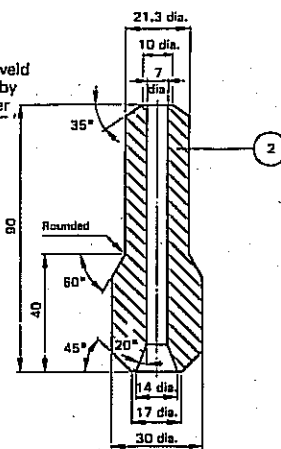
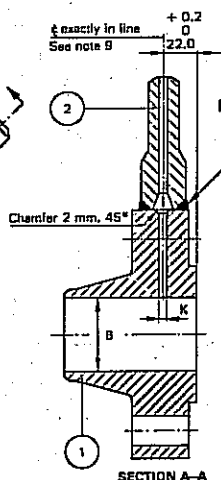
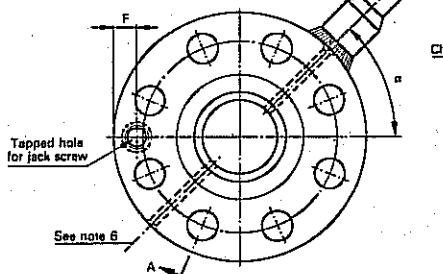
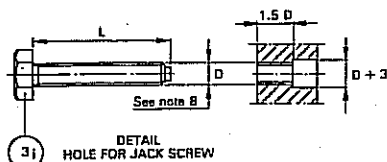
3.1.7 References

ISO 5167

ANSI B 46.1

ANSI B 16.36

ISO 261



WELDING NIPPLE

CLASS 300 WN-RAISED FACE							
Nom. line size DN	Bore B	Jack screw data			Flange tapping		
		Dia. D	Length L	Position F	Bore K	Angle α	
50	2	M16	70	16	4		
80	3		80		6	45°	
100	4				8		
150	6		90				
200	8	M20	100	20		30°	
250	10		120			45°	
300	12						
350	14		130		12	36°	
400	16		140				
450	18		150				
500	20	M24	160	24		45°	
600	24		180				

CLASS 600 WN-RAISED FACE							
Nom. line size DN	Bore B	Jack screw data			Flange tapping		
		Dia. D	Length L	Position F	Bore K	Angle α	
50	2	M16		16	4		
80	3		80		6	45°	
100	4		100		8		
150	6		120				
200	8	M20	130	20		30°	
250	10		140			45°	
300	12		150				
350	14		160		12	36°	
400	16		180				
450	18		190				
500	20	M24	200	24		45°	
600	24		240				

CLASS 900 WN-RAISED FACE							
Nom. line size DN	Bore B	Jack screw data			Flange tapping		
		Dia. D	Length L	Position F	Bore K	Angle α	
50	2	M16	90	16	4		
80	3		100		6	45°	
100	4	M20	110	20	8		
150	6		120				
200	8		140			30°	
250	10		150			45°	
300	12		170				
350	14		180				
400	16	M24	190	24	12	36°	
450	18		220				
500	20						
600	24	M30	280	30			

CLASS 1500 WN-RAISED FACE							
Nom. line size DN	Bore B	Jack screw data			Flange tapping		
		Dia. D	Length L	Position F	Bore K	Angle α	
50	2	M16	90	16	4		
80	3		100		6	45°	
100	4	M20	120	20	8		
150	6		160				
200	8		180			30°	
250	10	M24	200	24			
300	12		220				
350	14		240		12		
400	16		260				
450	18		300				
500	20		320				
600	24	M36	360	36		45°	

CLASS 2500 WN-RAISED FACE							
Nom. line size DN	Bore B	Jack screw data			Flange tapping		
		Dia. D	Length L	Position F	Bore K	Angle α	
50	2	M16	100	16	4		
80	3		130	20	6	45°	
100	4		150		8		
150	6	M24	200	24			
200	8		220				
250	10		280		12	30°	
300	12	M30	300	30			

ITEM	Qty per flange	DESCRIPTION	REMARKS
1	1	Orifice flange	Welding neck-RF, generally in accordance with ANSI B16.36. For further information see notes.
2	1 or 2*	Butt welding nipple	One to each flange tapping. See detail *) See notes 6 and 7
3	1	Jack screw	Material stainless steel

Notes:

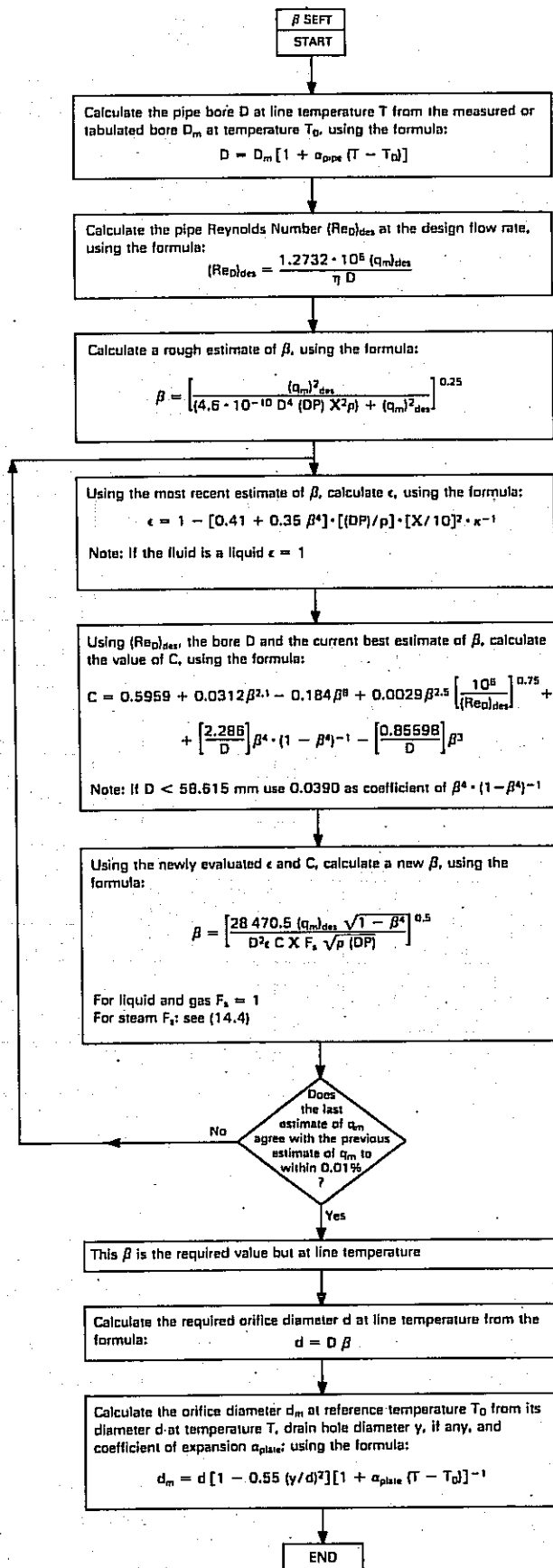
- Dimensions
- Design
- Material
- Flange face finish

In millimetres unless otherwise indicated.
Generally in accordance with ANSI B16.36 – "Steel Orifice Flanges" –, except flange face finish, flange tappings and jack bolt data.
As specified.
Flange face finish shall be smooth, to be interpreted as a surface finish between Ra 3.2–6.3 µm in accordance with ANSI B46.1.
This finish is exclusively to be obtained by machining with a round nosed cutting tool having a 0.8 mm radius at a feed rate between 0.35 and 0.45 mm per revolution.
Checking of facing roughness shall be judged by visual or tactile comparison with a roughness comparison specimen "RUBERT 319" or "FLEXITALLIC 319".
- Flange bore
- Tappings

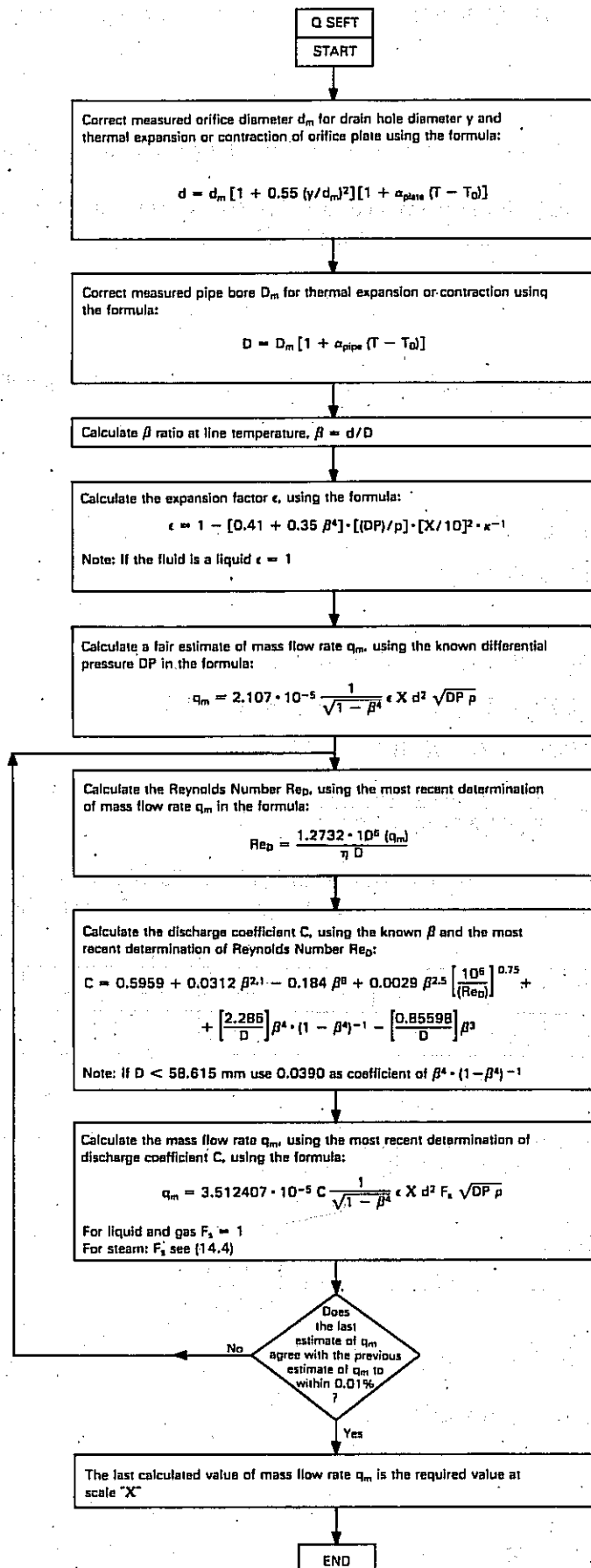
Bore diameter of flange as specified.
Each flange shall have one tapping unless otherwise stated.
If two tappings per flange are required the position shall be diametrically opposite.
- Butt welding nipple
- Thread of jack screw

Each tapping shall be provided with a welding nipple as shown.
Metric coarse thread series as per ISO 261. Class of fit (hole/bolt) 6H/6g.
- It must be possible to rod through the nipple bore with a rod of 0.5 mm less than the bore of the nipple or flange tapping whichever is the smaller.
- Additional requirements such as marking, coating, protection against damage during transport and storage.

3.1.9 ANSI RF orifice flanges with flange tappings



3.1.10 Calculation of orifice diameter



3.1.11 Calculation of flow rate

3.2 SQUARE EDGE ORIFICE WITH CORNER TAPPINGS

3.2.1 Construction

The pressure tapping holes open into a recess in the flange face adjacent to the orifice plate, see (3.2.9).

The general form of the orifice is in accordance with (3.1.8) (except for the dimensions "O" in the relevant table, which can be different for other than ANSI B16.36 orifice flanges, so that the plate fits in exactly between the bolts).

3.2.2 Application

In view of standardization not recommended but required, e.g. for small-diameter meter runs ($D < 50$ mm) to satisfy pipe roughness limitations.

3.2.3 Limitations

Pipe bore: $50 \leq D \leq 1000$ mm

Orifice diameter: $12.5 \leq d \leq 800$ mm

Beta ratio: $0.23 \leq \beta \leq 0.80$

Reynolds Number: $5000 \leq Re_D \leq 10^8$ for $0.23 \leq \beta \leq 0.45$

$10\,000 \leq Re_D \leq 10^8$ for $0.45 < \beta \leq 0.77$

$20\,000 \leq Re_D \leq 10^8$ for $0.77 < \beta \leq 0.80$

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

The upper limits of the relative roughness factor k/D (for a distance of at least $10D$ upstream of the orifice plate) and the orifice plate's β ratio, must be such as to conform to the values in the following table:

β	≤ 0.3	0.32	0.34	0.36	0.38	0.40	0.45	0.50	0.60	0.70	0.80
$k/D \cdot 10^4$	25	18.1	12.9	10	8.3	7.1	5.6	4.9	4.2	4.0	3.9

If $k/D < 3.8 \cdot 10^{-4}$ no limitation for β

If this requirement cannot be fulfilled, a roughness correction factor (3.2.6) may be applied, however the installation is then not in accordance with the ISO 5167.

3.2.4 Discharge coefficient

$$C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)} \right]^{0.75}$$

$$\text{Uncertainty: } \frac{\delta C}{C} = \pm 0.6\% \text{ for } \beta \leq 0.6$$

$$\frac{\delta C}{C} = \pm \beta\% \text{ for } 0.6 < \beta \leq 0.8$$

3.2.5 Expansion factor

$$\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$$

Uncertainty: $\frac{\delta\epsilon}{\epsilon} = \pm 4 \frac{dp}{p} \%$ for $0.23 \leq \beta \leq 0.75$
 $\frac{\delta\epsilon}{\epsilon} = \pm 8 \frac{dp}{p} \%$ for $0.75 < \beta \leq 0.8$
 (note: dp and p in same units)

3.2.6 Roughness correction factor

$$Z_{Re_D} = (Z_0 - 1) (\log (Re_D)/6)^2 + 1$$

with the exception that, if $Re_D \geq 10^6$, one puts $Z_{Re_D} = Z_0$

Values of Z_0 as a function of beta and relative roughness k/D are given in the following table where k/D is a measure of the inside pipe wall roughness expressed in units of length.

Values of Z_0 as a function of beta and k/D

β	$k/D \cdot 10^4$								
	25.00	12.50	8.30	6.25	5.00	4.17	3.57	3.13	2.91
0.31	1.0020	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.35	1.0023	1.0006	1.0003	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.40	1.0026	1.0013	1.0006	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.45	1.0030	1.0020	1.0010	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.50	1.0045	1.0030	1.0015	1.0005	1.0000	1.0000	1.0000	1.0000	1.0000
0.55	1.0060	1.0040	1.0020	1.0010	1.0000	1.0000	1.0000	1.0000	1.0000
0.60	1.0079	1.0053	1.0033	1.0016	1.0006	1.0000	1.0000	1.0000	1.0000
0.65	1.0103	1.0068	1.0045	1.0025	1.0013	1.0003	1.0000	1.0000	1.0000
0.70	1.0134	1.0086	1.0058	1.0038	1.0019	1.0009	1.0000	1.0000	1.0000
0.75	1.0180	1.0117	1.0080	1.0053	1.0027	1.0017	1.0000	1.0000	1.0000
0.80	1.0240	1.0160	1.0110	1.0070	1.0040	1.0020	1.0020	1.0000	1.0000

3.2.7 Calculation

Limitations, see (3.2.3)

Sizing, see (3.2.10)

Flow rate, see (3.2.11)

Pressure loss, see (2.4.4)

Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

3.2.8 References

ISO 5167

ANSI B 46.1

ANSI B 16.36

ISO 261

Transaction Details				Accounting Entries			
Date	Description	Amount	Category	Debit	Credit	Balance	Notes
2023-01-01	Initial Balance	1000.00	Assets			1000.00	
2023-01-05	Revenue from Sale	500.00	Revenue		500.00	1500.00	
2023-01-10	Payment to Supplier	250.00	Expenses	250.00		1250.00	
2023-01-15	Interest Income	10.00	Revenue		10.00	1260.00	
2023-01-20	Transfer to Reserve	100.00	Assets		100.00	1360.00	
2023-01-25	Dividend Payment	75.00	Expenses	75.00		1285.00	
2023-02-01	Revenue from Sale	300.00	Revenue		300.00	1585.00	
2023-02-05	Payment to Supplier	150.00	Expenses	150.00		1435.00	
2023-02-10	Interest Income	15.00	Revenue		15.00	1450.00	
2023-02-15	Transfer to Reserve	50.00	Assets		50.00	1500.00	

4. The fourth part of the document discusses the role of the internal audit function in ensuring the accuracy and reliability of the financial records. It outlines the scope of the internal audit and the specific responsibilities of the internal auditors. This section also includes a list of the various types of audits that are conducted by the internal audit function.

5. The fifth part of the document provides a detailed explanation of the various controls that are in place to ensure the accuracy and reliability of the financial records. These controls include a range of checks and balances designed to prevent errors and to detect any potential fraud or misuse of funds.

7. The seventh part of the document outlines the specific procedures that must be followed when recording transactions. It details the steps from the initial entry of a transaction into the system to the final review and approval process. This section also includes a list of the various types of transactions that are subject to these procedures.

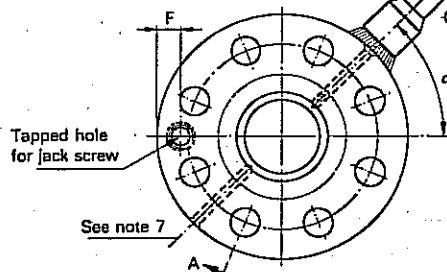
8. The eighth part of the document provides a detailed explanation of the various controls that are in place to ensure the accuracy and reliability of the financial records. These controls include a range of checks and balances designed to prevent errors and to detect any potential fraud or misuse of funds.

9. The ninth part of the document discusses the role of the internal audit function in ensuring the accuracy and reliability of the financial records. It outlines the scope of the internal audit and the specific responsibilities of the internal auditors. This section also includes a list of the various types of audits that are conducted by the internal audit function.

10. The tenth part of the document provides a detailed explanation of the various controls that are in place to ensure the accuracy and reliability of the financial records. These controls include a range of checks and balances designed to prevent errors and to detect any potential fraud or misuse of funds.

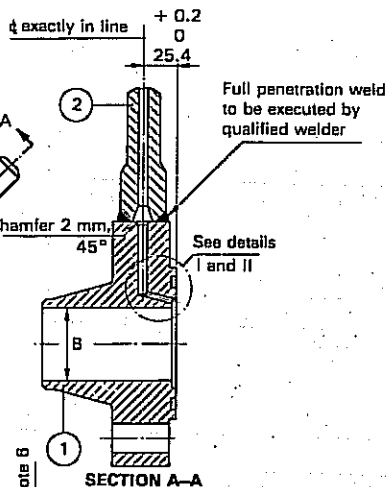


HOLE FOR JACK SCREW

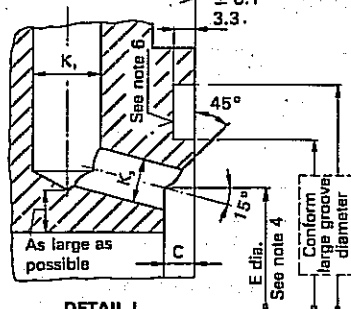


Tapped hole for jack screw

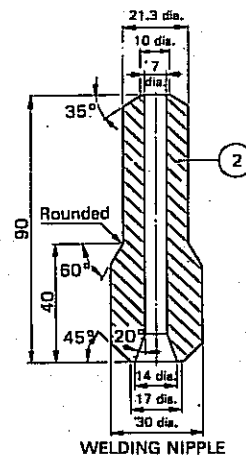
See note 7



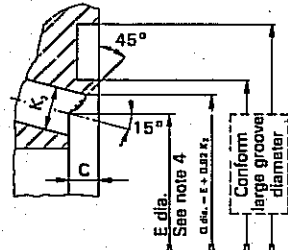
SECTION A-A



DETAIL I



WELDING NIPPLE



DETAIL II

Only applicable to flange sizes:
> DN 200 - class 300,
DN 250 and DN 300 - class 600

ITEM	Qty per flange	DESCRIPTION	REMARKS
1	1	Orifice flange	Welding neck RF, generally in accordance with ANSI B16.36. For further information see notes.
2	1 or 2*	Butt welding nipple	One to each flange tapping. See detail *) See notes 7 and 8
3	1	Jack screw	Material stainless steel

CLASS 300 WN-RAISED FACE									
Nom. line size DN	Bore	Jack screw data			Flange tapping		E dia. ±0.5	C ±0.1	
mm in.	B	Dia.	Length	Position	Bore K ₁ K ₂	Angle α			
50 2	SEE	M16	70	16	4 2	45°	62.5	1.0	
80 3	SEE		80		6 3	45°	94	1.1	
100 4	SEE		90		8 4	30°	118.7	1.5	
150 6	NOTE	M20	100	20	4	30°	175	2.4	
200 8	NOTE		120		3.5	45°	234.1	3.5	
250 10	NOTE		120		5	45°	274.8	4.4	
300 12	NOTE		130		5	36°	328.6	5.2	
350 14	NOTE		140		5	36°	360.8	5.8	
400 16	NOTE		150		10	45°	411.4		
450 18	NOTE		180		9	45°	468.5		
500 20	NOTE		180		10	45°	515.4		
600 24	NOTE		180		10	45°	619.5		

CLASS 600 WN-RAISED FACE									
Nom. line size DN	Bore	Jack screw data			Flange tapping		E dia. ±0.5	C ±0.1	
mm in.	B	Dia.	Length	Position	Bore K ₁ K ₂	Angle α			
50 2	SEE	M16	80	16	4 2	45°	61.5	1.0	
80 3	SEE		80		6 3	45°	91.8	1.1	
100 4	SEE		100		8 4	30°	116.1	1.5	
150 6	NOTE	M20	130	20	5	30°	171.7	2.4	
200 8	NOTE		140		5	45°	220.2	3.2	
250 10	NOTE		150		8	45°	270.3	4.0	
300 12	NOTE		160		8	36°	324.2	4.8	
350 14	NOTE		180		10	36°	347.7	5.3	
400 16	NOTE		190		10	36°	396.6		
450 18	NOTE		200		10	45°	435.8		
500 20	NOTE		240		10	45°	502.1		
600 24	NOTE		240		10	45°	603.2		

CLASS 900 WN-RAISED FACE									
Nom. line size DN	Bore	Jack screw data			Flange tapping		E dia. ±0.5	C ±0.1	
mm in.	B	Dia.	Length	Position	Bore K ₁ K ₂	Angle α			
50 2	SEE	M16	90	16	4 2	45°	61.5	1.0	
80 3	SEE		100		6 3	45°	91.8	1.1	
100 4	SEE	M20	110	20	8 4	30°	113.8	1.5	
150 6	NOTE		120		6	30°	168.3	2.4	
200 8	NOTE		140		6	45°	216.2	3.2	
250 10	NOTE		150		9	45°	267.3	4.0	
300 12	NOTE		170		9	36°	321.5	4.8	
350 14	NOTE		180		10	36°	343.5	5.3	
400 16	NOTE		190		10	36°	392.4		
450 18	NOTE		220		10	45°	441.7		
500 20	NOTE		220		10	45°	486.5		
600 24	NOTE		280	30	10	45°	584.2		

CLASS 1500 WN-RAISED FACE									
Nom. line size DN	Bore	Jack screw data			Flange tapping		E dia. ±0.5	C ±0.1	
mm in.	B	Dia.	Length	Position	Bore K ₁ K ₂	Angle α			
50 2	SEE	M16	90	16	4 2	45°	60	1.0	
80 3	SEE		100		6 3	45°	90	1.1	
100 4	SEE	M20	120	20	8 4	30°	113.9	1.5	
150 6	NOTE		160		6	30°	165.3	2.4	
200 8	NOTE		180		8	30°	211.3	3.2	
250 10	NOTE		200		8	45°	259.6	4.0	
300 12	NOTE		220		10	45°	310.2	4.8	
350 14	NOTE		240		10	45°	339.9	5.3	
400 16	NOTE		260		10	45°	391.2		
450 18	NOTE		300		10	45°	441.7		
500 20	NOTE		320		10	45°	486.5		
600 24	NOTE		360	36	10	45°	584.2		

CLASS 2500 WN-RAISED FACE									
Nom. line size DN	Bore	Jack screw data			Flange tapping		E dia. ±0.5	C ±0.1	
mm in.	B	Dia.	Length	Position	Bore K ₁ K ₂	Angle α			
50 2	SEE	M16	100	16	4 2	45°	57.2	1.0	
80 3	SEE		130	20	6 3	45°	86.9	1.1	
100 4	NOTE	M24	150		8 4	45°	109.4	1.5	
150 6	NOTE		200	24	6	30°	181.8	2.4	
200 8	NOTE		220		8	30°	207	3.2	
250 10	NOTE	M30	280		10	30°	253.2	4.0	
300 12	NOTE		300	30	10	30°	303.1	4.8	

Notes:

1) Dimensions

2) Design

3) Material

4) Dimensions "C" and "E"

5) Flange bore

In millimetres unless otherwise indicated.
Generally in accordance with ANSI B16.36 - "Steel Orifice Flanges" - except flange face finish, flange tapping and jack bolt data.
As specified.
Dimensions "C" and "E" are suitable for flange bore to schedule numbers 10S up to 160 incl.
Bore diameter of flange as 10) Additional requirements such as marking, coating, protection against damage during transport and storage.

6) Flange face finish

The gasket contact area in the groove and flange face shall be smooth, to be interpreted as a surface finish between Ra 3.2-6.3 µm in accordance with ANSI B46.1

This finish is exclusively to be obtained by machining with a round nosed cutting tool having a 0.8 mm radius at a feed rate between 0.35 and 0.45 mm per revolution.

Checking of facing roughness shall be judged by visual or tactile comparison with a roughness comparison specimen. "RUBERT 319" or "FLEXITALLIC 319".

Each flange shall have one tapping unless otherwise stated.

If two tappings per flange are required the position shall be diametrically opposite. Drill of tappings must be free from burrs.

Each tapping shall be provided with a welding nipple as shown.

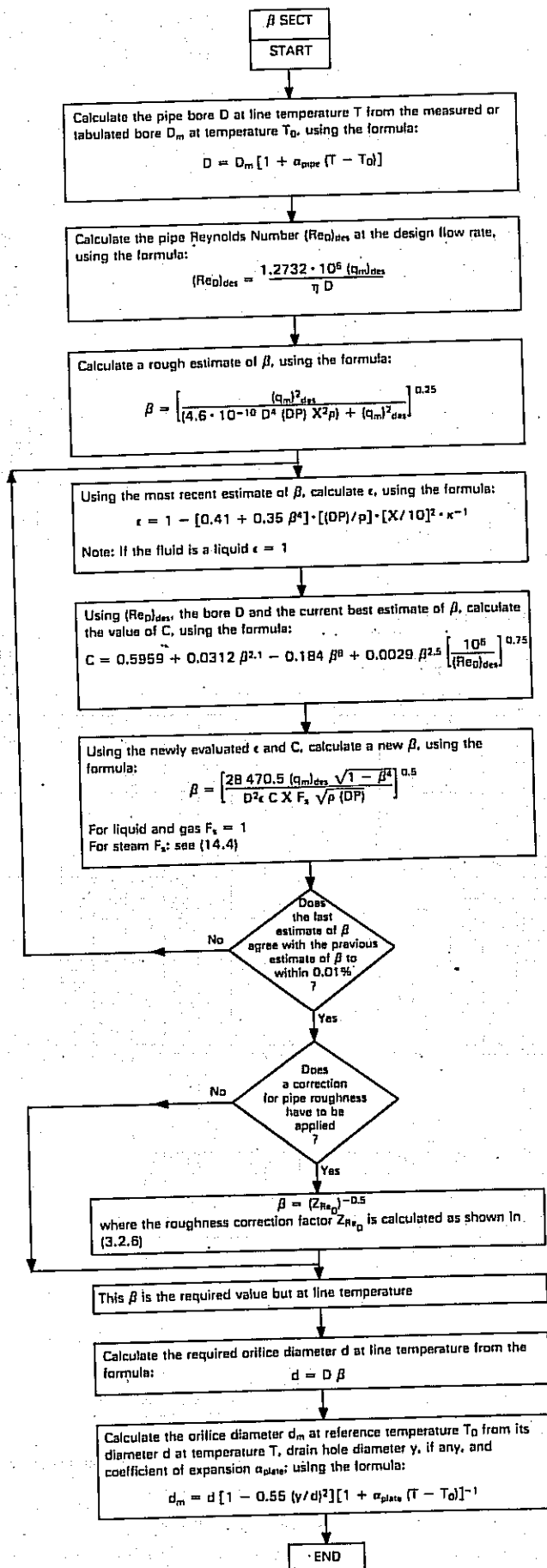
Metric coarse thread series as per ISO 261. Class of fit (hole/bolt) 6H/6g.

7) Tappings

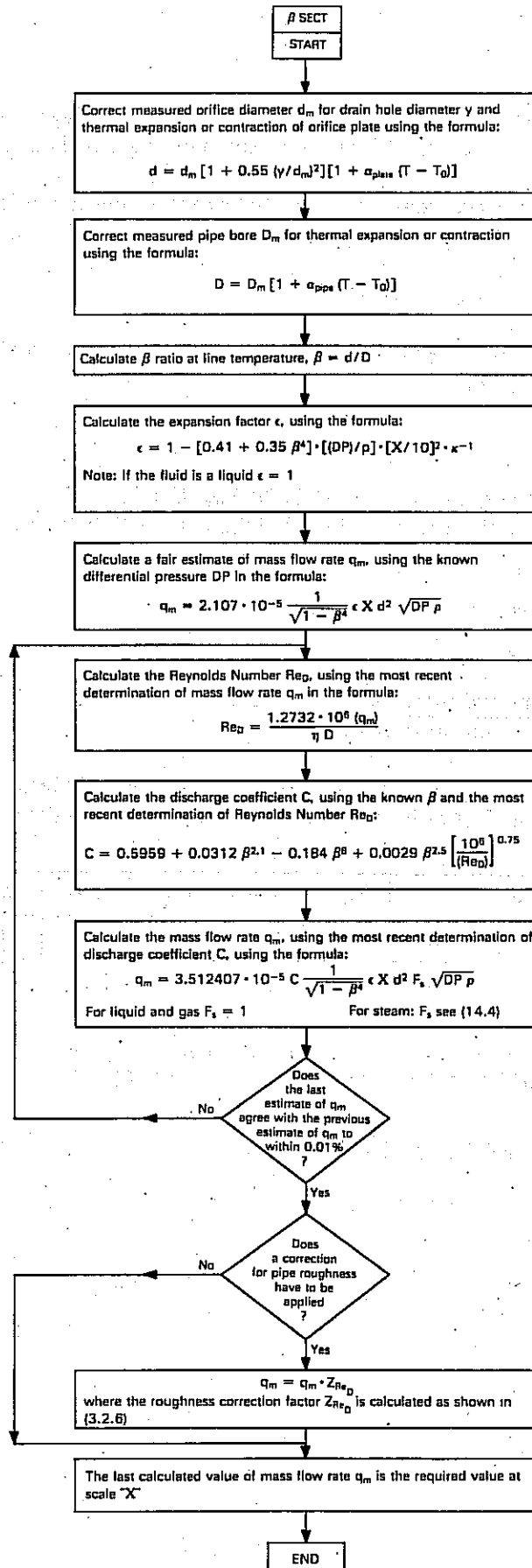
8) Butt welding nipple

9) Thread of jack screw

3.2.9 ANSI RF orifice flanges with corner tappings



3.2.10 Calculation of orifice diameter



3.2.11 Calculation of flow rate

3.3 SQUARE EDGE ORIFICE WITH RADIUS TAPPINGS

3.3.1 Construction

Radius tappings are a modified version of vena contracta tappings. The high-pressure tapping is $1.0D \pm 0.1D$ upstream of the inlet face of the plate. The low-pressure tapping is $0.5D \pm 0.05D$ downstream of the outlet face of the plate.

The general form of the orifice is in accordance with (3.1.8) (except for the dimensions "O" in the relevant table, which can be different for non-ANSI flanges, so that the plate fits in exactly between the bolts.)

3.3.2 Application

Not recommended for general application. Only to be considered where an orifice plate installation between existing flanges is required.

3.3.3 Limitations

Pipe bore: if slip-on flanges used $(DN\ 200)_{min} \leq D \leq 760\ mm$
if welding neck flanges used $(DN\ 400)_{min} \leq D \leq 760\ mm$

Orifice diameter: $12.5 \leq d \leq 570\ mm$

Beta ratio: $0.2 \leq \beta \leq 0.75$

Reynolds Number: $1260\ \beta^2 D \leq Re_D \leq 10^8$

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

The upper limits of the relative roughness factor k/D (for a distance of at least $10D$ upstream of the orifice plate) and the orifice plate's β ratio, must be such as to conform to the values in the following table:

β	≤ 0.3	0.32	0.34	0.36	0.38	0.40	0.45	0.50	0.60	0.70	0.75
$k/D \cdot 10^4$	25	18.1	12.9	10	10	10	10	10	10	10	10

3.3.4 Discharge coefficient

$$C = 0.5959 + 0.0312\ \beta^{2.1} - 0.184\ \beta^8 + 0.0029\ \beta^{2.5} \left[\frac{10^6}{(Re_D)} \right]^{0.75} + 0.039\ \beta^4 (1 - \beta^4)^{-1} - 0.015839\ \beta^3$$

$$\text{Uncertainty: } \frac{\delta C}{C} = \pm 0.6\% \text{ for } 0.2 \leq \beta \leq 0.6$$

$$\frac{\delta C}{C} = \pm \beta\% \text{ for } 0.6 < \beta \leq 0.75$$

3.3.5 Expansion factor

$$\epsilon = 1 - [0.41 + 0.35\ \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot k^{-1}$$

$$\text{Uncertainty: } \frac{\delta \epsilon}{\epsilon} = \pm 4 \frac{dp}{p} \% \text{ for } 0.2 \leq \beta \leq 0.75$$

(note: dp and p in same units)

3.3.6 Calculation

Limitations, see (3.3.3)

Sizing, see (3.3.8)

Flow rate, see (3.3.9)

Pressure loss, see (2.4.4)

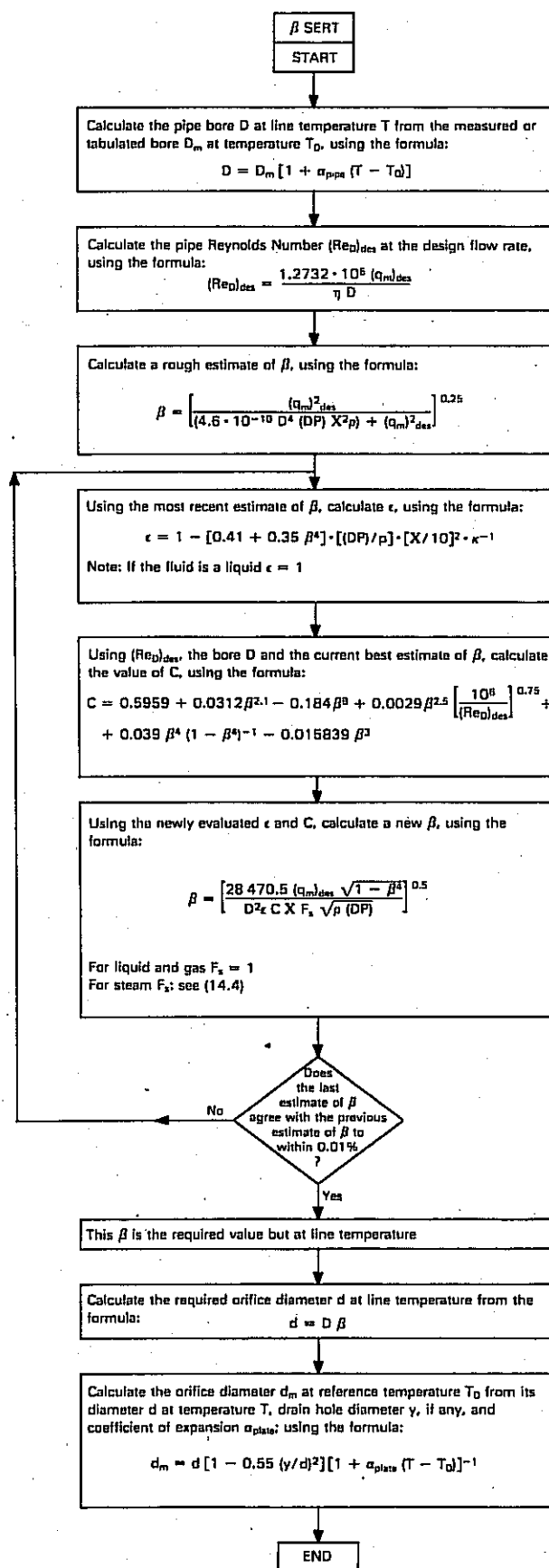
Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

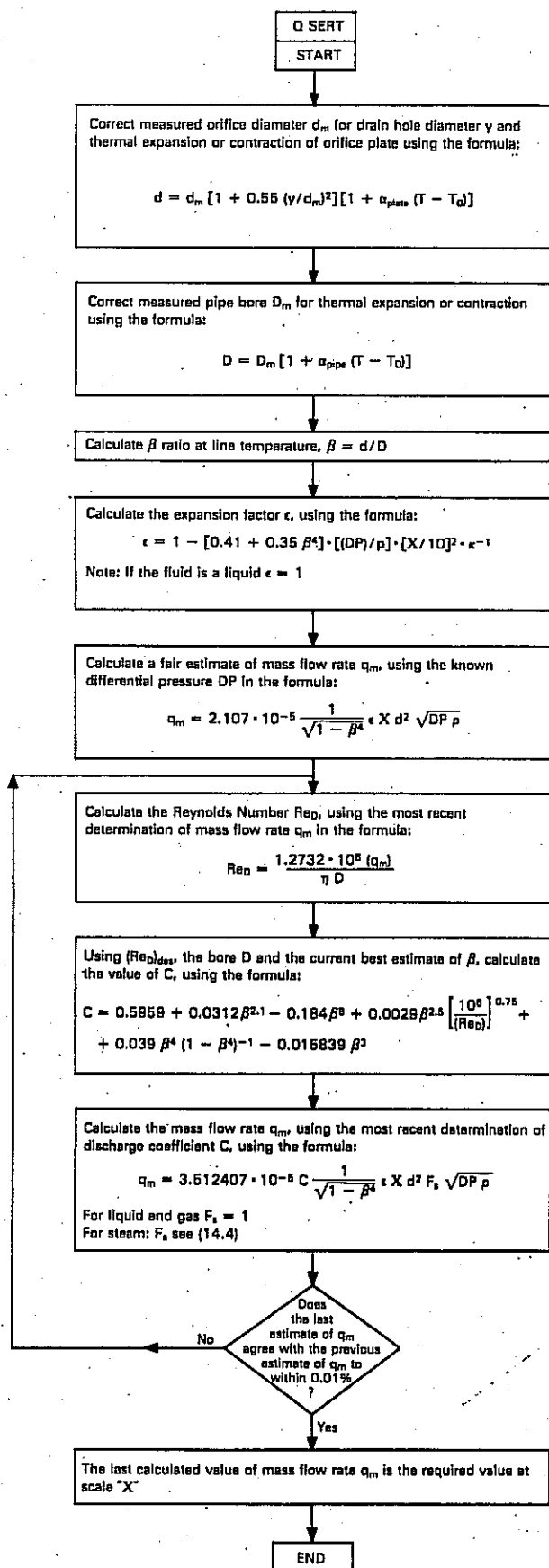
3.3.7 References

ISO 5167

ANSI B 46.1



3.3.8 Calculation of orifice diameter



3.3.9 Calculation of flow rate

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

1944

Section 4. Orifices with special entrance forms

4.1 Quarter of circle orifice

- 4.1.1 Construction**
- 4.1.2 Application**
- 4.1.3 Limitations**
- 4.1.4 Pressure tapings**
- 4.1.5 Discharge coefficient**
- 4.1.6 Expansion factor**
- 4.1.7 Calculation**
- 4.1.8 References**
- 4.1.9 Quarter of circle orifice plate for ANSI orifice flanges**
- 4.1.10 Calculation of orifice diameter**
- 4.1.11 Calculation of flow rate**

4.2 Conical entrance orifice

- 4.2.1 Construction**
- 4.2.2 Application**
- 4.2.3 Limitations**
- 4.2.4 Pressure tapings**
- 4.2.5 Discharge coefficient**
- 4.2.6 Expansion factor**
- 4.2.7 Calculation**
- 4.2.8 References**
- 4.2.9 Conical entrance orifice plate for ANSI orifice flanges**
- 4.2.10 Calculation of orifice diameter**
- 4.2.11 Calculation of flow rate**

4.1 QUARTER OF CIRCLE ORIFICE

4.1.1 Construction

The form of the upstream edge of the orifice is a quarter of a circle, see (4.1.9.). The radius r of the upstream profile shall be not less than 3.175 mm, and shall lie between 0.101 d and 0.208 d inclusive.

The thickness of the orifice plate shall be not less than 2.54 mm and not exceed 0.1D.

4.1.2 Application

Low pipe Reynolds Number applications.

4.1.3 Limitations

Pipe bore: in accordance with $D/k \leq 750$ but not less than 25 mm. Maximum pipe bore is 750 mm

Orifice diameter: $d \geq 15$ mm

Beta ratio: $0.245 \leq \beta \leq 0.6$

Reynolds Number: $(Re_D)_{\min} \leq Re_D \leq 10^5 \beta$

$(Re_D)_{\min} = 1000 \beta + 9.4 \cdot 10^6 (\beta - 0.24)^8$, some particular values of which are given in the following table:

β	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
$(Re_D)_{\min}$	250	300	350	405	485	695	1350	3250

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

Pipe internal roughness is not specified directly but reflected in the minimum pipe size that can be used for the following qualities of pipe:

bituminized: $75 \leq D$ (mm)

rusty steel: $100 \leq D$ (mm)

slightly encrusted steel: $200 \leq D$ (mm)

rusty cast iron: $200 \leq D$ (mm)

The radius r expressed as a fraction of d shall be determined by the ratio β in accordance with:

$$\frac{r}{d} = \frac{(0.0757141\beta - 0.06253143)}{(\beta - 0.6828572)}$$

The table below gives values of r/d as a function of β :

β	r/d	β	r/d	β	r/d
0.24	0.100	0.38	0.113	0.52	0.142
0.26	0.101	0.40	0.115	0.54	0.151
0.28	0.103	0.42	0.117	0.56	0.165
0.30	0.104	0.44	0.121	0.58	0.184
0.32	0.106	0.46	0.125	0.60	0.207
0.34	0.107	0.48	0.130		
0.36	0.110	0.50	0.135		

4.1.4 Pressure tappings

Flange tappings are recommended, but corner and radius tappings can be used with the same flow coefficient, except for nominal line sizes smaller than 40 mm, where corner tappings shall be used only.

4.1.5 Discharge coefficient

$$C = 0.73823 + 0.3309 \beta - 1.1615 \beta^2 + 1.5084 \beta^3$$

$$\text{Uncertainty: } \frac{\delta C}{C} = \pm 2.00 \% \text{ for } \beta > 0.316$$

$$\frac{\delta C}{C} = \pm 2.50 \% \text{ for } \beta < 0.316$$

4.1.6 Expansion factor

$$\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot K^{-1}$$

$$\text{Uncertainty: } \frac{\delta \epsilon}{\epsilon} = \pm 33(1-\epsilon) \%$$

4.1.7 Calculation

Limitations, see (4.1.3)

Sizing, see (4.1.10)

Flow rate, see (4.1.11)

Pressure loss, see (2.4.4)

For steam correction factor F_s , see (14.4)

Uncertainty, see (13)

4.1.8 References

British Standard 1042: Part 1: 1964. Some figures are updated in this section.

Quarter Circle Orifices, Transactions of the Institution of Chemical Engineers, Vol. 38, No. 1, 1960

The Quadrant Edge Orifice, Journal of Basic Engineering, September 1960

ANSI B 46.1

Notes:

1) Dimensions

Expressed in millimetres unless otherwise indicated.

Stated tolerances shall be strictly adhered to.

As specified. (Typically SS 316).

2) Material

3) Plate thickness

The plate thickness N shall be equal to the value for N_{min} listed in the table, or be equal to the radius r specified, whichever value is higher.

The difference between any two measurements of plate thickness shall not differ by more than 0.001 DN in mm.

The plate shall not depart from flatness along any diameter by more than 0.01 D_o .

The upstream profile of the orifice shall be a quarter of circle with its centre at the downstream recessed face of the plate. The radius shall be tangential with the upstream face; the downstream edge shall be square and the tangent shall be perpendicular to the upstream face of the plate within $\pm 1^\circ$.

The centre of the orifice shall not differ from the centre of the plate by more than 0.1 mm for DN ≤ 200 mm and 0.2 mm for DN > 200 mm.

4) Orifice

The throat and outlet recess shall have a surface roughness $R_a \leq 0.4 \mu m$ in accordance with ANSI B46.1.

The downstream edge shall be sharp and free from burrs, so that when viewed with the naked eye no light is reflected by the corner.

5) Finish of throat

The upstream and downstream faces of the orifice plate to a diameter equal to D_o shall have a surface roughness $R_a \leq 0.8 \mu m$ in accordance with ANSI B46.1.

The remaining annular part (between O and D_o) of upstream and downstream faces shall have a surface roughness R_a between 3.2 and 6.3 μm in accordance with ANSI B46.1. This finish may be obtained by machining with a round nosed cutting tool having a 0.8 mm radius at a feed rate between 0.35 and 0.45 mm per revolution.

Facing roughness shall be checked by visual or tactile comparison with roughness comparison specimens:

"RUBERT 319" or "FLEXITALLIC 319".

Only to be provided if so specified.

The upstream side of the orifice tab shall be stamped at the indicated locations with:

- the word UPSTREAM
- the Tag Number (in three lines)
- the ANSI flange class, followed by RF
- the nominal line size DN (in mm)
- the measured orifice diameter d (in mm)
- the material of the orifice plate
- the word 1/4 CIRCLE

Letter height approx. 4 mm.

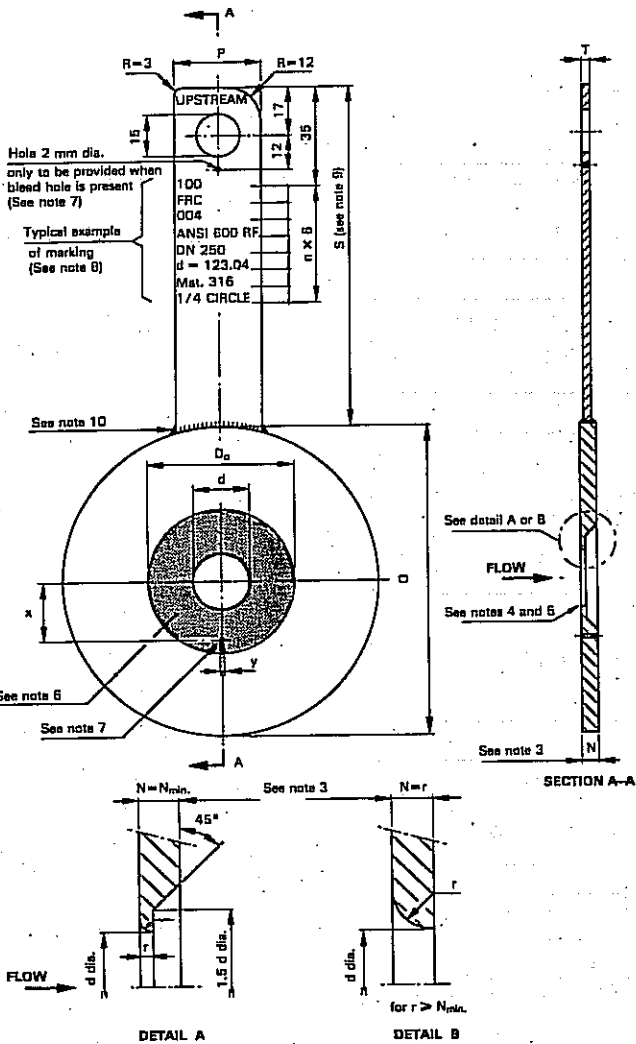
For insulated piping e.g. LNG facilities, the length S shall be made larger to cover for the isolation thickness.

6) Finish of plate

7) Bleed hole

8) Marking

9) Tap length

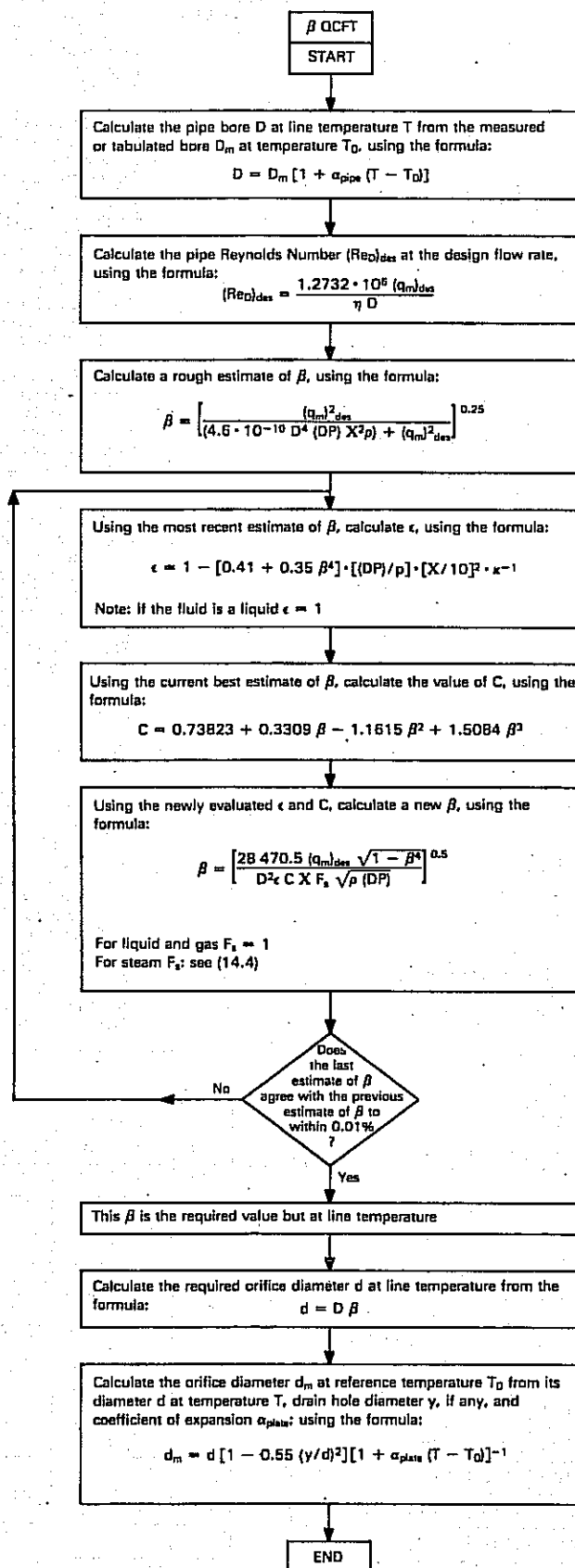


- 10) Welding of tap Tap may be integral with orifice plate up to and incl. 7 mm plate thickness. In other cases full penetration joint to be applied.

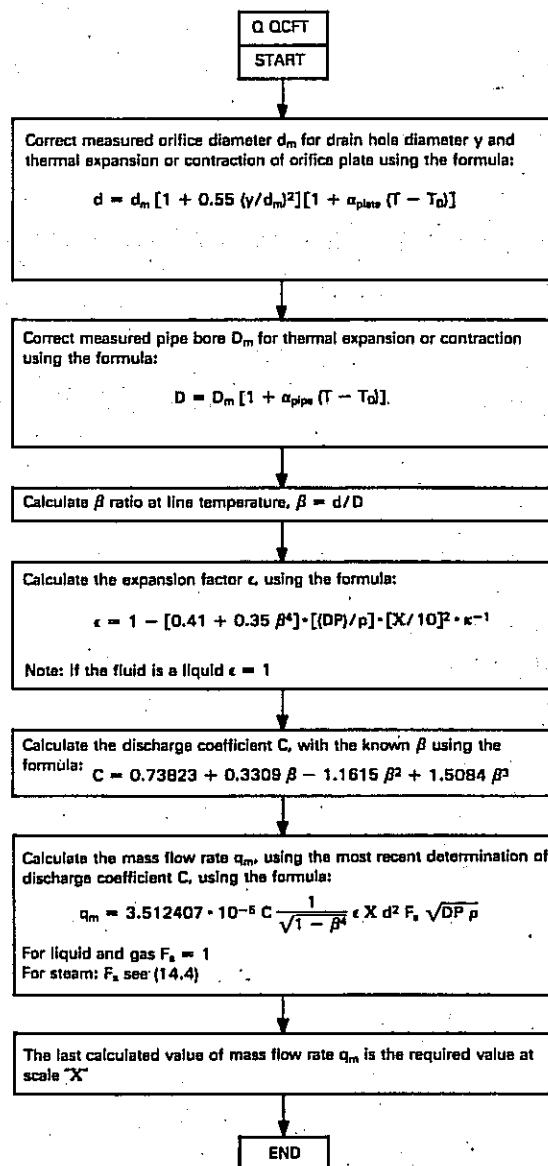
Nom. line size DN		d ±0.1%	D _o ±1 mm	N _{min.} ±2% See note 3	0 O-0.4 mm					P ±1 mm	r ±1%	s±1 mm					T (see note 8)	x ±1 mm	y
					ANSI flange class							ANSI flange class							
mm	in.	dia.	dia.		300	600	900	1500	2500			300	600	900	1500	2500		(See note 7)	
15*	1/2	As specified	26	1.5	62.2	62.2	62.2	62.2	30	As specified	120	120	130	130		1.5	21.0	1.0	
20*	3/4		42		84.2	84.2	84.2	84.2			125	125	135	135					2.0
25*	1			60	3.0	102.2	102.2	102.2			102.2	120	120	145		145			
40*	1 1/2		51		4.0	110.6	110.6	143.8			143.8	146.4	115	115	125	130			5.0
50	2		84	6.5	148.1	148.1	169.7	175.0			197.6	120	120	125	135	140			
80	3		109	8.5	180.0	194.8	206.9	209.5			235.7	125	125	130	140	150			10.0
100	4		164	13.0	251.8	267.1	289.6	283.9	317.1		120	130	135	145	170	11.0			
150	6		208	17.0	308.3	320.6	359.7	353.0	386.9		125	135	145	155	185		13.0		
200	8		261	21.0	361.8	400.0	435.5	435.0	476.2		130	145		165	195	16.0			
250	10		315	25.0	422.2	456.8	498.3	520.4	549.2		135	140	145	175			18.0		
300	12		356	28.0	485.0	492.3	520.9	577.8	140		145	150				155		180	
350	14		406	32.0	539.5	564.7	574.3	840.7	50		145	155	160	195					
400	16		456	38.0	596.3	612.2	637.4	703.8			150		165	205					
450	18		508	43.0	653.1	682.0	696.8	754.9			160	185	190	220					
500	20		610	51.0	774.0	789.0	837.0	901.0			60								
600	24																		

*) For meter runs, see (10.1.9)

4.1.9 Quarter of circle orifice plate for ANSI orifice flanges



4.1.10 Calculation of orifice diameter



4.1.11 Calculation of flow rate

4.2 CONICAL ENTRANCE ORIFICE

4.2.1 Construction

The entrance of the orifice consists of a cone forming an angle of $45^\circ \pm 1^\circ$ with the centre line. See (4.2.9).

4.2.2 Application

Conical entrance orifices can be used for very low pipe Reynolds Number applications. (Fabrication of conical entrance orifice plates is simpler than the fabrication of quarter of circle orifice plates).

4.2.3 Limitations

Pipe bore: not less than 25 mm. Maximum pipe bore is probably unlimited.

Orifice diameter: $d \geq 6 \text{ mm}$

Beta ratio: $0.1 \leq \beta \leq 0.316$

Reynolds Number: $250 \beta \leq Re_D \leq 2 \cdot 10^5 \beta$

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

Available data are reliable but limited.

4.2.4 Pressure tapings

Reliable data are available for corner tapings only. See (3.2.9)

4.2.5 Discharge coefficient

$C = 0.734$ for $250 \beta \leq Re_D \leq 5000 \beta$

$C = 0.730$ for $5000 \beta \leq Re_D \leq 2 \cdot 10^5 \beta$

Uncertainty: $\frac{\delta C}{C} = \pm 2\%$

4.2.6 Expansion factor

$\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$

Uncertainty: $\frac{\delta \epsilon}{\epsilon} = \pm 33(1 - \epsilon) \%$

4.2.7 Calculation

Limitations, see (4.2.3)

Sizing, see (4.2.10)

Flow rate, see (4.2.11)

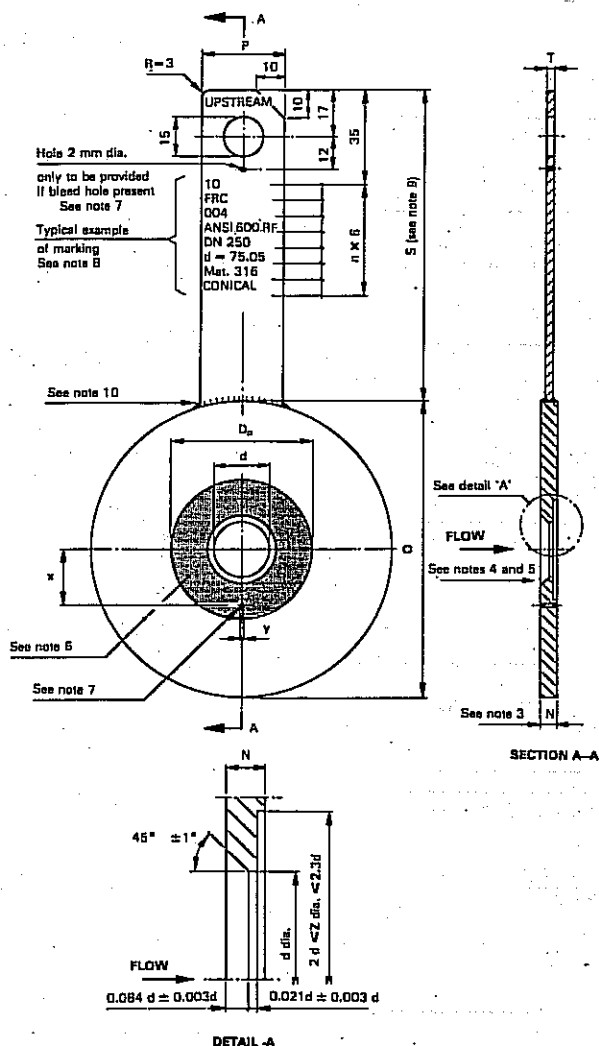
Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

4.2.8 References

BS 1042 (1964)

ANSI B 46.1



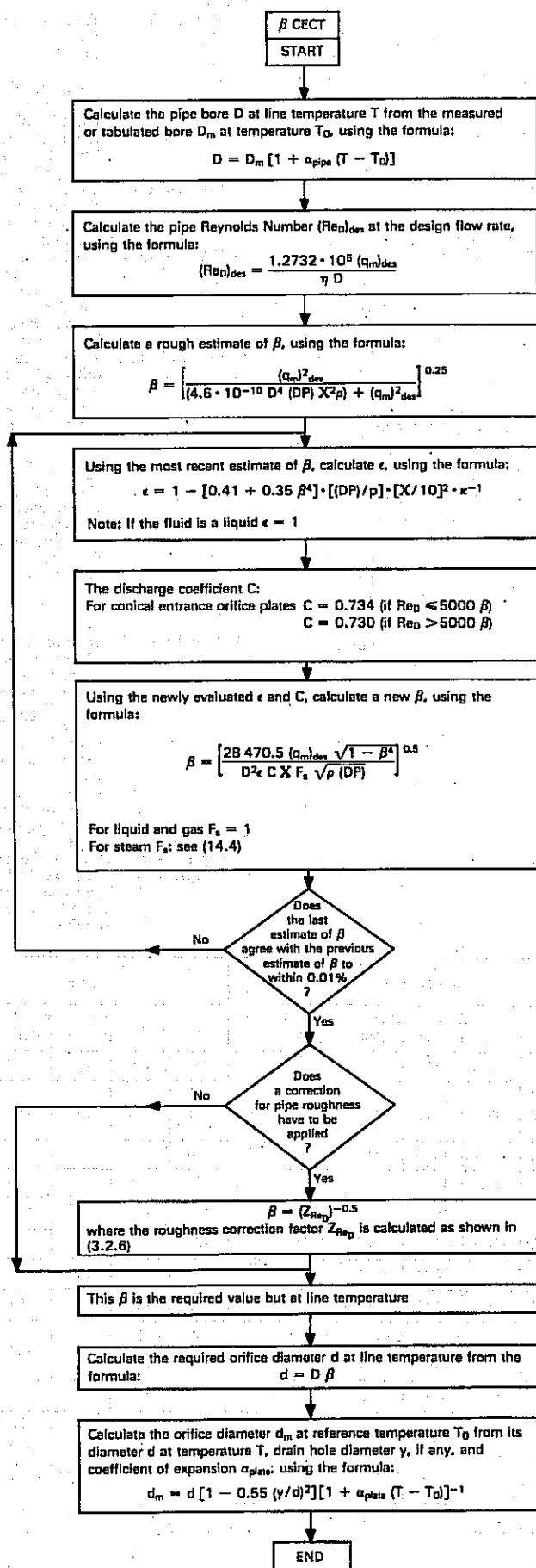
Notes:

- 1) Dimensions Expressed in millimetres unless otherwise indicated.
Stated tolerances shall be strictly adhered to.
- 2) Material As specified (Typically SS 316).
- 3) Plate thickness The difference between any two measurements of plate thickness shall not differ by more than 0.001 DN in mm.
The plate shall not depart from flatness along any diameter by more than 0.01 D_o.
The centre of the orifice shall not differ from the centre of the plate by more than 0.1 mm for DN ≤ 200 mm and 0.2 mm for DN > 200 mm.
- 4) Concentricity The inlet cone, throat and outlet recess shall have a surface roughness Ra ≤ 0.4 µm in accordance with ANSI B46.1.
All edges shall be sharp and free from burrs, so that when viewed with the naked eye no light is reflected by the corners.
- 5) Finish of throat The upstream and downstream faces of the orifice plate to a diameter equal to D_o shall have a surface roughness Ra ≤ 0.8 µm in accordance with ANSI B46.1.
The remaining annular part (between O and D_o) of upstream and downstream faces shall have a surface roughness Ra between 3.2 and 6.3 µm in accordance with ANSI B46.1.
This finish may be obtained by machining with a round nosed cutting tool having a 0.8 mm radius at a feed rate between 0.35 and 0.45 mm per revolution.
Facing roughness shall be checked by visual or tactile comparison with roughness comparison specimens:
"RUBERT 319" or "FLEXITALLIC 319".
- 6) Finish of plate Only to be provided if so specified.
The upstream side of the orifice tab shall be stamped at the indicated locations with:
- the word UPSTREAM
- the Tag Number (in three lines)
- the ANSI flange class, followed by RF
- the nominal line size DN (in mm)
- the measured orifice diameter d (in mm)
- the material of the orifice plate
- the word CONICAL
Letter height approx. 4 mm.
- 7) Bleed hole For insulated piping e.g. LNG facilities, the length S shall be made larger to cover for the isolation thickness.
- 8) Marking Tap may be integral with orifice plate up to and incl. 7 mm plate thickness.
In other cases full penetration joint to be applied.
- 9) For insulated piping e.g. LNG facilities, the length S shall be made larger to cover for the isolation thickness.
- 10) Welding of tap Tap may be integral with orifice plate up to and incl. 7 mm plate thickness.
In other cases full penetration joint to be applied.

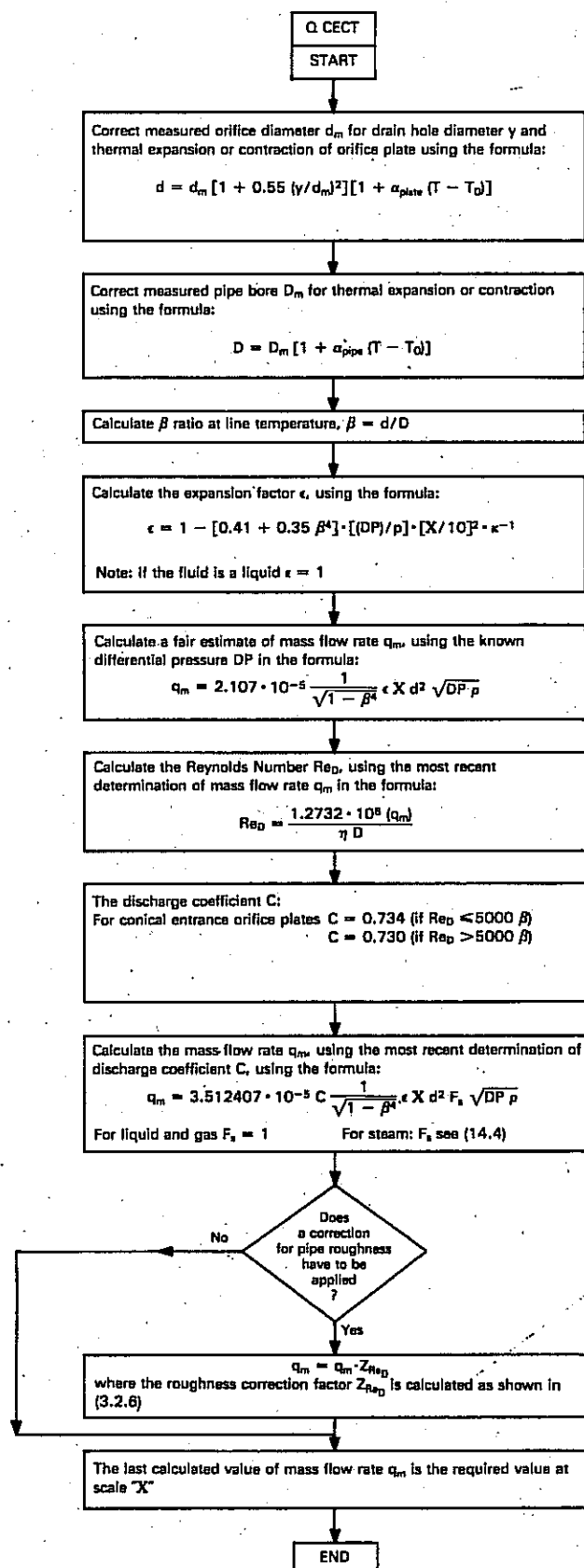
Nom. line size DN		d ±0.1%	D _o ±1 mm	N ±2%	0 O-0.4 mm					P ±1 mm	S±1 mm					T (see note 8)	x ±1 mm	y		
mm	in.	dia.	dia.		ANSI flange class						ANSI flange class						(See note 7)			
					300	600	900	1500	2500		300	600	900	1500	2500					
15*	$\frac{1}{2}$		26	1.5	62.2	62.2	62.2	62.2		30	120	120	130	130		1.5				
20*	$\frac{3}{4}$		42		84.2	84.2	84.2	84.2			125	125	135	135						
25*	1		60		102.2	102.2	102.2	102.2			120	120	145	145						
40*	$1\frac{1}{2}$		51		2.5	110.6	110.6	143.8			143.8	146.4	115	115					125	130
50	2		84	3.5	148.1	148.1	169.7	175.0	197.6	40	120	120	125	135	140	3.5	33.0	1.5		
80	3		109	4.5	180.0	194.6	206.9	209.5	235.7		125	125	130	140	150	4.5	45.5	2.0		
100	4		164	6.5	251.8	267.1	289.6	283.9	317.1		120	130	135	145	170	4.0	70.5	2.0		
150	6		208	8.0	308.3	320.6	359.7	353.0	386.9		125	135	155	185			5.0	95.0	2.5	
200	8		261	10.0	361.8	400.0	435.5	436.0	476.2	45	130	145	165		195	7.0		120.0	3.0	
250	10		315	12.0	422.2	456.8	498.3	520.4	549.2		135	140	175				144.0	3.5		
300	12		356	13.0	485.0	492.3	520.9	577.6	140		145	50					145	150	155	180
350	14		406	15.0	539.5	564.7	574.3	640.7	60		150		155	160	195		9.0	213.5	4.5	
400	16		456	17.0	596.3	612.2	637.4	703.8		165				205	10.0	238.0	5.0			
450	18		508	18.5	653.1	682.0	696.8	754.9		180				220	12.0	288.0	6.0			
500	20		610	22.5	774.0	789.0	837.0	901.0												
600	24																			

* For meter runs, see (10.1.9)

4.2.9 Conical entrance orifice plate for ANSI orifice flanges



4.2.10 Calculation of orifice diameter



4.2.11 Calculation of flow rate

Section 5. Non-concentric orifices

5.1 Segmental orifices

5.1.1 Construction

5.1.2 Application

5.1.3 Limitations

5.1.4 Pressure tapings

5.1.5 Discharge coefficient

5.1.6 Expansion factor

5.1.7 Calculation

5.1.8 Reference

5.1.9 Discharge coefficients C for segmental orifices ($Re_D = 10\,000$)

5.1.10 a/D as a function of β

5.1.11 Segmental orifice, fixed and adjustable (flange tapings)

5.1.12 Calculation of orifice diameter

5.1.13 Calculation of flow rate

5.1 SEGMENTAL ORIFICES

5.1.1 Construction

The form of the orifice is a segment of a circle of approximately the same diameter as the internal pipe. See (5.1.11).

5.1.2 Application

This construction permits complete drainage of any extraneous matter present in fluids such as slurries, etc. The shape of the orifice also makes this device suitable for use as a variable gate orifice (an adjustable orifice similar to a gate valve) to obtain a wide rangeability.

5.1.3 Limitations

Pipe bore: $100 \leq D \leq 350 \text{ mm}$

Beta ratio: $0.3 \leq \beta \leq 0.8$ where $\beta = \sqrt{m}$
 $m = \text{orifice area/pipe area}$

Reynolds Number: $Re_D > 80 \cdot D$ for $125 \leq D \leq 350 \text{ mm}$

$Re_D > 10\,000$ for $100 \leq D \leq 125 \text{ mm}$

Upper pipe Reynolds Number probably unlimited.

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.3$

The available data are incomplete; the only data available for the discharge coefficient C are valid for a Re_D of 10 000.

5.1.4 Pressure tapings

Flange tapings are recommended. The tapping location shall always be in line with the maximum dam height of the orifice plate.

5.1.5 Discharge coefficient

See (5.1.9)

5.1.6 Expansion factor

$$\epsilon = 1 - (0.41 + 0.35\beta^4) (DP/p) \cdot (X/10)^2 \cdot \kappa^{-1}$$

$$\text{Uncertainty: } \frac{\delta\epsilon}{\epsilon} = \pm 3.3 \frac{dp}{p} \%$$

5.1.7 Calculation

Limitations, see (5.1.3)

Flow rate according to the formula as described for the square edge orifice with flange tapings, except for values of C , see (5.1.5). Special calculation of the hypothetical value of β and d is required because of the form of the orifice.

$$\beta = \sqrt{\frac{1}{\pi} \left[\arccos \left(1 - \frac{2a}{D} \right) - 2 \left(1 - \frac{2a}{D} \right) \sqrt{\frac{a}{D} - \left(\frac{a}{D} \right)^2} \right]}$$

For orifice height, see (5.1.10)

$$d = \beta \cdot D$$

Sizing, see (5.1.12)

Flow rate, see (5.1.13)

Pressure loss, see (2.4.4)

Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

5.1.8 Reference

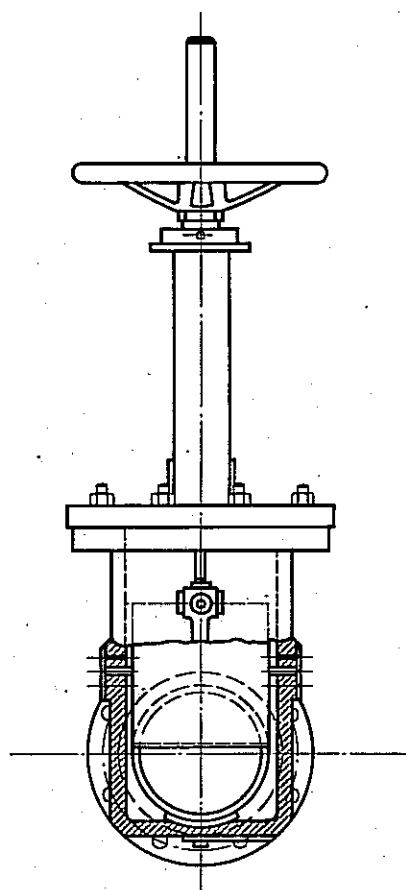
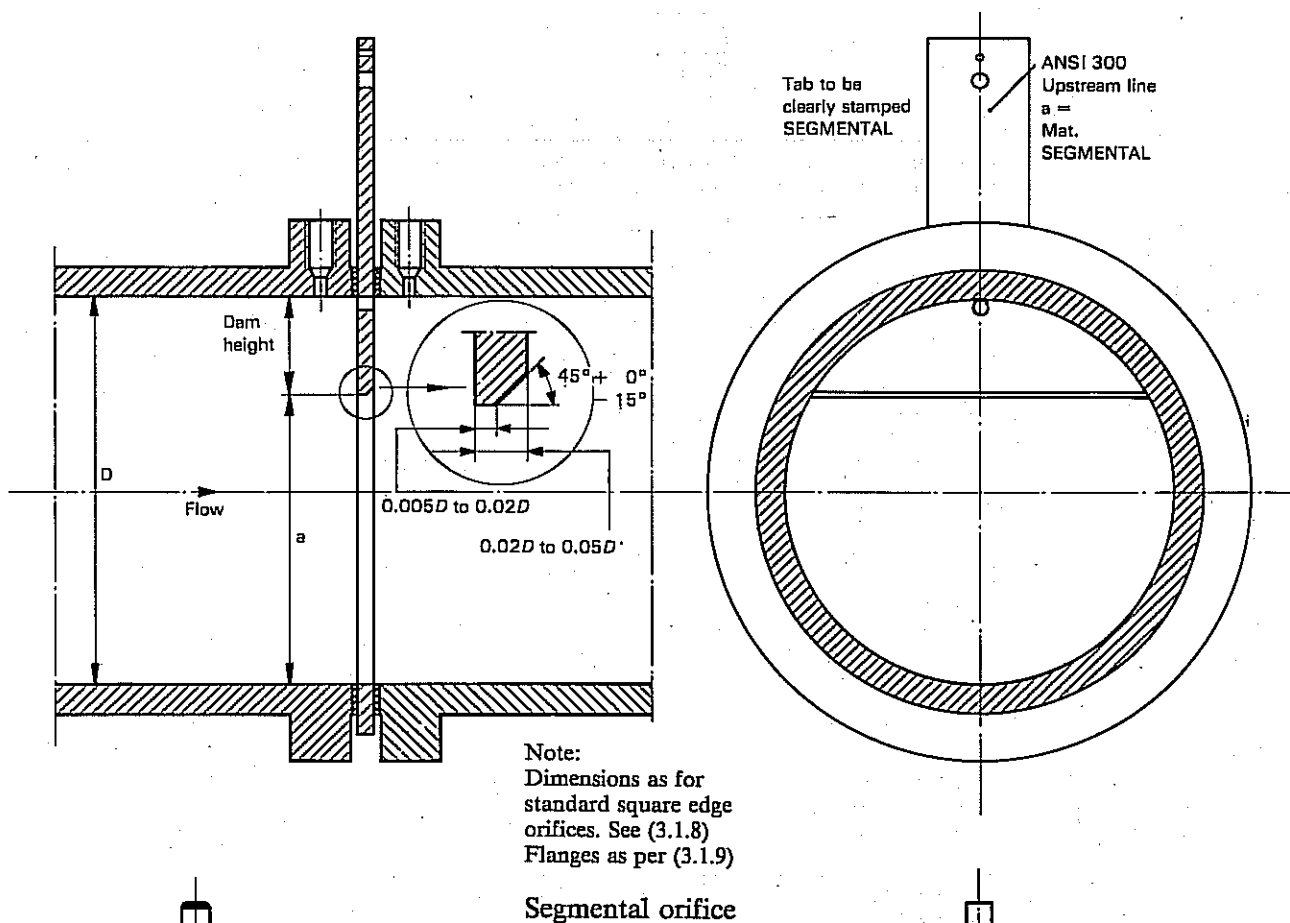
Fluid meters, their Theory and Application, ASME (1971)

5.1.9 Discharge coefficients C for segmental orifices ($Re_D = 10\,000$)

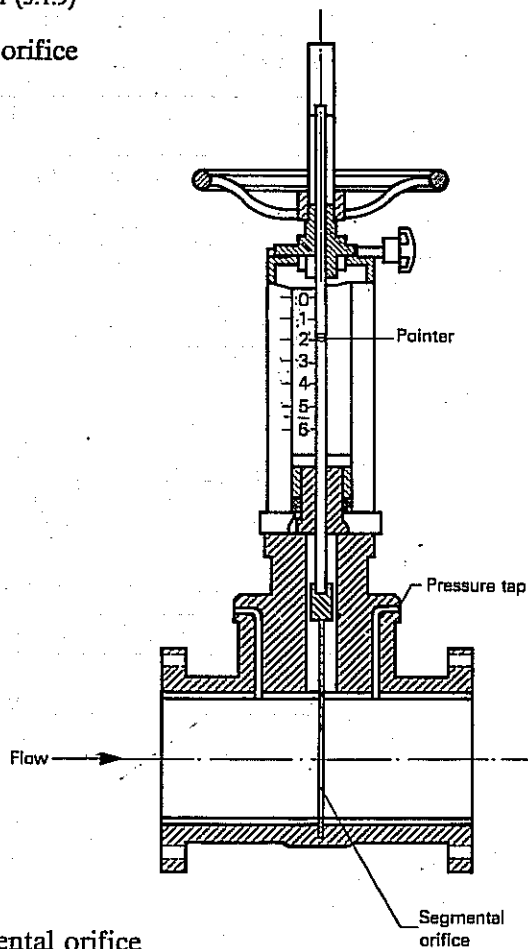
β	nominal pipe size		β	nominal pipe size	
	100 mm	150 to 350 mm		100 mm	150 to 350 mm
0.30	0.6354	0.6294	0.55	0.6415	0.6253
0.31	0.6350	0.6291	0.56	0.6409	0.6248
0.32	0.6356	0.6297	0.57	0.6412	0.6242
0.33	0.6352	0.6292	0.58	0.6413	0.6234
0.34	0.6357	0.6297	0.59	0.6403	0.6225
0.35	0.6362	0.6292	0.60	0.6409	0.6213
0.36	0.6356	0.6296	0.61	0.6405	0.6210
0.37	0.6360	0.6300	0.62	0.6398	0.6204
0.38	0.6373	0.6303	0.63	0.6397	0.6196
0.39	0.6375	0.6296	0.64	0.6386	0.6194
0.40	0.6377	0.6298	0.65	0.6381	0.6190
0.41	0.6378	0.6299	0.66	0.6373	0.6175
0.42	0.6378	0.6300	0.67	0.6353	0.6166
0.43	0.6378	0.6290	0.68	0.6349	0.6180
0.44	0.6387	0.6289	0.69	0.6332	0.6147
0.45	0.6385	0.6287	0.70	0.6320	0.6146
0.46	0.6392	0.6284	0.71	0.6296	0.6141
0.47	0.6388	0.6291	0.72	0.6285	0.6131
0.48	0.6393	0.6286	0.73	0.6262	0.6118
0.49	0.6397	0.6281	0.74	0.6242	0.6108
0.50	0.6400	0.6274	0.75	0.6226	0.6102
0.51	0.6402	0.6276	0.76	0.6204	0.6090
0.52	0.6402	0.6267	0.77	0.6176	0.6080
0.53	0.6401	0.6267	0.78	0.6151	0.6063
0.54	0.6409	0.6256	0.79	0.6134	0.6048
0.55	0.6415	0.6253	0.80	0.6109	0.6032

5.1.10 a/D as a function of β

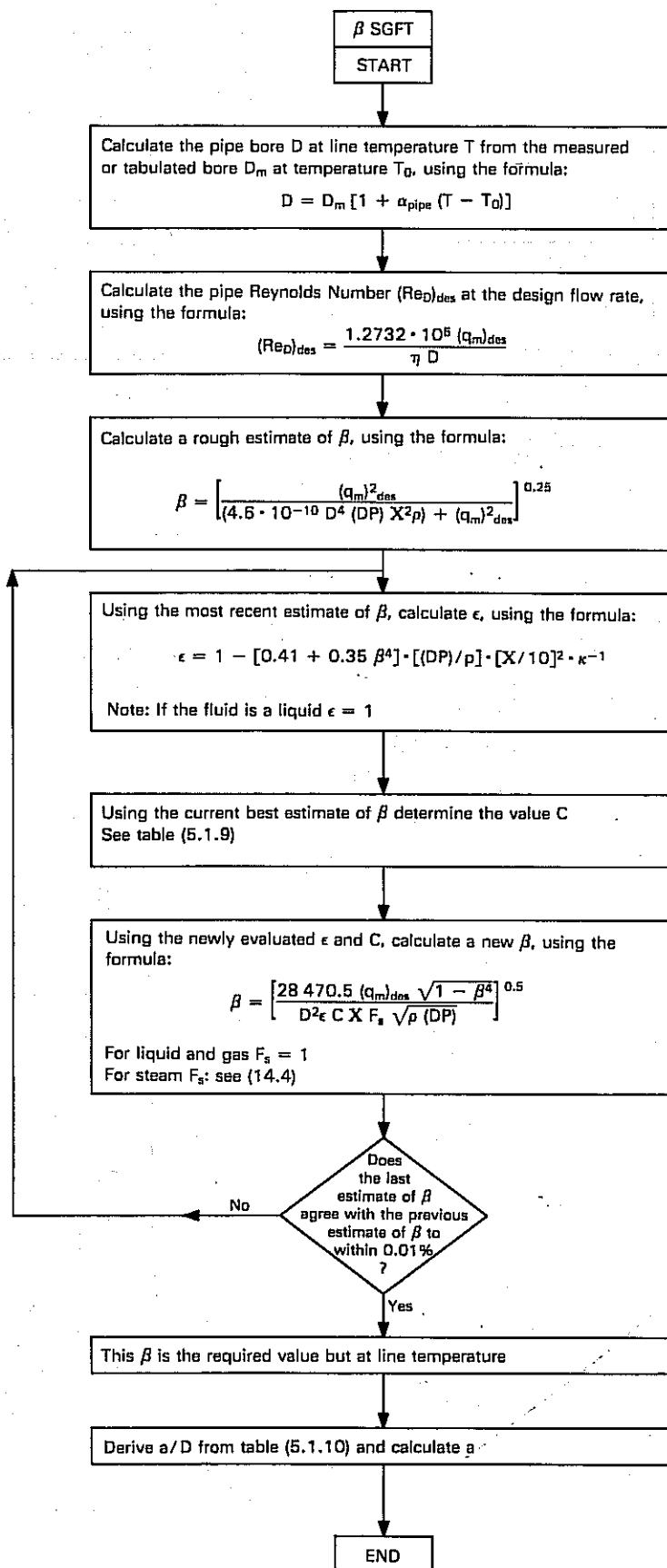
β	0	1	2	3	4	5	6	7	8	9
	a/D									
0.30	0.146	0.146	0.147	0.148	0.148	0.149	0.150	0.150	0.151	0.152
0.31	0.152	0.153	0.154	0.154	0.155	0.156	0.156	0.157	0.158	0.158
0.32	0.159	0.160	0.160	0.161	0.162	0.163	0.163	0.164	0.165	0.165
0.33	0.166	0.167	0.167	0.168	0.169	0.169	0.170	0.171	0.172	0.172
0.34	0.173	0.174	0.174	0.175	0.176	0.177	0.177	0.178	0.179	0.179
0.35	0.180	0.181	0.182	0.182	0.183	0.184	0.184	0.185	0.186	0.187
0.36	0.187	0.188	0.189	0.189	0.190	0.191	0.192	0.192	0.193	0.194
0.37	0.195	0.195	0.196	0.197	0.198	0.198	0.199	0.200	0.200	0.201
0.38	0.202	0.203	0.203	0.204	0.205	0.206	0.206	0.207	0.208	0.209
0.39	0.209	0.210	0.211	0.212	0.212	0.213	0.214	0.215	0.216	0.216
0.40	0.217	0.218	0.219	0.219	0.220	0.221	0.222	0.222	0.223	0.224
0.41	0.225	0.225	0.226	0.227	0.228	0.229	0.229	0.230	0.231	0.232
0.42	0.232	0.233	0.234	0.235	0.236	0.236	0.237	0.238	0.239	0.240
0.43	0.240	0.241	0.242	0.243	0.243	0.244	0.245	0.246	0.247	0.247
0.44	0.248	0.249	0.250	0.251	0.251	0.252	0.253	0.254	0.255	0.256
0.45	0.256	0.257	0.258	0.259	0.260	0.260	0.261	0.262	0.263	0.264
0.46	0.264	0.265	0.266	0.267	0.268	0.269	0.269	0.270	0.271	0.272
0.47	0.273	0.274	0.274	0.275	0.276	0.277	0.278	0.279	0.279	0.280
0.48	0.281	0.282	0.283	0.284	0.284	0.285	0.286	0.287	0.288	0.289
0.49	0.289	0.290	0.291	0.292	0.293	0.294	0.295	0.295	0.296	0.297
0.50	0.298	0.299	0.300	0.301	0.301	0.302	0.303	0.304	0.305	0.306
0.51	0.307	0.308	0.308	0.309	0.310	0.311	0.312	0.313	0.314	0.315
0.52	0.315	0.316	0.317	0.318	0.319	0.320	0.321	0.322	0.322	0.323
0.53	0.324	0.325	0.326	0.327	0.328	0.329	0.330	0.330	0.331	0.332
0.54	0.333	0.334	0.335	0.336	0.337	0.338	0.339	0.339	0.340	0.341
0.55	0.342	0.343	0.344	0.345	0.346	0.347	0.348	0.349	0.350	0.350
0.56	0.351	0.352	0.353	0.354	0.355	0.356	0.357	0.358	0.359	0.360
0.57	0.361	0.362	0.363	0.363	0.364	0.365	0.366	0.367	0.368	0.369
0.58	0.370	0.371	0.372	0.373	0.374	0.375	0.376	0.377	0.378	0.379
0.59	0.380	0.380	0.381	0.382	0.383	0.384	0.385	0.386	0.387	0.388
0.60	0.389	0.390	0.391	0.392	0.393	0.394	0.395	0.396	0.397	0.398
0.61	0.399	0.400	0.401	0.402	0.403	0.404	0.405	0.406	0.407	0.408
0.62	0.409	0.410	0.411	0.412	0.413	0.414	0.415	0.416	0.417	0.418
0.63	0.419	0.420	0.421	0.422	0.423	0.424	0.425	0.426	0.427	0.428
0.64	0.429	0.430	0.431	0.432	0.433	0.434	0.435	0.436	0.437	0.438
0.65	0.439	0.440	0.441	0.442	0.443	0.444	0.445	0.446	0.447	0.448
0.66	0.449	0.450	0.451	0.452	0.453	0.455	0.456	0.457	0.458	0.459
0.67	0.460	0.461	0.462	0.463	0.464	0.465	0.466	0.467	0.468	0.469
0.68	0.470	0.472	0.473	0.474	0.475	0.476	0.477	0.478	0.479	0.480
0.69	0.481	0.482	0.483	0.484	0.486	0.487	0.488	0.489	0.490	0.491
0.70	0.492	0.493	0.494	0.495	0.497	0.498	0.499	0.500	0.501	0.502
0.71	0.503	0.504	0.505	0.507	0.508	0.509	0.510	0.511	0.512	0.513
0.72	0.514	0.516	0.517	0.518	0.519	0.520	0.521	0.522	0.524	0.525
0.73	0.526	0.527	0.528	0.529	0.530	0.532	0.533	0.534	0.535	0.536
0.74	0.537	0.539	0.540	0.541	0.542	0.543	0.544	0.546	0.547	0.548
0.75	0.549	0.550	0.552	0.553	0.554	0.555	0.556	0.557	0.559	0.560
0.76	0.561	0.562	0.563	0.565	0.566	0.567	0.568	0.570	0.571	0.572
0.77	0.573	0.574	0.576	0.577	0.578	0.579	0.581	0.582	0.583	0.584
0.78	0.586	0.587	0.588	0.589	0.591	0.592	0.593	0.594	0.596	0.597
0.79	0.598	0.599	0.601	0.602	0.603	0.604	0.606	0.607	0.608	0.610
0.80	0.611	0.612	0.613	0.615	0.616	0.617	0.619	0.620	0.621	0.623



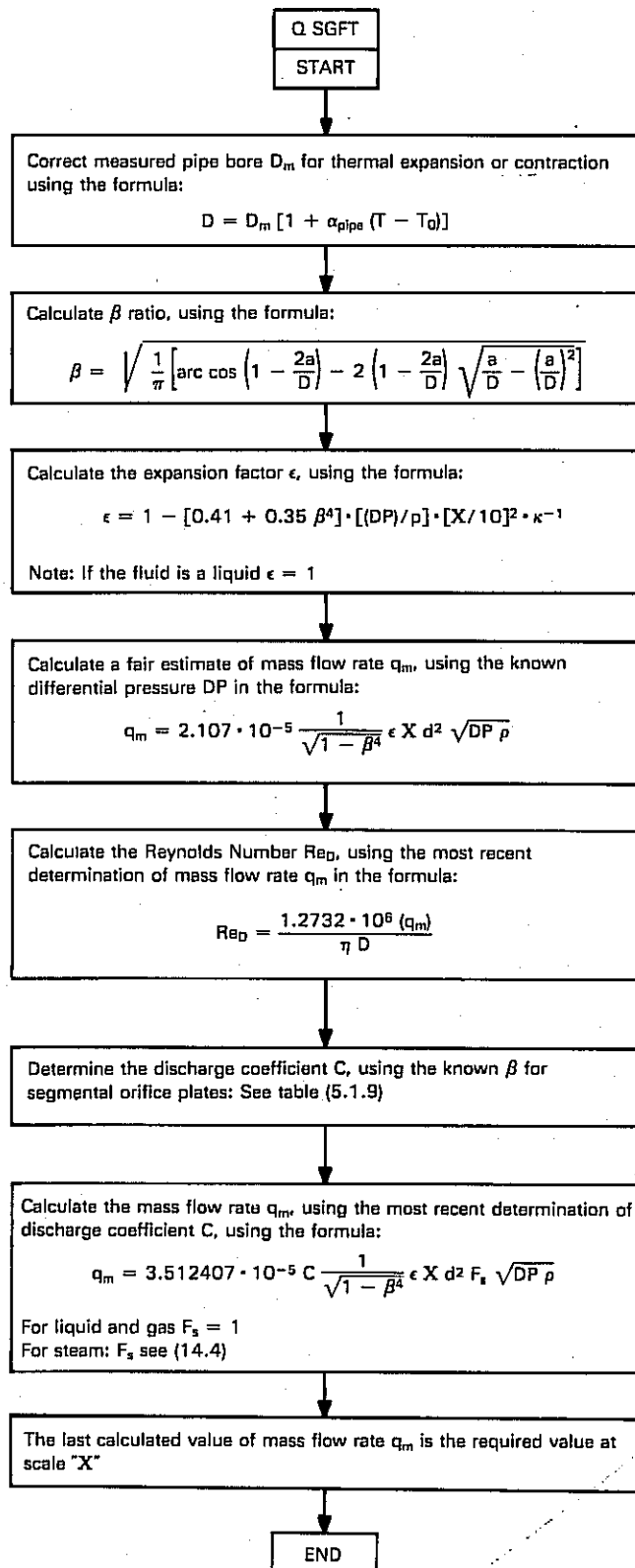
Adjustable segmental orifice



5.1.11 Segmental orifice, fixed and adjustable (flange tapplings)



5.1.12 Calculation of orifice diameter



5.1.13 Calculation of flow rate

THE
FEDERAL
BUREAU OF
INVESTIGATION
OF THE
DEPARTMENT OF JUSTICE
WASHINGTON, D. C.
20535

TO : DIRECTOR, FBI
FROM : SAC, NEW YORK
SUBJECT: [Illegible]

RE: [Illegible]

DATE: [Illegible]

1. [Illegible]

2. [Illegible]

3. [Illegible]

4. [Illegible]

5. [Illegible]

6. [Illegible]

7. [Illegible]

8. [Illegible]

9. [Illegible]

10. [Illegible]

11. [Illegible]

12. [Illegible]

Section 6. Venturi-type devices

6.1 Venturi tube (classical)

- 6.1.1 Construction
- 6.1.2 Application
- 6.1.3 Limitations
- 6.1.4 Pressure tapings
- 6.1.5 Discharge coefficient
- 6.1.6 Expansion factor
- 6.1.7 Calculation
- 6.1.8 References
- 6.1.9 Venturi tubes
- 6.1.10 Calculation of throat diameter
- 6.1.11 Calculation of flow rate

6.2 Rectangular Venturi tube

- 6.2.1 Construction
- 6.2.2 Application
- 6.2.3 Limitations
- 6.2.4 Pressure tapings
- 6.2.5 Discharge coefficient
- 6.2.6 Expansion factor
- 6.2.7 Calculation
- 6.2.8 Reference
- 6.2.9 Rectangular Venturi tubes
- 6.2.10 Calculation of throat diameter
- 6.2.11 Calculation of flow rate

6.1 VENTURI TUBE (CLASSICAL)

6.1.1 Construction

The classical (Herschel type) Venturi tube is a short, narrowed pipe (throat) between two tapered sections. When the exit diameter is smaller than the downstream pipe diameter it is called a truncated Venturi tube. See (6.1.9).

6.1.2 Application

For low-pressure loss (2.4.4) and for accurate measurement of fluids containing suspended solids.

6.1.3 Limitations

High initial cost.

Not easily removable.

Length of element may be a disadvantage.

In principle suitable for all fluids, but ISO 5167 so far restricts its use to liquids.

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

Roughness of upstream pipe $k/D \leq 10^{-3}$ (for at least 2D upstream).

The limitations of the classical Venturi tube depend on the way in which the Venturi tubes are manufactured, see (6.1.9), and are given in the table below:

Type	Pipe size	β ratio	Reynolds Number
A Venturi with a rough cast convergent	$100 \leq D \leq 800$	$0.3 \leq \beta \leq 0.75$	$2 \times 10^5 \leq Re_D \leq 2 \times 10^6$
B Venturi with a machined convergent	$50 \leq D \leq 250$	$0.4 \leq \beta \leq 0.75$	$2 \times 10^5 \leq Re_D \leq 10^6$
C Venturi with a rough cast, welded sheet iron convergent	$200 \leq D \leq 1200$	$0.4 \leq \beta \leq 0.70$	$2 \times 10^5 \leq Re_D \leq 2 \times 10^6$

6.1.4 Pressure tapings

See (6.1.9).

6.1.5 Discharge coefficient

Type A: $C = 0.984$

Type B: $C = 0.995$

Type C: $C = 0.985$

Uncertainty: Type A: $\frac{\delta C}{C} = \pm 0.7\%$

Type B: $\frac{\delta C}{C} = \pm 1.0\%$

Type C: $\frac{\delta C}{C} = \pm 1.5\%$

6.1.6 Expansion factor

$$\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{1/2}$$

where $K = [p - (DP) (X/10)^2]/p$

Uncertainty: $\frac{\delta \epsilon}{\epsilon} = \pm (4 + 100 \beta^8) \frac{dp}{p} \%$
(dp and p in same units)

6.1.7 Calculation

Limitations, see (6.1.3)

Sizing, see (6.1.10)

Flow rate, see (6.1.11)

Pressure loss, see (2.4.4)

Steam correction factor F_s , see (14.4)

Uncertainty, see (13).

6.1.8 References

ISO 5167

DIN 4760

DIN 4762

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

1914

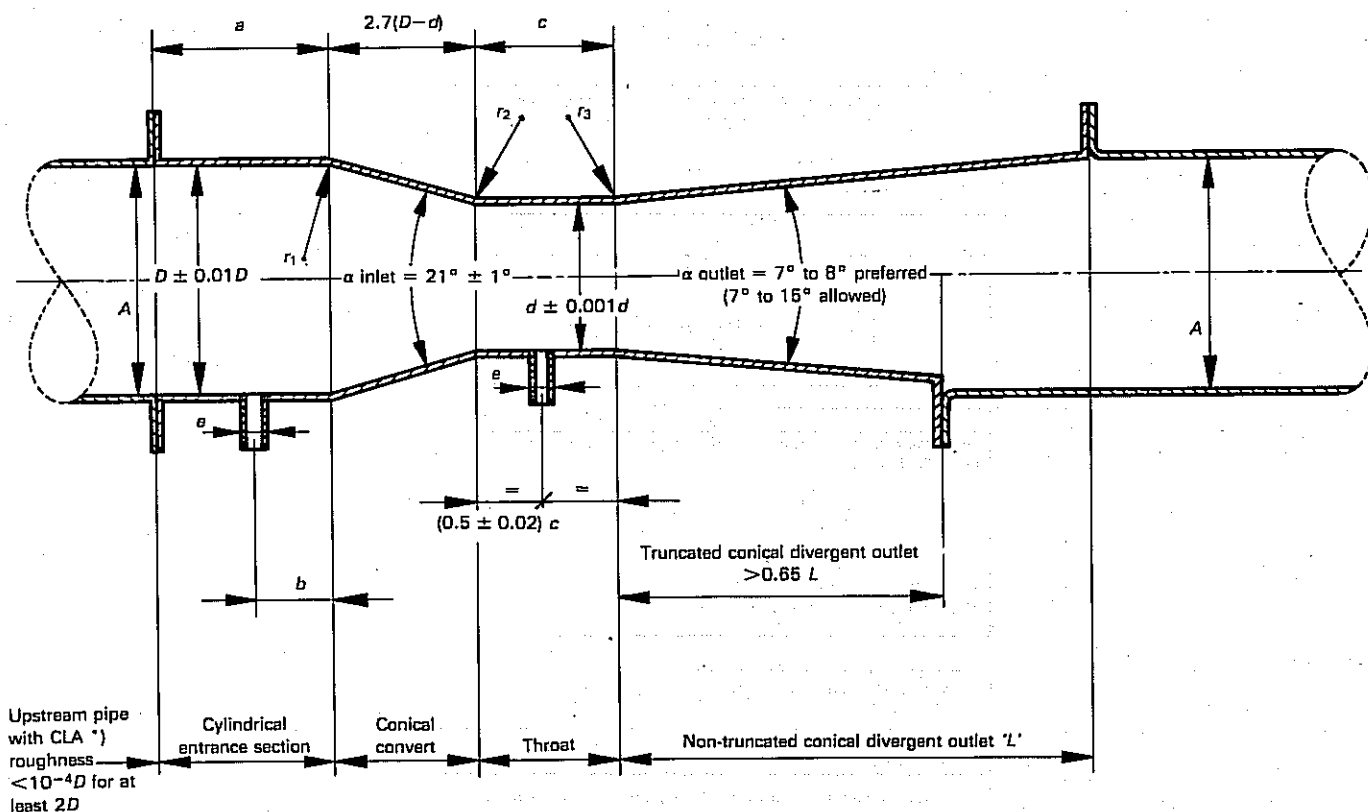
1914

1914

1914

1914

1914

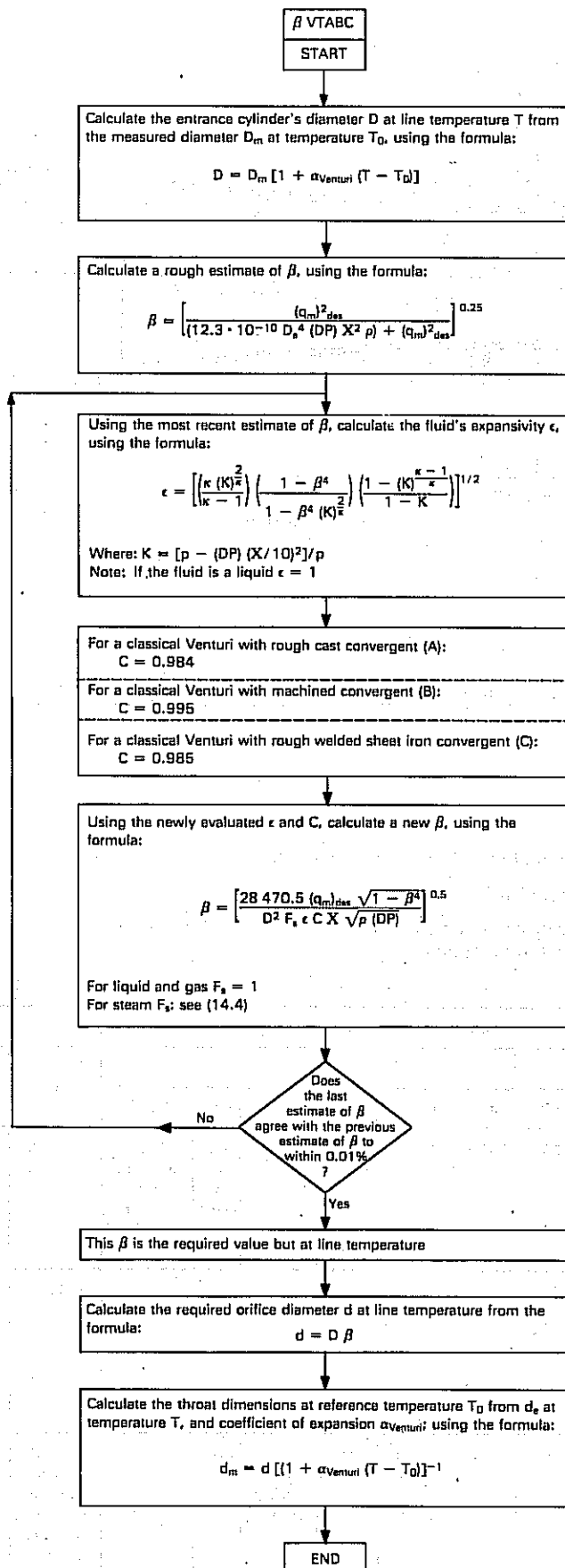


Note: $b = 0.50D \pm 0.25D$ for $100 \text{ mm (4 in.)} \leq D \leq 150 \text{ mm (6 in.)}$
 $0.50D + 0D$
 $0.50D - 0.25D$ for $150 \text{ mm (6 in.)} < D \leq 800 \text{ mm (32 in.)}$
 $e = 4\text{--}10 \text{ mm}$ but $< 0.1D$ for upstream tapplings and
 $< 0.13d$ for throat tapplings

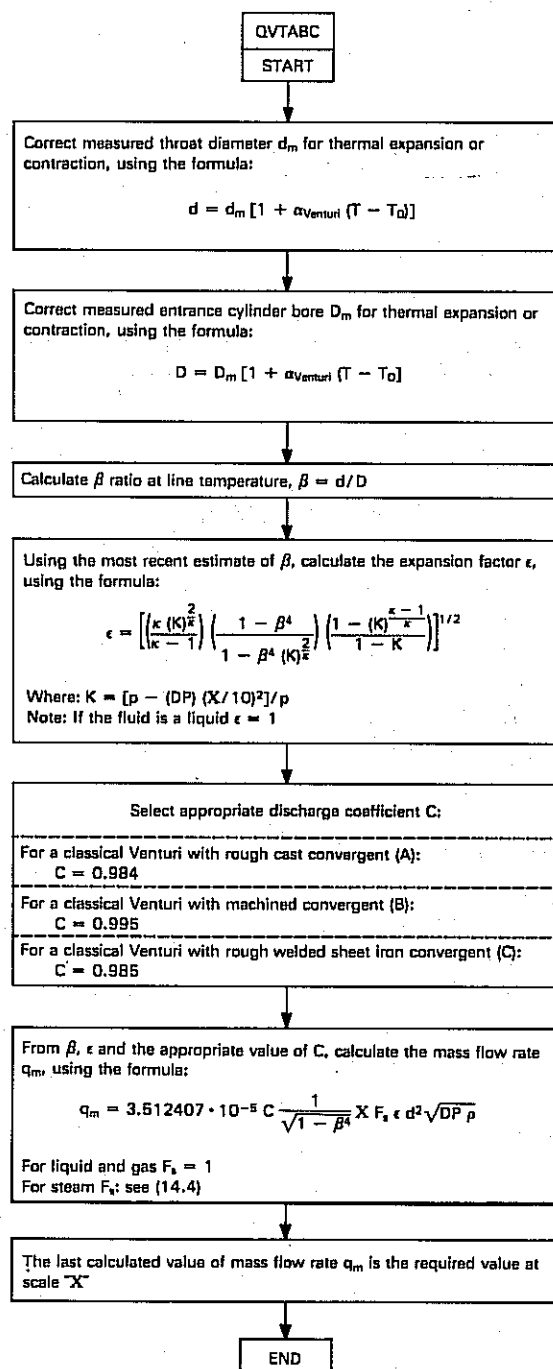
Manufacturing and/or construction method	Dimensions (recommended by ISO)										Finish CLA*) roughness			
	a		c		r_1		r_2		r_3		Entrance section	Conical convert	Throat	Conical divergent
	Rec.	Limits	Rec.	Limits	Rec.	Limits	Rec.	Limits	Rec.	Limits				
Type A: Cast, with throat and entrance cylinder machined	$> D$	$> 0.25D + 250 \text{ mm}$ or $+ 10''$	d	$> 0.33d$	$1.375D$	$+ 20\%$	$3.625d$	$+0.125d$	$10d$ for α outlet 7°	$5\text{--}15d$ increasing with decreasing α outlet	$< 10^{-4}D$	$< 10^{-4}D$	$< 10^{-3}d$ but preferably $< 0.5 \cdot 10^{-3}d$	Rough cast, smooth and clean
Type B: Cast, with throat, convergent portion and entrance cylinder machined	$> D$	—	d	$> 0.6d$	Zero	$< 0.25D$	Zero	$< 0.25d$	Zero	$< 0.25d$	$< 10^{-4}D$	$< 10^{-4}D$	$< 10^{-3}d$ but preferably $< 0.5 \cdot 10^{-3}d$	Rough cast, smooth and clean
Type C: manufactured by welding sheet iron	$> D$	—	d	—	Zero	Curvature due to welding allowed	Zero	Curvature due to welding allowed	Zero	—	$5 \cdot 10^{-4}D$ (Clean, free from encrustation) Height of internal weld seams $< 0.05D$	$5 \cdot 10^{-4}D$ (Clean, free from encrustation) Height of internal weld seams $< 0.05d$	$< 10^{-3}d$ but preferably $< 0.5 \cdot 10^{-3}d$	Smooth and clean

*) CLA = centre line average value or arithmetic mean roughness value (see DIN 4760 to DIN 4762)

6.1.9 Venturi tubes



6.1.10 Calculation of throat diameter



6.1.11 Calculation of flow rate

6.2 RECTANGULAR VENTURI TUBE

6.2.1 Construction

In general, the construction of the rectangular Venturi tube is as described for the classical (circular) Venturi tube except that the cross section has a rectangular shape. See (6.2.9A) and (6.2.9B) of which (6.2.9A) is the recommended version.

6.2.2 Application

For moderately accurate measurements in rectangular conduits, where other measuring devices are impossible or unpractical, e.g. in large rectangular air ducts of furnaces.

6.2.3 Limitations

1. Equivalent diameter of entrance: $1.13 \sqrt{WH} \leq 1200 \text{ mm}$
2. Ratio of duct at the entrance: preferably: $0.67 \leq W/H \leq 1.5$
limits: $0.5 \leq W/H \leq 2.0$
ideally: $W/H = 1$
3. Ratio of the throat: preferably: $0.67 \leq w/h \leq 1.5$
limits: $0.5 \leq w/h \leq 2.0$
ideally: $w/h = 1$

Note: If Venturi contracted in two planes $w/h = W/H$

4. Equivalent beta ratio: $0.44 \leq \sqrt{wh/WH} \leq 0.74$
5. Entrance Reynolds Number: $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^7$
(based on equivalent diameter $D = 1.13 \sqrt{WH}$)
6. Differential pressure: $dp \leq 0.25 \text{ bar}$
7. Differential pressure/upstream pressure:
(dp/p) ≤ 0.25
8. Duct internal roughness: $(K/D) \leq 5 \cdot 10^{-3}$

6.2.4 Pressure tapings

The low-pressure tapping is placed in the centre of the throat in one of the larger sides of the contraction.

The high-pressure tapping is placed in the same plane at a distance equal to $\sqrt{\frac{4}{\pi}} \cdot WH$ (equivalent "D") from the inlet. For WH, see (6.2.9A).

6.2.5 Discharge coefficient

$$C = 0.975$$

As a guide the flow meter's basic discharge coefficient can be expected to be uncertain to approx. $\pm 10\%$ within the limits quoted in (6.2.3). For equivalent β ratios of about 0.6 and W/H and w/h equal to 1.0, the uncertainty of the discharge coefficient is approx. 5%.

6.2.6 Expansion factor

$$\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{1/2}$$

$$\text{where } K = [p - (DP) (X/10)^2] / p$$

$$\text{Uncertainty: } \frac{\delta \epsilon}{\epsilon} = \pm (4 + 100\beta^8) \frac{dp}{p} \text{ for } 0.2 \leq \beta \leq 0.75$$

(dp and p in the same units)

6.2.7 Calculation

Limitations, see (6.2.3)

Sizing, see (6.2.10)

Flow rate, see (6.2.11)

For steam use F_s according to (14.4)

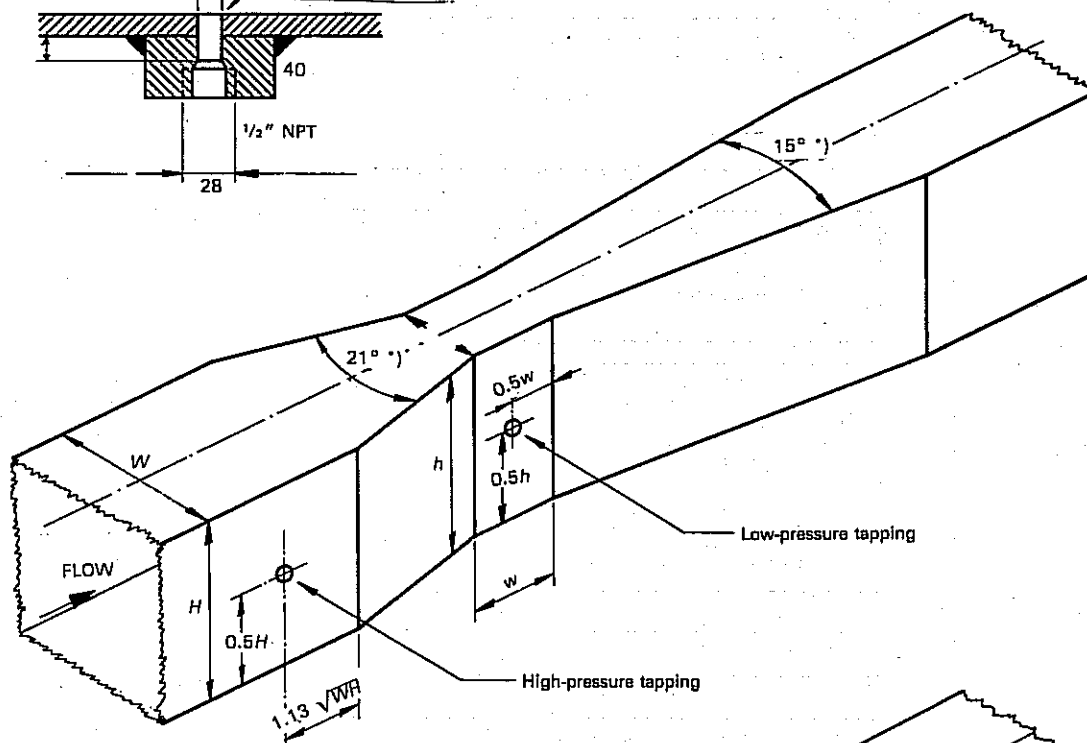
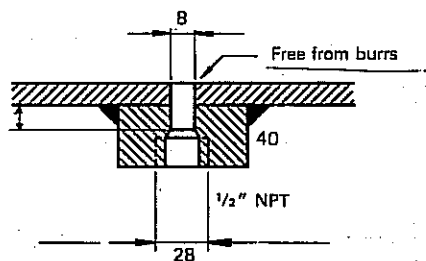
Pressure loss, depending on $\frac{wh}{WH}$ and the taper of the outlet section, but slightly (approximately 5%)

higher than indicated for circular Venturi tubes, see (6.1.7)

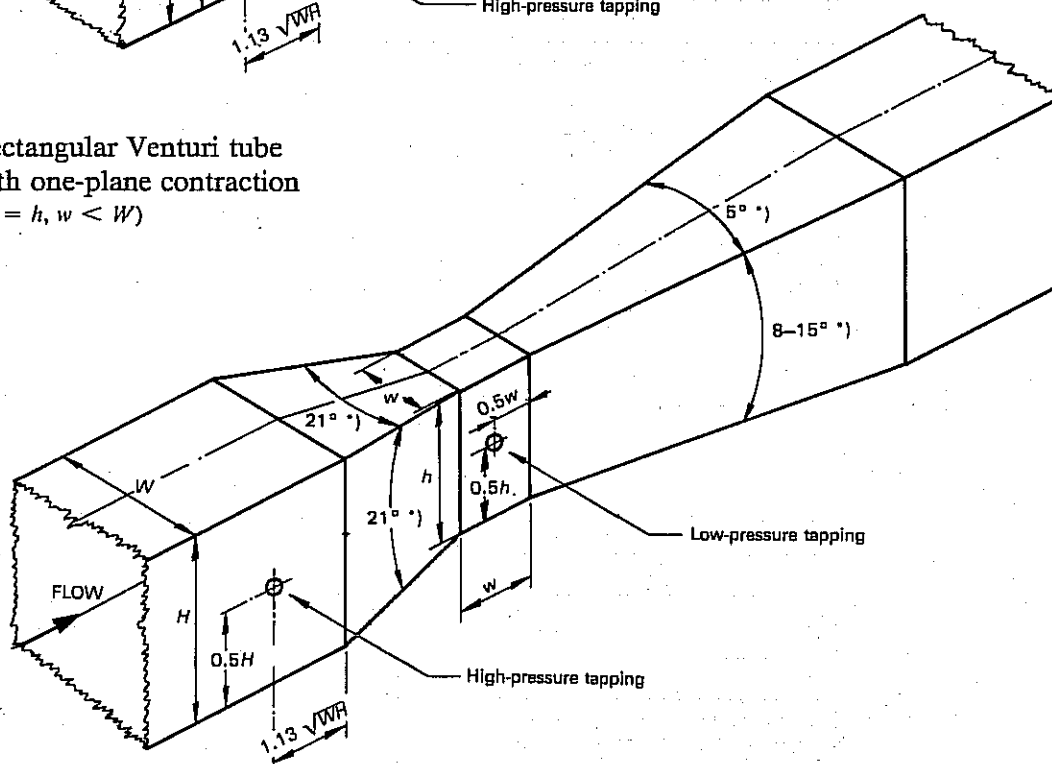
Uncertainty, see (13)

6.2.8 Reference

"Rectangular Venturi Tube Design", Part. 1, R.G. West



A. Rectangular Venturi tube
with one-plane contraction
($H = h, w < W$)



B. Rectangular Venturi tube
with two-plane contraction

($h < H, w < W$)

Notes:

Upstream conduit area = WH ,

where H/W or $W/H = 0.67$ to 1.5

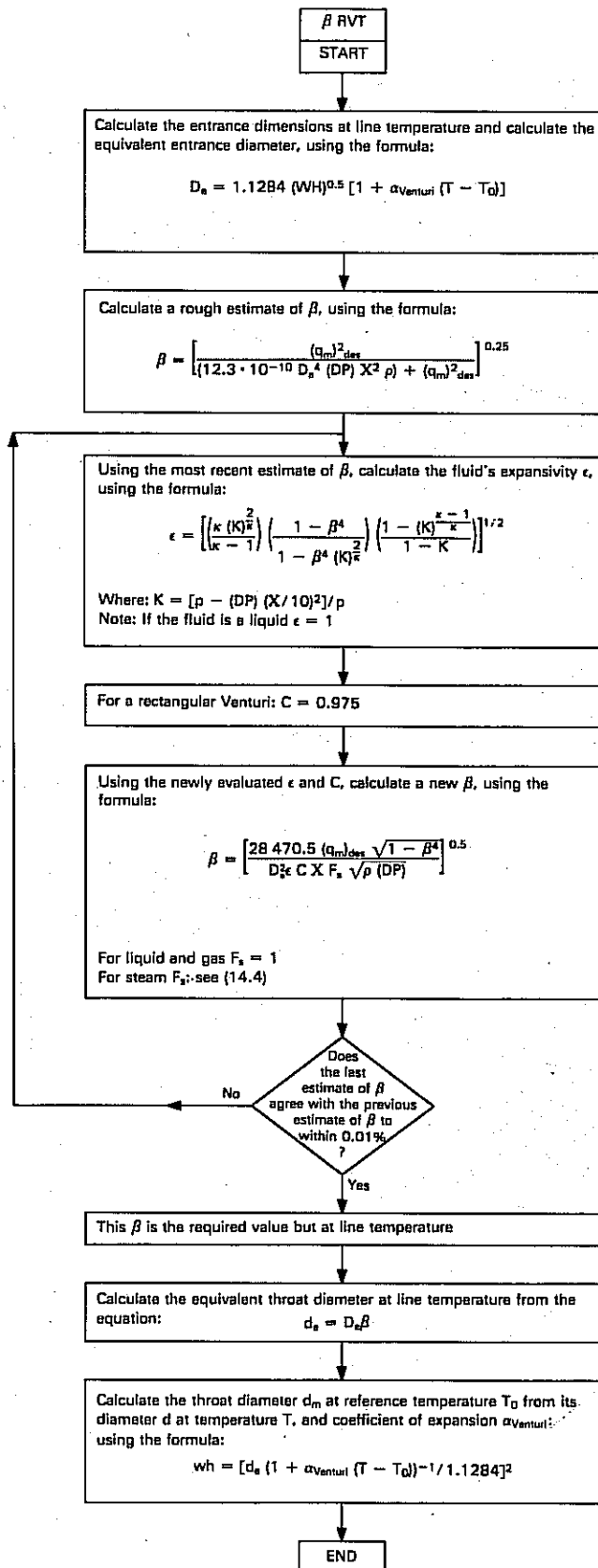
Throat area = wh , where h/w or $w/h = 0.67$ to 1.5

$m = wh/WH$; $\beta = \sqrt{m}$

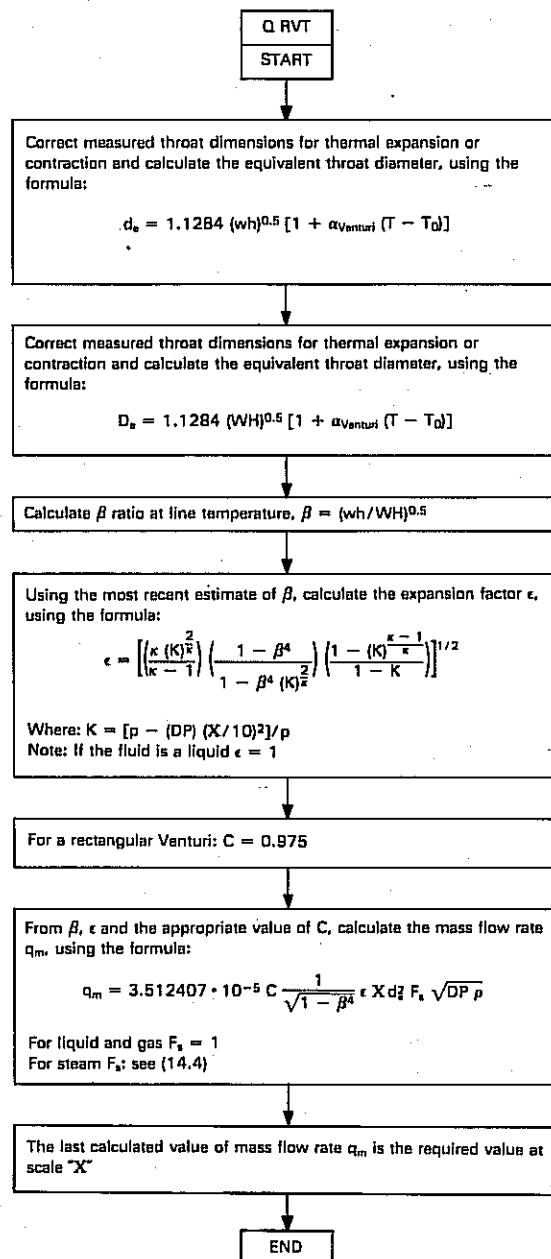
The planes of a preceding bend, the pressure taps and the two non-contracted walls of the duct shall run parallel

*) Angle between planes depending on w/h .

6.2.9 Rectangular Venturi tubes



6.2.10 Calculation of throat diameter



6.2.11 Calculation of flow rate

Section 7. Nozzles

7.1 ISA 1932 nozzle

- 7.1.1 Construction
- 7.1.2 Application
- 7.1.3 Limitations
- 7.1.4 Pressure tappings
- 7.1.5 Discharge coefficient
- 7.1.6 Expansion factor
- 7.1.7 Calculation
- 7.1.8 Reference
- 7.1.9 ISA 1932 nozzle
- 7.1.10 Calculation of throat diameter
- 7.1.11 Calculation of flow rate

7.2 Long radius nozzle

- 7.2.1 Construction
- 7.2.2 Application
- 7.2.3 Limitations
- 7.2.4 Pressure tappings
- 7.2.5 Discharge coefficient
- 7.2.6 Expansion factor
- 7.2.7 Calculation
- 7.2.8 Reference
- 7.2.9 Long radius nozzle
- 7.2.10 Calculation of throat diameter
- 7.2.11 Calculation of flow rate

7.1 ISA 1932 NOZZLE

7.1.1 Construction

The nozzle is a curve-shaped convergent entry leading to a short-cylindrical throat without a discharge cone. See (7.1.9).

7.1.2 Application

Where a Venturi tube is too long. Where erosion or cavitation prohibits the use of square edge orifices.

7.1.3 Limitations

Pipe bore: $50 \leq D \leq 500 \text{ mm}$

Beta ratio: $0.3 \leq \beta \leq 0.8$

Pipe Reynolds Number: $70\,000 \leq Re_D \leq 10^7$ for $0.3 \leq \beta \leq 0.44$
 $20\,000 \leq Re_D \leq 10^7$ for $0.44 < \beta \leq 0.8$

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

β	≤ 0.35	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.60	0.70	0.77	0.80
$k/D \cdot 10^4$	25	18.6	13.5	10.6	8.7	7.5	6.7	6.1	5.6	4.5	4.0	3.9	3.9

or without a restriction if $k/D \leq 3.8 \cdot 10^{-4}$

7.1.4 Pressure tapings

Corner tapings only, see (3.2.9).

7.1.5 Discharge coefficient

$$C = 0.99 - 0.2262 \beta^{4.1} + [0.000215 - 0.001125 \beta + 0.00249 \beta^{4.7}] \cdot \left[\frac{10^6}{(Re_D)} \right]^{1.15}$$

$$\text{Uncertainty: } \frac{\delta C}{C} = \pm 0.8\% \text{ for } \beta \leq 0.6$$

$$\frac{\delta C}{C} = \pm (2\beta - 0.4)\% \text{ for } \beta > 0.6$$

7.1.6 Expansion factor

$$\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{1/2}$$

where $K = [p - (DP) (X/10)^2]/p$

$$\text{Uncertainty: } \frac{\delta \epsilon}{\epsilon} = \pm 2 \frac{dp}{p} \%$$

(dp and p in the same units)

7.1.7 Calculation

Limitations, see (7.1.3)

Sizing, see (7.1.10)

Flow rate, see (7.1.11)

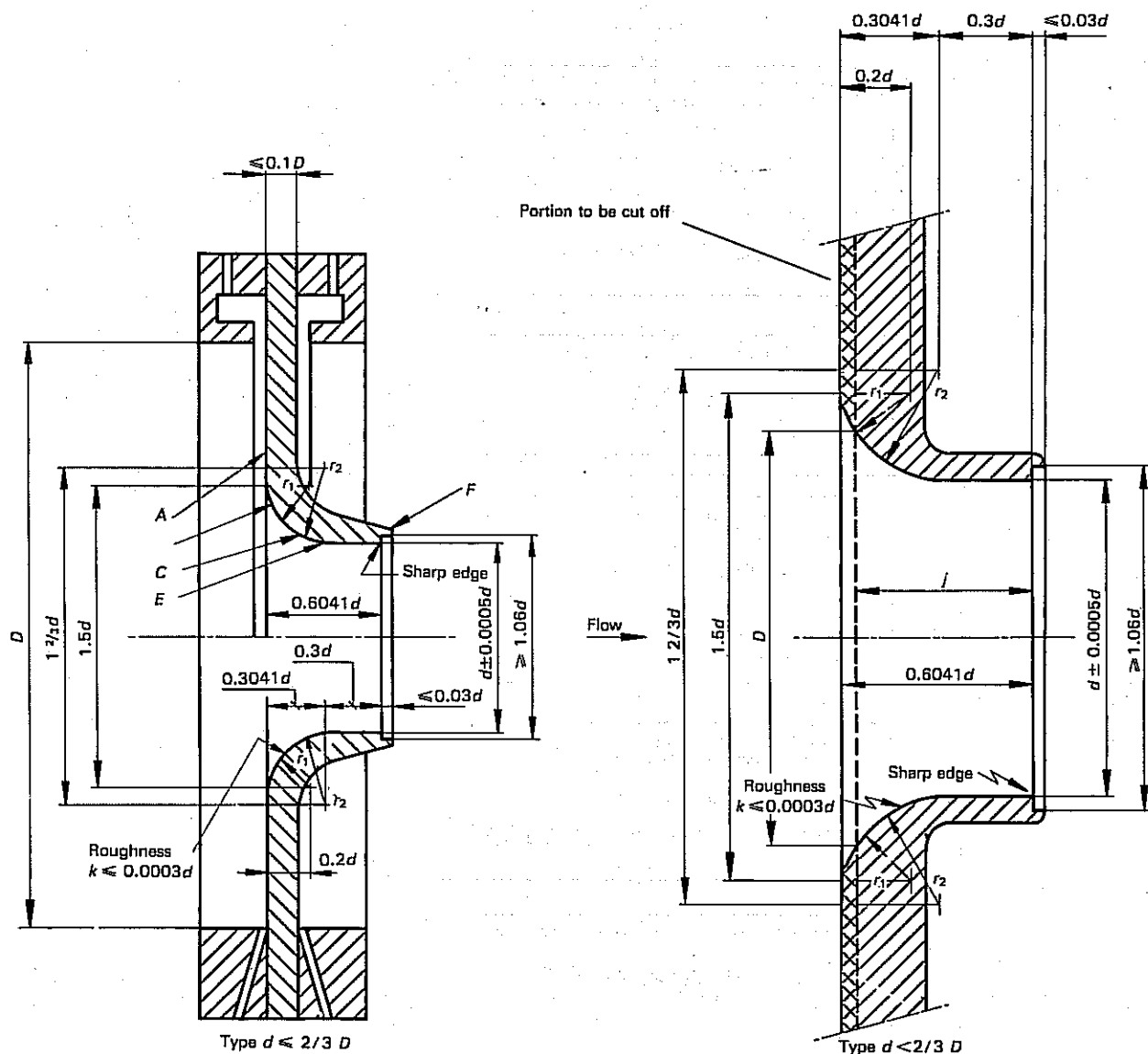
Pressure loss, see (2.4.4)

Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

7.1.8 Reference

ISO 5167



A = Flat portion perpendicular to the axis
 B and C = Convergent defined by r_1 and r_2
 E = Cylindrical throat
 F = Recess

$r_1 = 0.2d \pm 10\%$ for $\beta < 0.5$
 $= 0.2d \pm 3\%$ for $\beta \geq 0.5$
 $r_2 = d/3 \pm 10\%$ for $\beta < 0.5$
 $= d/3 \pm 3\%$ for $\beta \geq 0.5$

Notes:

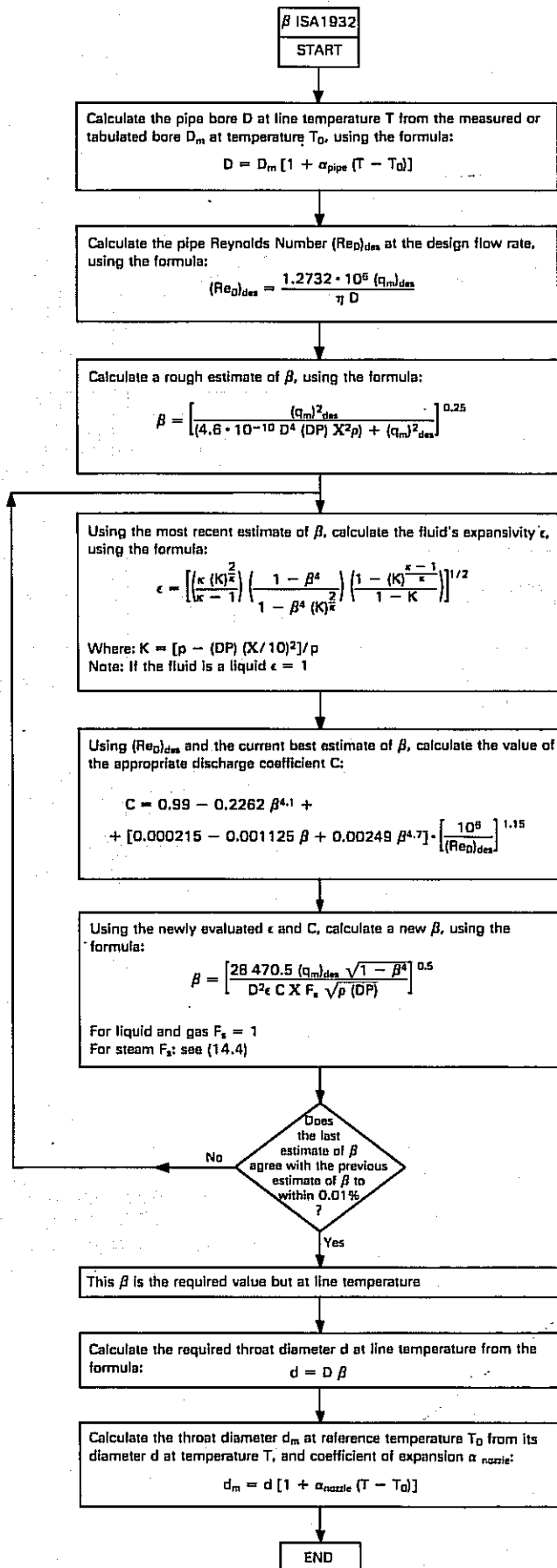
The flat portion A inside the pipe equals zero when $d = 2/3 D$. When $d > 2/3 D$, the inlet face is machined so that its largest diameter is just equal to D

The length j of the nozzle in that case is:

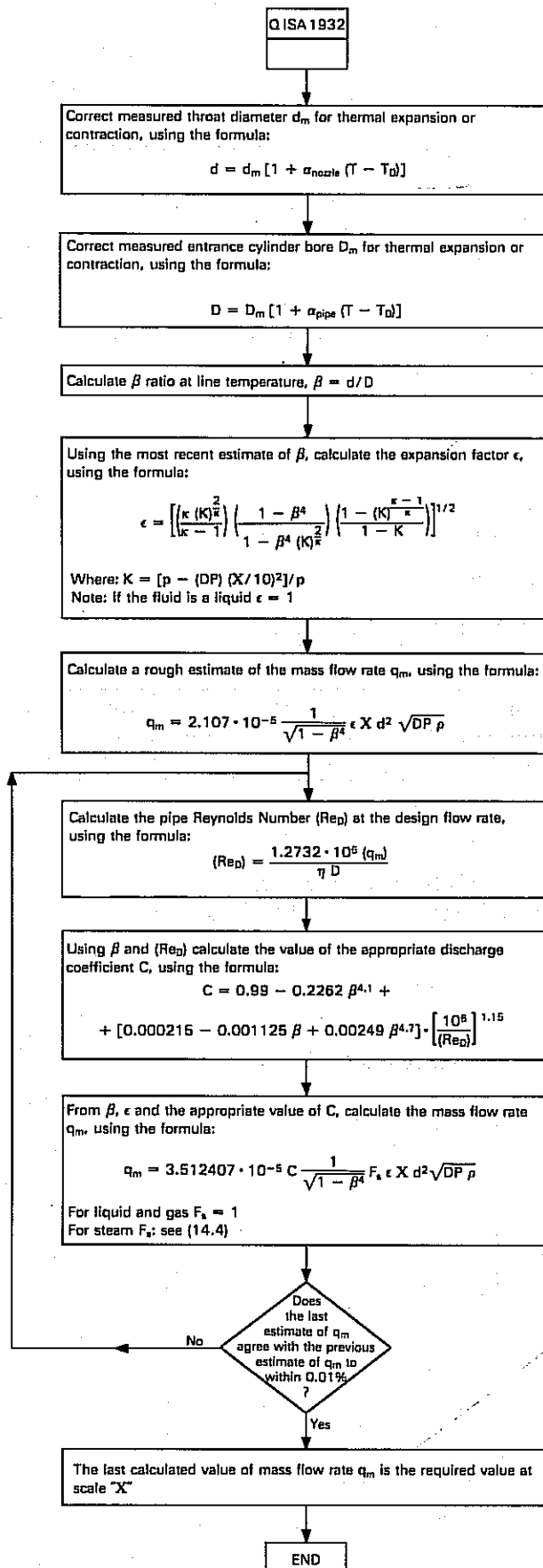
$$\left[0.4041 + \sqrt{\frac{0.75}{\beta} - \frac{0.25}{\beta^2} - 0.5225} \right] d$$

Any diameter d of any cross section shall not differ by more than 0.05% from the value of the mean diameter.

7.1.9 ISA 1932 nozzle



7.1.10 Calculation of throat diameter



7.1.11 Calculation of flow rate

7.2 LONG RADIUS NOZZLE

7.2.1 Construction

The nozzle is a curved convergent entry leading to a short cylindrical throat without a discharge cone. See (7.2.9).

7.2.2 Application

When a Venturi tube is too long.

Where erosion or cavitation prohibits the use of square edge orifices.

7.2.3 Limitations

Pipe bore: $50 \leq D \leq 630 \text{ mm}$

Beta ratio: $0.2 \leq \beta \leq 0.50$ for a low-ratio nozzle
 $0.25 \leq \beta < 0.80$ for a high-ratio nozzle

Reynolds Number: $10^4 \leq Re_D \leq 10^7$

For compressible fluids: $\frac{\text{differential pressure (dp)}}{\text{upstream pressure (p)}} \leq 0.25$

β	≤ 0.35	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.60	0.70	0.77	0.80
$k/D \cdot 10^4$	25	18.6	13.5	10.6	8.7	7.5	6.7	6.1	5.6	4.5	4.0	3.9	3.9

or without a restriction if $k/D \leq 10 \cdot 10^{-4}$

The initial cost is high, and it is difficult to manufacture.

The thickness of the element complicates its removal from the line.

7.2.4 Pressure tapings

Upstream tapping $1D \begin{smallmatrix} +0.2 D \\ -0.1 D \end{smallmatrix}$ upstream of the inlet face of the nozzle.

Downstream tapping $0.5 D \pm 0.01 D$ downstream of the inlet face of the nozzle but no further downstream than the nozzle outlet. See (7.2.9)

7.2.5 Discharge coefficient

$$C = 0.9965 - 0.00653 \beta^{0.5} \left[\frac{10^6}{(Re_D)} \right]^{0.5}$$

$$\text{Uncertainty: } \frac{\delta C}{C} = \pm 2.0 \%$$

7.2.6 Expansion factor

$$\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{1/2}$$

where $K = [p - (DP) (X/10)^2]/p$

$$\text{Uncertainty: } \frac{\delta \epsilon}{\epsilon} = \pm 2 \frac{dp}{p} \%$$

(dp and p in the same units)

7.2.7 Calculation

Limitations, see (7.2.3)

Sizing, see (7.2.10)

Flow rate, see (7.2.11)

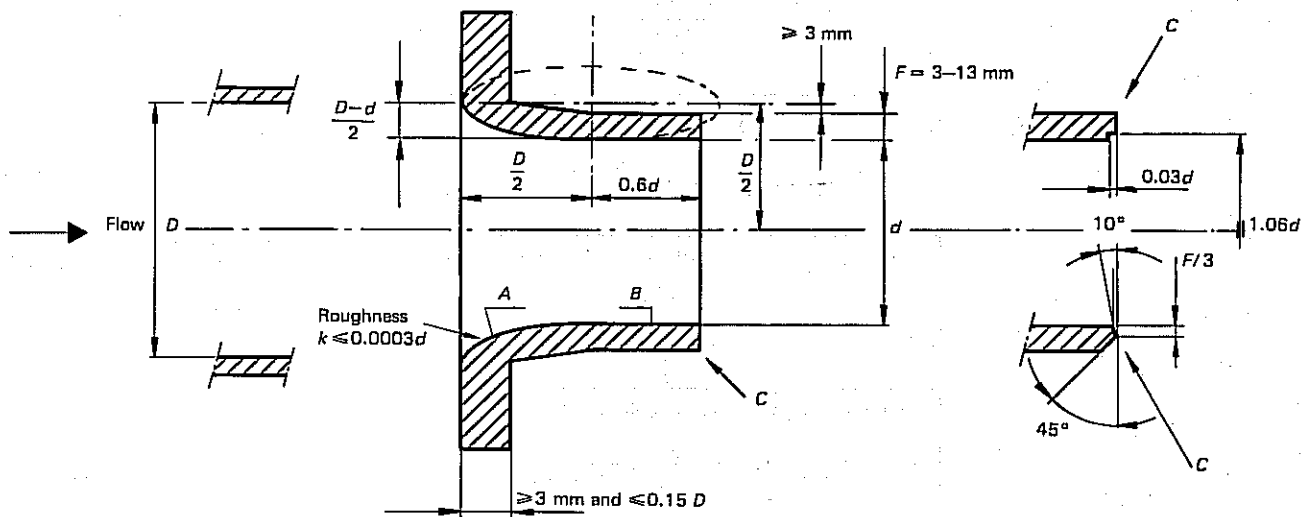
Pressure loss, see (2.4.4)

For steam correction factor F_s , see (14.4)

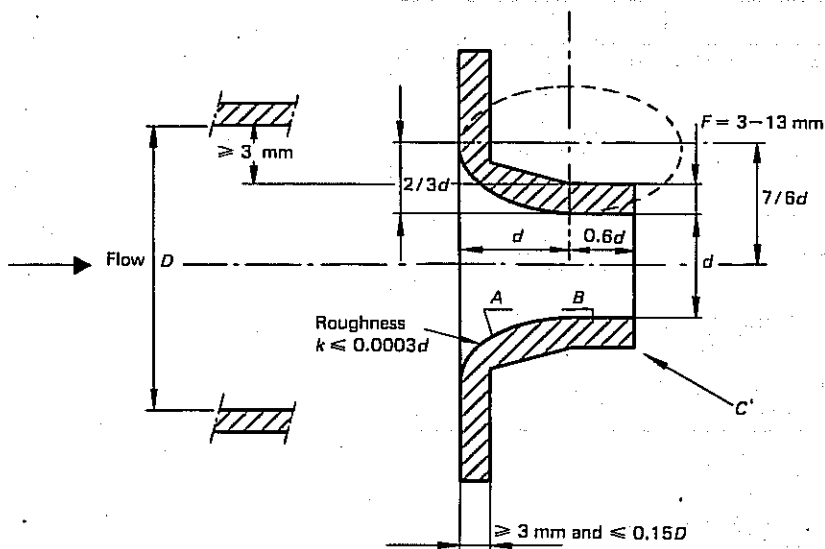
Uncertainty, see (13)

7.2.8 Reference

ISO 5167



High-ratio type (β from 0.25 to 0.80)



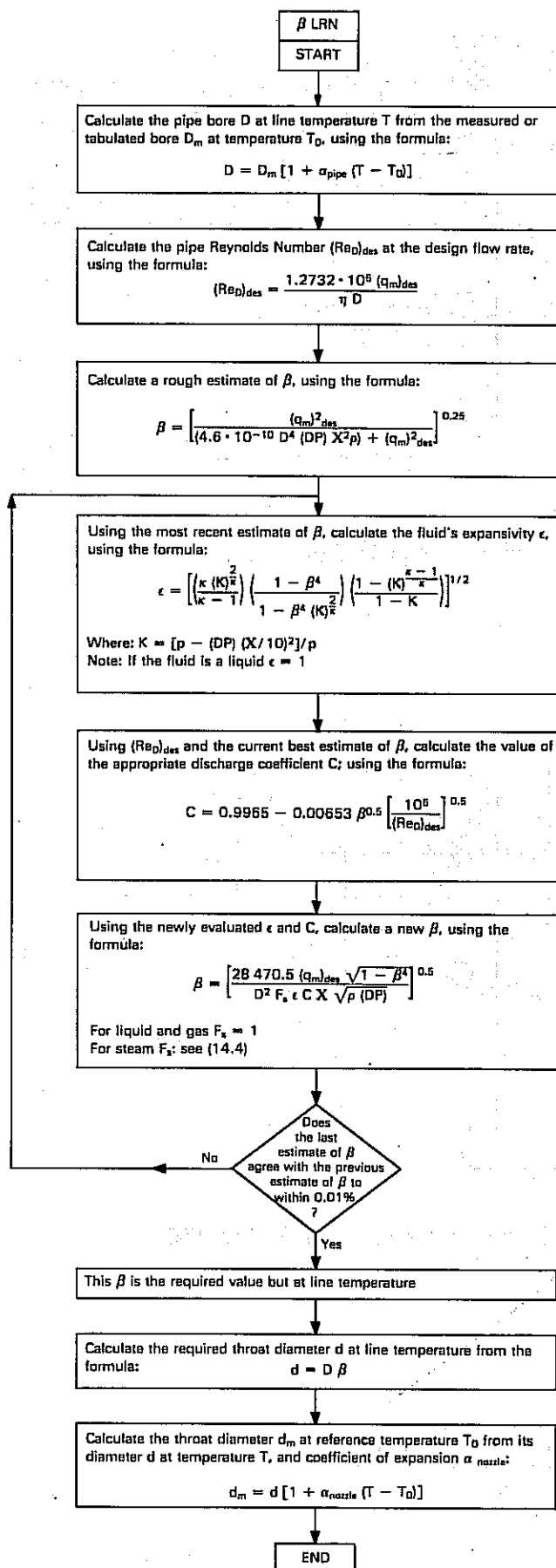
Low-ratio type (β from 0.20 to 0.50)

A = convergent portion
B = cylindrical throat
C = bevel, recess or plain end

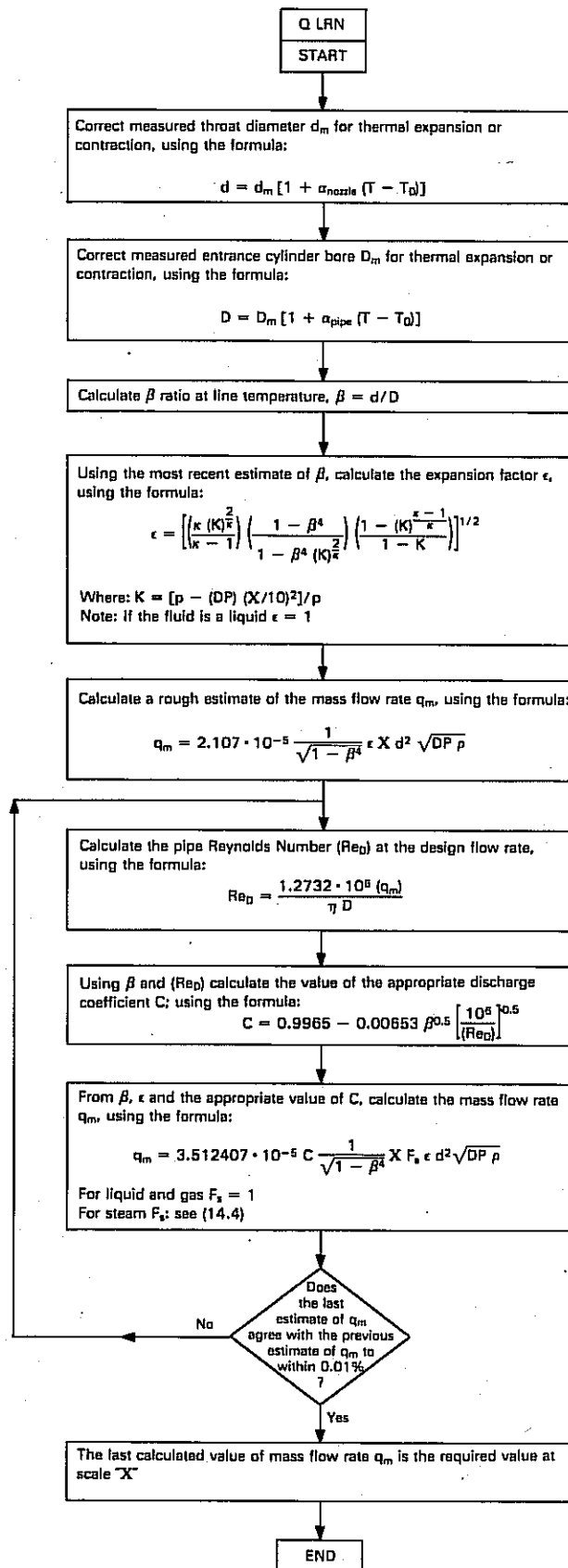
Notes:

Two diameters of the convergent in the same plane perpendicular to the axis shall not differ by more than 0.1% from their mean value. Any diameter d of any cross section of the throat shall not differ by more than 0.05% from the mean value.

7.2.9 Long radius nozzle



7.2.10 Calculation of throat diameter



7.2.11 Calculation of flow rate

Section 8. Centrifugal force devices

- 8.1 Pipe bend (90°)**
 - 8.1.1 Construction
 - 8.1.2 Application
 - 8.1.3 Limitations
 - 8.1.4 Pressure tapings
 - 8.1.5 Discharge coefficient
 - 8.1.6 Expansion factor
 - 8.1.7 Calculation
 - 8.1.8 Reference
 - 8.1.9 90° pipe bend
 - 8.1.10 Values of $\sqrt{(R/2D)}$ for welding end pipe elbows
 - 8.1.11 Calculation of flow rate

8.1 PIPE BEND (90°)

8.1.1 Construction

The differential pressure between tappings located on the inside and outside curves of a bend, caused by the centrifugal force of the flow, is used to measure the rate of flow. The device described here is the 90° pipe bend or pipe elbow. See (8.1.9).

The fully circular pipe bend (360°), sometimes claimed to be superior, is not recommended owing to the lack of reliable data.

8.1.2 Application

A simple and cheap device for measuring the rate of flow without pressure loss.

8.1.3 Limitations

Minimum line size according to $R/D \geq 1.25$

Lower pipe Reynolds Number 10 000; upper pipe Reynolds Number unlimited.

The flow coefficient varies with Re_D but the measurement itself is easily reproducible.

The created differential pressure is relatively low.

The available data are limited but reliable.

8.1.4 Pressure tappings

Diametrically opposite one another, on the inside and outside of the bend, at 45° from the end of the bend. The diameter of the tapping holes should be less than 0.125 D.

8.1.5 Discharge coefficient

Because no restriction is employed, flow coefficient C_1 (related to D) has to be used instead of flow coefficient C (related to d).

$$C_1 = \sqrt{(R/2D) - 6.5 \sqrt{(R/2D)}} / \sqrt{Re_D}$$

For $\sqrt{(R/2D)}$, see (8.1.10).

Uncertainty = $\pm 1.50\%$ for measured values of (8.1.10)

= $\pm 2.00\%$ for interpolated values of (8.1.10)

= $\pm 2.50\%$ for extrapolated values of (8.1.10)

8.1.6 Expansion factor

$$\epsilon = 1.00$$

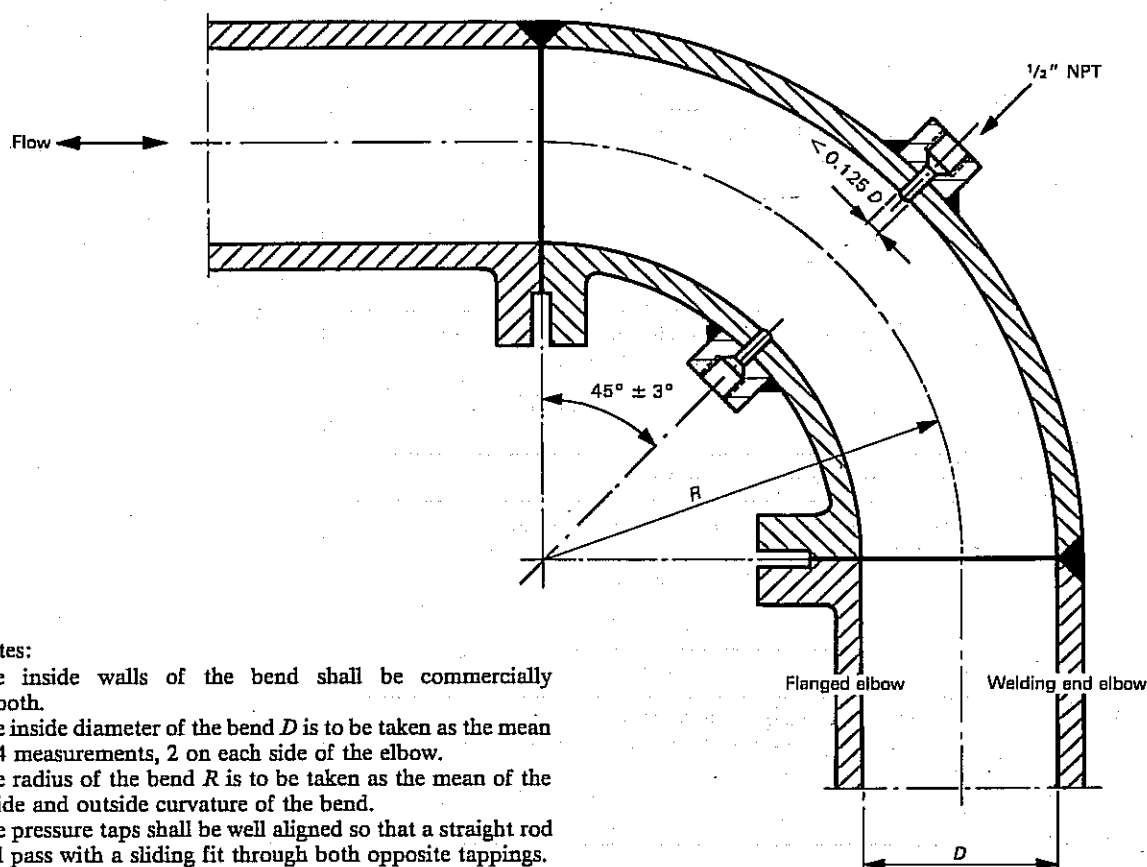
8.1.7 Calculation

Limitations, see (8.1.3)

Flow rate, see (8.1.11)

8.1.8 Reference

Private information



Notes:

The inside walls of the bend shall be commercially smooth.

The inside diameter of the bend D is to be taken as the mean of 4 measurements, 2 on each side of the elbow.

The radius of the bend R is to be taken as the mean of the inside and outside curvature of the bend.

The pressure taps shall be well aligned so that a straight rod will pass with a sliding fit through both opposite tappings. The pressure taps shall be free from burrs at the pipe inside.

The inside diameter of the elbow and the adjacent pipe is to be equal to within 1%.

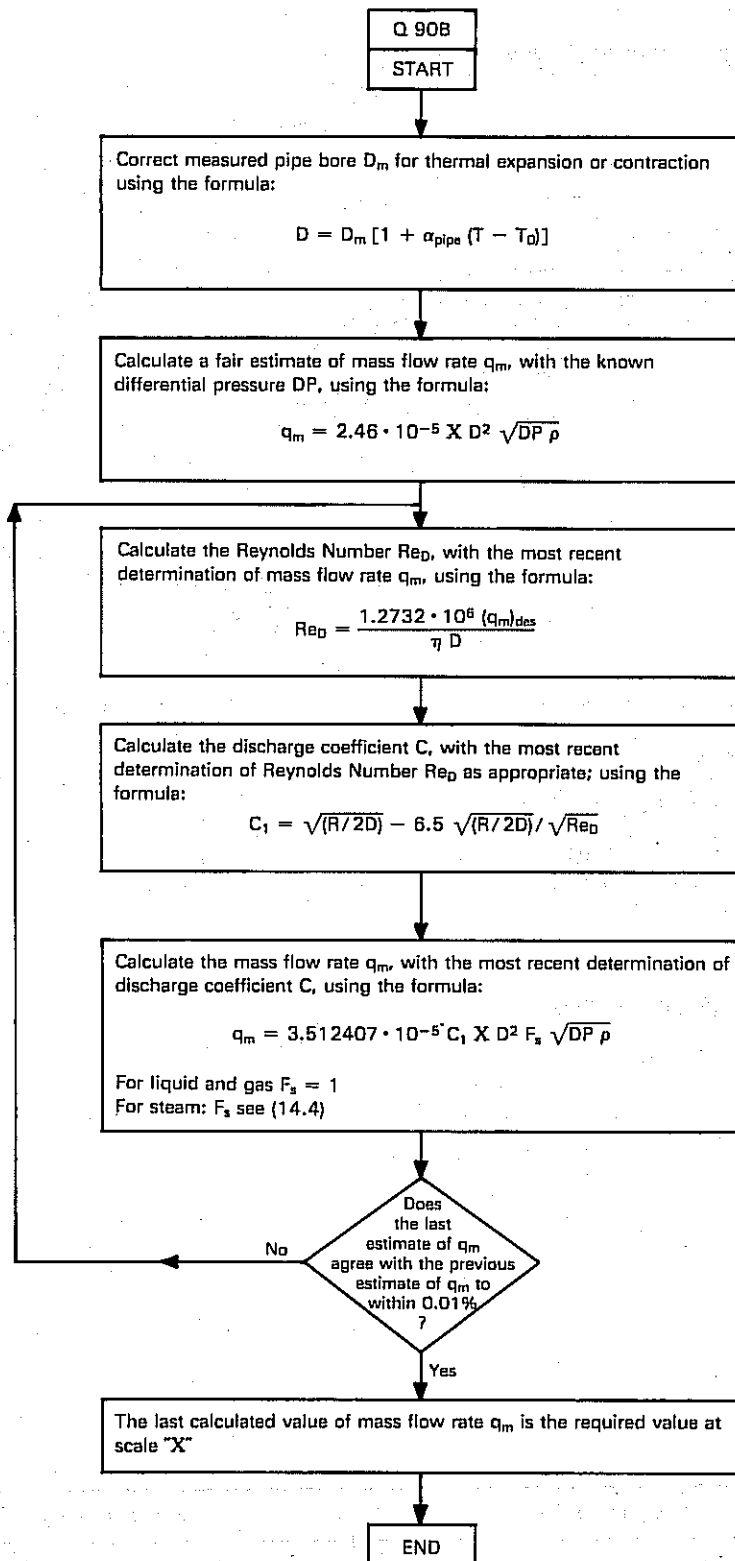
For welding end elbows care shall be taken that the internal side of the weld is kept smooth.

For flanged elbows care shall be taken that the gasket does not protrude inside the pipe.

8.1.9 90° pipe bend

Nominal pipe size		Long radius bends		Short radius bends	
		Schedule 40	Schedule 80	Schedule 40	Schedule 80
in.	mm	$\sqrt{R/2D}$	$\sqrt{R/2D}$	$\sqrt{R/2D}$	$\sqrt{R/2D}$
2	50	0.852	0.880	0.696	0.718
3	75	0.856	0.881	0.699	0.719
4	100	0.863	0.885	0.705	0.723
6	150	0.861	0.884	0.703	0.721
8	200	0.867	0.887	0.708	0.724
10	250	0.865	0.877	0.706	0.716
12	300	0.866	0.875	0.707	0.715

8.1.10 Values of $\sqrt{R/2D}$ for welding end pipe elbows



8.1.11 Calculation of flow rate

Section 9. Velocity head devices

- 9.1 Pitot tube**
 - 9.1.1 Construction**
 - 9.1.2 Application**
 - 9.1.3 Limitations**
 - 9.1.4 Pressure tappings**
 - 9.1.5 Discharge coefficient**
 - 9.1.6 Expansion factor**
 - 9.1.7 Calculation**
 - 9.1.8 Reference**
 - 9.1.9 Pitot tubes**
 - 9.1.10 Calculation of flow rate**

9.1 PITOT TUBE

9.1.1 Construction

The Pitot tube is a tube with an open end placed in the direction of the fluid stream. The difference between the pressure in the Pitot tube (impact pressure) and the static pressure in the line is a measure of the flow rate. Several commercial versions are available, see (9.1.9).

9.1.2 Application

For larger pipe sizes this is a simple flow measuring device which is easy to install. The commercial-type Pitot tube may be inserted or withdrawn while the line is in operation.

Very low pressure loss.

9.1.3 Limitations

Less attractive for smaller lines, minimum line sizes approximately 100 mm.

Dirty fluids tend to clog the pressure holes.

Long Pitot tubes may present difficulties owing to vibration.

Low differential pressure is available for measurement.

A retractable construction is not recommended for high-pressure applications.

9.1.4 Pressure tapings

See (9.1.9).

9.1.5 Discharge coefficient

Because no restriction is employed, flow coefficient C_1 (related to D) has to be used instead of flow coefficient C (related to d).

$$C_1 = a_p M_p.$$

a_p = ratio between the average fluid velocity and the velocity at the point of measurement.

M_p = Pitot tube factor, depending on the construction and on the position of the holes in the Pitot tube, see (9.1.9).

To obtain accurate values of M_p it is advisable to consult the manufacturer.

The value of a_p is determined by the average position method.

The Pitot tube impact hole is located between $0.25D/2$ and $0.29D/2$ from the pipe wall (see table below). At this position the fluid velocity equals the average velocity; thus $a_p = 1$.

Sufficient straight lengths should be available in the meter run.

Re_D	Location of impact hole from the pipe wall	a_p
<2000	$0.29D/2$	1.00
2000–10 000	$0.27D/2$	1.00
$>10\,000$	$0.25D/2$	1.00

9.1.6 Expansion factor

$$\epsilon = 1.00$$

9.1.7 Calculation

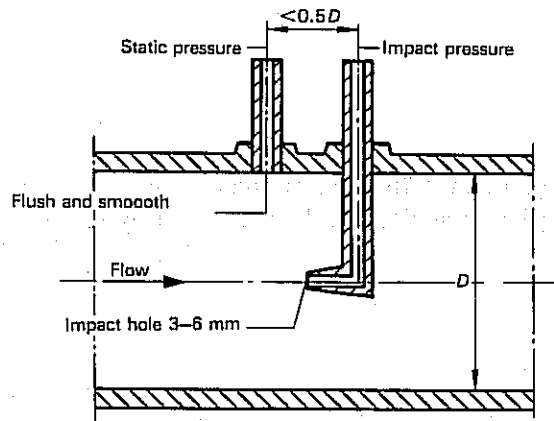
Limitations, see (9.1.3)

Flow rate, see (9.1.10)

The formula for the flow rate is in line with the formula described for the square edge orifice with flange tappings except for the term Cd^2 , which should be replaced by C_1D^2 , see (9.1.5), while $\epsilon = 1.00$

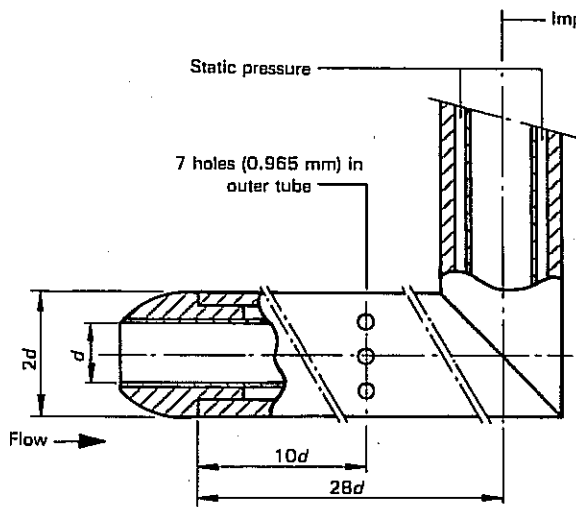
9.1.8 Reference

Private information

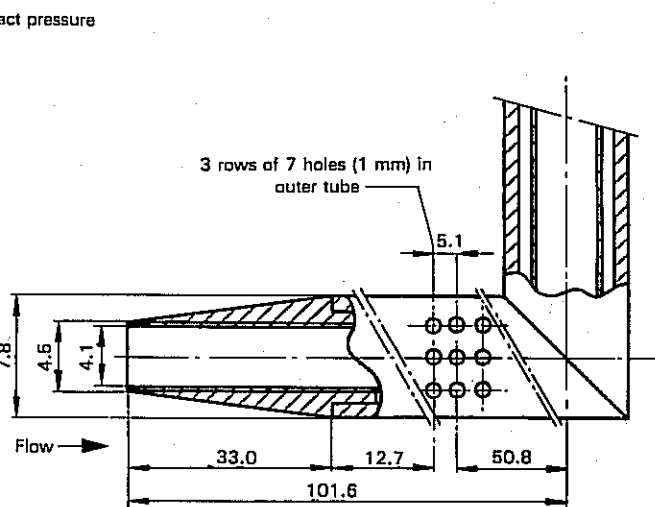


Note:
Always consult manufacturer for
correct Pitot coefficient M_p

Single-hole Pitot tube with separate
static tapping $M_p = 1.00$

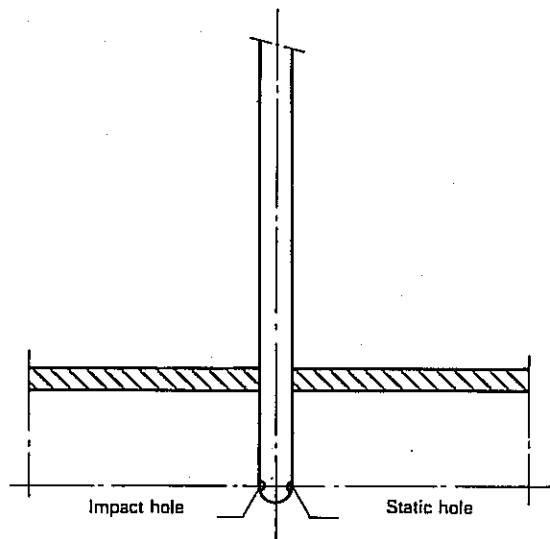


NPL hemispherical head $M_p = 1.00$



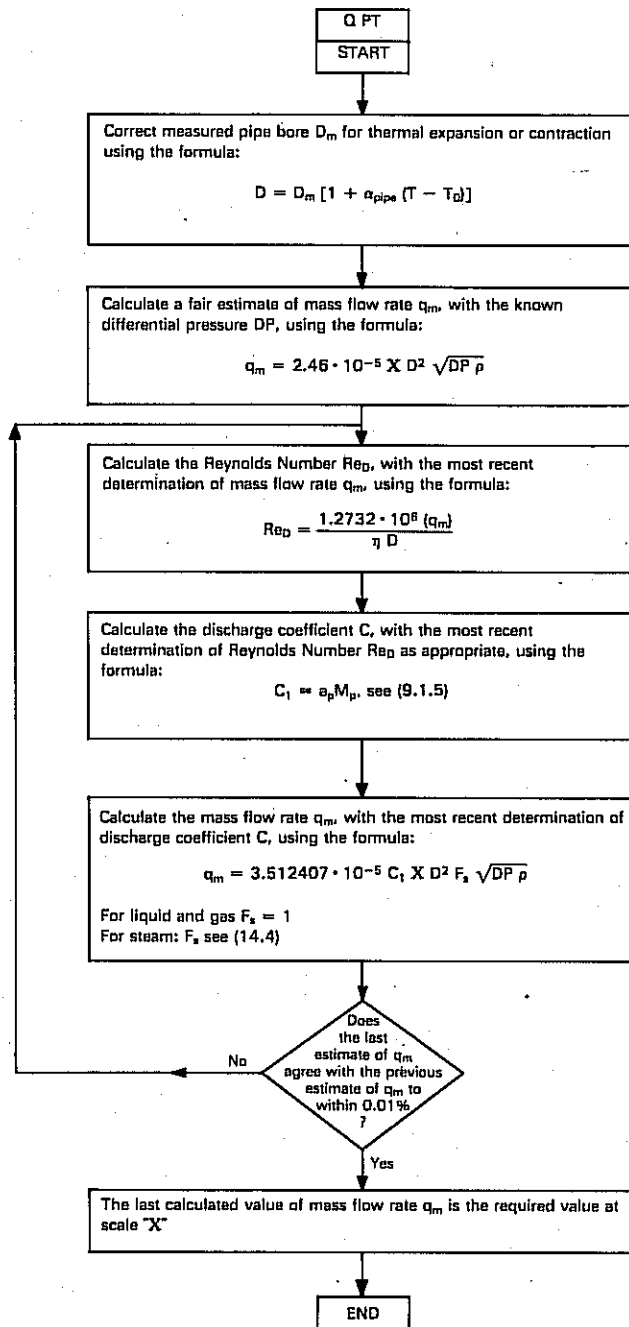
NPL sharp-ended head $M_p = 1.00$

NPL = National Physical Laboratory, U.K.



Commercial Pitot tube $M_p = 0.86$

9.1.9 Pitot tubes



Section 10. Special applications

10.1 Prefabricated orifice meter runs

- 10.1.1 Construction
- 10.1.2 Application
- 10.1.3 Limitations
- 10.1.4 Pressure tapings
- 10.1.5 Discharge coefficient
- 10.1.6 Expansion factor
- 10.1.7 Calculation
- 10.1.8 References
- 10.1.9 Orifice meter run for pipes DN 15 to DN 40
- 10.1.10 Orifice meter run for pipes DN 50 to DN 300

10.2 Integral orifices

- 10.2.1 Construction
- 10.2.2 Application
- 10.2.3 Limitations
- 10.2.4 Calculation

10.3 Restriction orifices

- 10.3.1 Construction
- 10.3.2 Application
- 10.3.3 Limitations
- 10.3.4 Pressure tapings
- 10.3.5 Discharge coefficient
- 10.3.6 Expansion factor
- 10.3.7 Calculation
- 10.3.8 References
- 10.3.9 Restriction orifice, union-type construction

10.4 Special intake devices

- 10.4.1 Construction
- 10.4.2 Application
- 10.4.3 Limitations
- 10.4.4 Pressure tapings
- 10.4.5 Discharge coefficient
- 10.4.6 Expansion factor
- 10.4.7 Calculation
- 10.4.8 References
- 10.4.9 Special intake devices
- 10.4.10 Discharge coefficient C for special intake devices

10.5 Flow straighteners

- 10.5.1 General
- 10.5.2 The installation of flow straighteners
- 10.5.3 The tube bundle flow straightener
- 10.5.4 Radial vanes
- 10.5.5 The "Sprenkle" flow straightener
- 10.5.6 The "Zanker" flow straightener
- 10.5.7 Reference

10.1 PREFABRICATED ORIFICE METER RUNS

10.1.1 Construction

The orifice assembly is mounted between prefabricated and machined pieces of pipe with flanges. Two versions are recommended i.e.:

- orifice meter run for line sizes DN 15 to DN 40, see (10.1.9)
- orifice meter run for line sizes DN 50 to DN 300, see (10.1.10).

10.1.2 Application

1. Meter run DN 15 to DN 40

For measuring small flows where the fluid temperature prohibits the use of integral orifice assemblies or where the accuracy of the integral orifice assembly is insufficient.

To ensure a correctly proportioned and installed orifice assembly by prefabrication of the meter run.

2. Meter run DN 50 to DN 300

To ensure that the correct piping is used with regard to roundness, roughness and that the effects of welding are minimized.

3. Meter run larger than DN 300

See (11.5).

10.1.3 Limitations

Line size not limited, but for lines smaller than 25 mm larger errors are to be expected and are therefore not recommended.

If line sizes smaller than 25 mm have to be used, calibration of the flow device is recommended.

The β and Re_D limits are according to the type of orifice used, see sections (3) and (4).

10.1.4 Pressure tapings

For line sizes ≤ 40 mm: corner tapings are required.

For line sizes > 40 mm: orifice assemblies with flange tapings are recommended.

10.1.5 Discharge coefficient

According to the type of orifice combination used, see sections (3) and (4).

For non-calibrated devices the uncertainty is as stated in the relevant sections, provided the line size is within the recommended limits of that section. For uncertainties of line sizes smaller than the limitations mentioned, reference is made to (13.3.3.2).

For calibrated small size orifice assemblies, the uncertainty depends fully on the accuracy of the calibration facilities.

10.1.6 Expansion factor

Refer to sections (3) or (4) as appropriate.

10.1.7 Calculation

Limitations, see (10.1.3)

Sizing, according to the selected type of orifice and flange tapings (see relevant section 3 or 4)

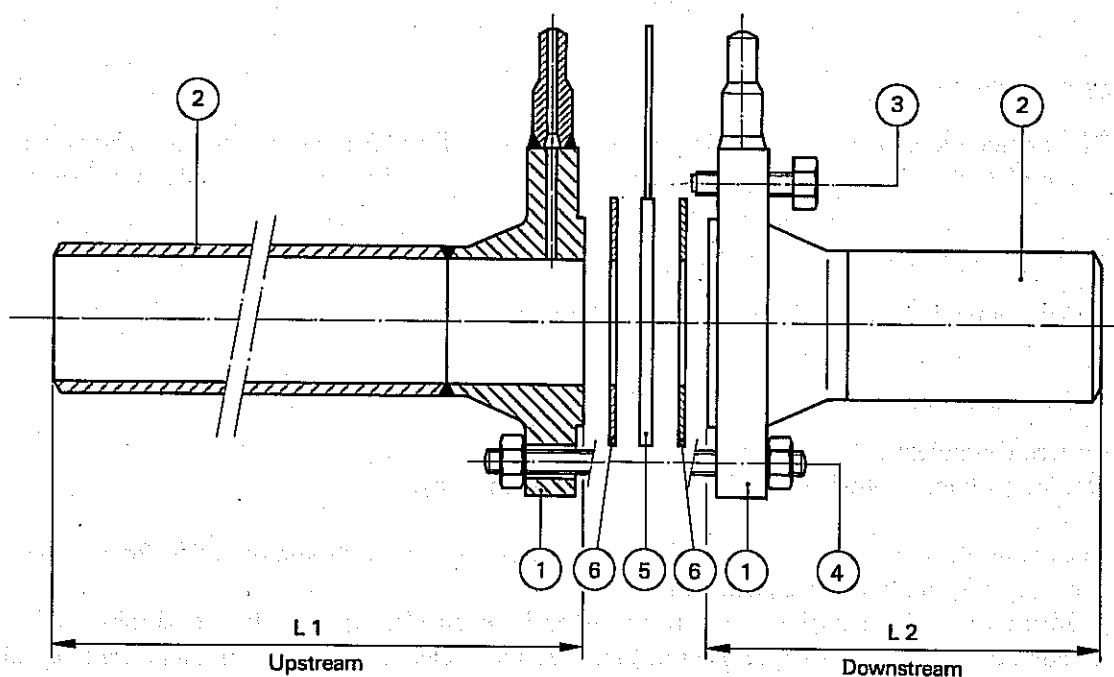
Flow rate, according to the selected type of orifice and flange tapings (see relevant section 3 or 4)
Pressure loss, according to type of orifice (2.4.4)

10.1.8 References

Private information

ANSI B 16.36

ANSI N 18.2.2



ITEM	DESCRIPTION
1	Orifice flange set, see (3.1.9. and 3.2.9)
2	Line pipe
3	Jack screw
4	Stud bolt with nut
5	Temporary spacer
6	Gasket

DN	L1	L2
50	750	350
80	1200	550
100	1500	700
150	2250	1050
200	3000	1400
250	3750	1750
300	4500	2100

Notes:

- 1) All dimensions are in mm.
- 2) The upstream length of the orifice meter run is part of the totally required straight upstream length.
- 3) The orifice flanges shall be fitted in such a way that the jack screws are diametrically opposed.

10.1.10 Orifice meter run for pipes DN 50 to DN 300

10.2 INTEGRAL ORIFICES

10.2.1 Construction

The orifice element is replaceable and mostly integrally mounted with the measuring instrument. Some of the orifice elements can be used with measuring instruments of other manufacturers.

10.2.2 Application

For measuring very small flows in small lines (i.e. $< \text{DN } 15$).

10.2.3 Limitations

Orifice diameter: $d > 1.0 \text{ mm}$

Orifice Reynolds Number: $600 d \leq \text{Re}_d$ (d in mm)

The available data are incomplete. The smallest sizes, $< 1 \text{ mm}$, should be avoided for applications where accuracy requirements are stringent.

Calibration of the complete assembly is essential even after dismantling for cleaning.

Because of the small orifices, it is vital that the fluid is clean. The allowable pressure and, depending on the construction, the temperature of the fluid is limited by the rating of the differential pressure instrument.

10.2.4 Calculation

The calculation of integral orifices depends on the selected manufacturer and shall be calculated in accordance with the instructions supplied by the manufacturer.

10.3 RESTRICTION ORIFICES

10.3.1 Construction

It is recommended to use the square edge orifice, see (3.1.8).

Construction and dimensions to match the type and size of flanges or fittings used; for the flanged construction, see (3.1.9) and for the union construction, see (10.3.9).

10.3.2 Application

Simple device for creating a certain pressure drop or limiting a flow rate.

Although not a device for measurement of flow, it has been incorporated because of similarity in the method of calculation.

10.3.3 Limitations

The minimum line size is 15 mm, the maximum line size is not limited.

Differential pressure/upstream pressure for compressible fluids:

$$dp/p_1 \leq 0.25.$$

The recommended minimum β limit is 0.10, the maximum β is not critical.

10.3.4 Pressure tapings

Tappings are not essential, although a line pressure indication upstream and downstream of the restriction orifice is recommended for checking of the behaviour of the device.

10.3.5 Discharge coefficient

For $15 > D > 50$ mm and $0.1 \leq \beta \leq 0.2$: $C = 0.6097$ for liquids

$C = 0.519$ for gas and steam.

For $D \geq 50$ mm and $\beta \geq 0.2$, see the following table:

β	C	β	C	β	C	β	C
0.20	0.6097	0.30	0.6318	0.40	0.6634	0.50	0.7073
0.21	0.6115	0.31	0.6345	0.41	0.6673	0.51	0.7125
0.22	0.6134	0.32	0.6373	0.42	0.6711	0.52	0.7179
0.23	0.6153	0.33	0.6403	0.43	0.6752	0.53	0.7234
0.24	0.6174	0.34	0.6433	0.44	0.6793	0.54	0.7292
0.25	0.6196	0.35	0.6464	0.45	0.6836	0.55	0.7351
0.26	0.6219	0.36	0.6496	0.46	0.6881	0.56	0.7411
0.27	0.6242	0.37	0.6529	0.47	0.6927	0.57	0.7473
0.28	0.6267	0.38	0.6562	0.48	0.6974	0.58	0.7538
0.29	0.6293	0.39	0.6598	0.49	0.7022	0.59	0.7605
0.30	0.6318	0.40	0.6634	0.50	0.7073	0.60	0.7673

10.3.6 Expansion factor

Use formula for square edge with flange tapings.

$$\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$$

10.3.7 Calculation

Limitations, see (10.3.3)

Sizing, according to the formula as for the square edge orifice with flange tapings (3.1.10), except for the values of C , see (10.3.5) and ϵ , see (10.3.6)

Flow rate, according to the formula as described for the square edge orifice with flange tapings, except for the values of C , see (10.3.5) and ϵ , see (10.3.6)

Steam correction factor F_s , see (14.4)

Uncertainty, see (13)

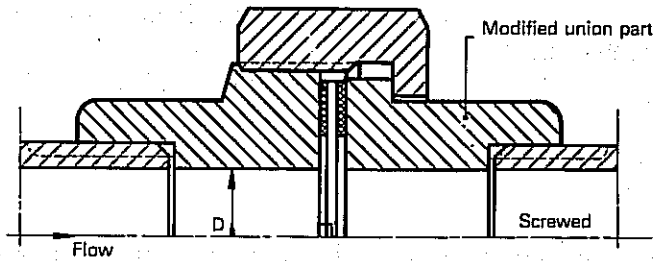
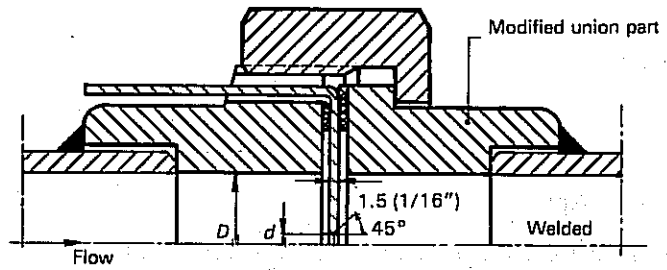
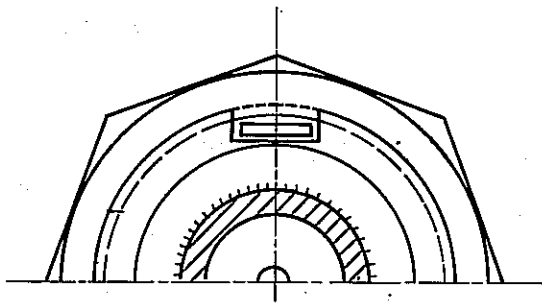
This calculation method under (10.3.7) is also valid for the constructions with a union-type of orifice (10.3.9)

10.3.8 References

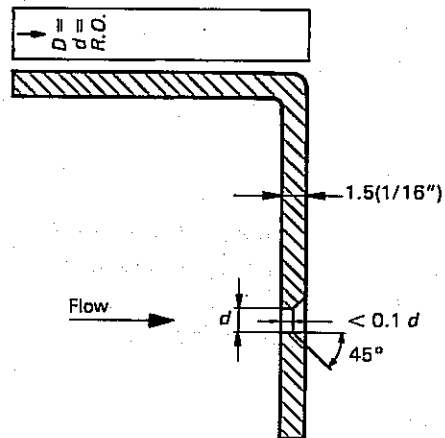
Fluid Meters, their Theory and Application, ASME (1959)

Principle and Practice of Flow Meter Engineering, L.K. Spink (1978)

Private information



Note:
The union-type construction
for restriction orifices shall
be used only for low pressures
and small lines



DETAIL OF ORIFICE

10.4 SPECIAL INTAKE DEVICES

10.4.1 Construction

Various intake devices are used in practice of which some designs are described, see (10.4.9).

10.4.2 Application

To measure the flow from a large space to a pipe.

The special intake devices are used to measure fan and compressor air deliveries at the inlet side. For a simple construction (10.4.9A), (10.4.9B) and (10.4.9C) are recommended, for minimum pressure loss (10.4.9D) and (10.4.9G), and for maximum differential pressure (10.4.9A), (10.4.9B), (10.4.9D), (10.4.9F) and (10.4.9G).

The use of other devices shall be considered first.

10.4.3 Limitations

Pipe sizes unlimited.

Beta limits not applicable ($\beta = \text{zero}$, since upstream pipe diameter is considered infinite).

Reynolds Number limitations (throat or pipe) as indicated by table, see (10.4.10). The available data are approximate figures and not meant for exact measurements.

High-differential pressure for measurement and low-pressure loss are contradictory requirements which cannot be combined in a single device.

10.4.4 Pressure tapings

The data presented are valid for the pressure tapping location as indicated in (10.4.9). The high-pressure tapping may be located in a plane perpendicular to the plane of the orifice or throat, e.g. in the inlet filter or in the open space shielded from draughts. The exact location of the low-pressure tapping is relatively unimportant for the accuracy limits indicated.

10.4.5 Discharge coefficient

For the values of C , see (10.4.10)

Uncertainty: $\frac{\delta C}{C} = \pm 1 \%$

10.4.6 Expansion factor

Because of the approximate measurements the expansion factor ϵ may be taken as 1.

Uncertainty: $\frac{\delta \epsilon}{\epsilon} = \pm 8 \frac{dp}{p} \%$

10.4.7 Calculation

Limitations, see (10.4.3)

Flow rate, according to the formula as for the square edge orifice with flange tapings (3.1.11), except for the values of C , see (10.4.10) and ϵ , see (10.4.6)

Pressure loss, see (10.4.9)

Total pressure difference, related to the inlet pressure, equals the sum of the non-recoverable pressure loss and the recoverable velocity head due to velocity increase, i.e.

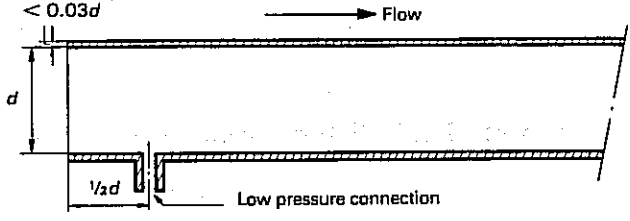
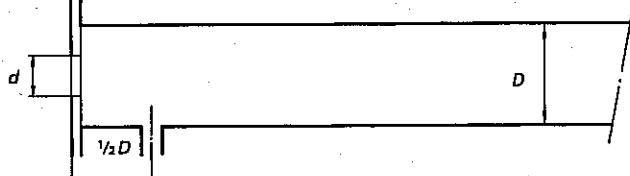
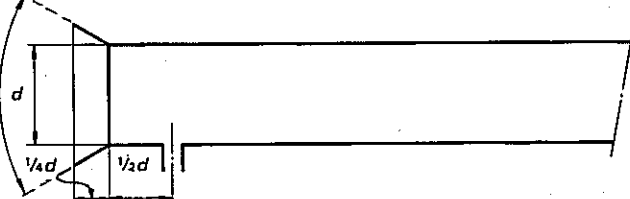
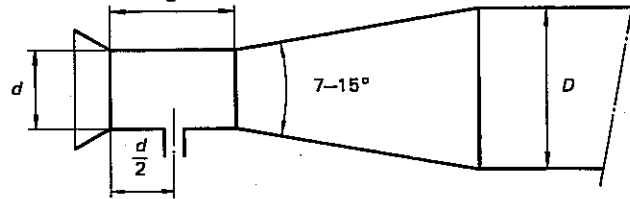
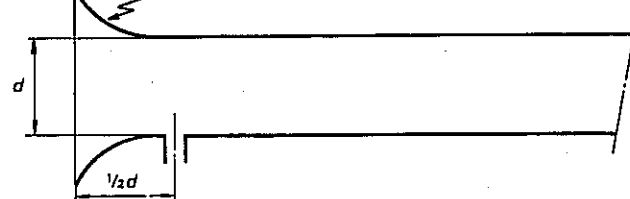
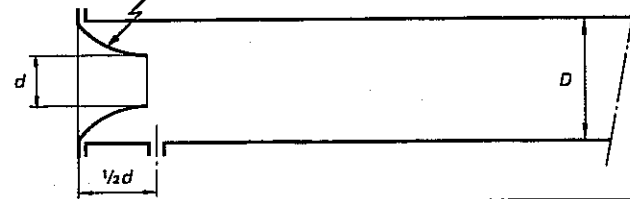
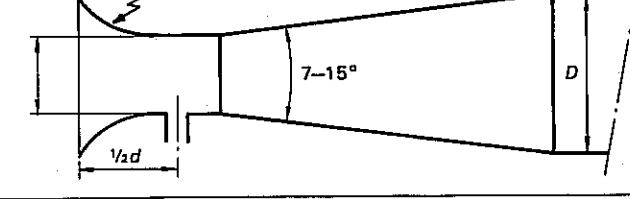
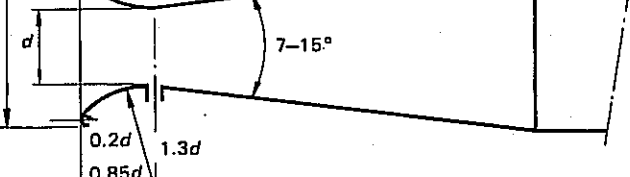
$$\Delta p_{\text{total}} = \Delta p_{\text{loss}} + 0.5 V^2, \text{ see (10.4.9)}$$

10.4.8 References

Developments in Differential Producers for Flow Measurement, H.E. Dall, Instrument Engineer, April 1959

BS 1042 (1964)

Private information

 A Plain intake	DESIGN CONSIDERATIONS Ratio between pressure loss and measured differential pressure $\frac{\Delta p_{\text{loss}}}{\Delta p}$ 0.25 Ratio between total pressure difference and measured differential pressure $\frac{\Delta p_{\text{tot.}}}{\Delta p}$ 0.50	
 B Orifice intake	0.16 0.52	
 C Cone intake	0.002 0.92	
 D Cone intake with diffuser	$\left(\frac{\Delta p_{\text{loss}}}{\Delta p}\right) \left(1 - \frac{d^4}{D^4}\right)$ $\frac{\Delta p_{\text{loss}}}{\Delta p} + 0.92 \frac{d^4}{D^4}$	
 E Nozzle intake	0 1.0	
 F Drum nozzle intake	$\left(1 - \frac{d^2}{D^2}\right)^2$ $\frac{\Delta p_{\text{loss}}}{\Delta p} + \frac{d^4}{D^4}$	
 G Nozzle intake with diffuser	$\left(\frac{\Delta p_{\text{loss}}}{\Delta p}\right) \left(1 - \frac{d^4}{D^4}\right)$ $\frac{\Delta p_{\text{loss}}}{\Delta p} + \frac{d^4}{D^4}$	
 H	Same as G Same as G	

10.4.9 Special circular intake devices

10.4.10 Discharge coefficient C for special intake devices

Re_D	Plaine intake (A)	Orifice intake (B)	Cone intakes (C, D)	Nozzle intakes (E, F, G, H)
$5 \cdot 10^3$	0.540	—	0.888	0.914
$6 \cdot 10^3$	0.548	—	0.896	0.922
$7 \cdot 10^3$	0.552	—	0.904	0.928
$8 \cdot 10^3$	0.555	—	0.910	0.932
$9 \cdot 10^3$	0.556	—	0.914	0.936
10^4	0.555	0.615	0.918	0.940
$1.1 \cdot 10^4$	0.553	0.612	0.922	0.942
$1.2 \cdot 10^4$	0.551	0.610	0.925	0.945
$1.3 \cdot 10^4$	0.547	0.608	0.927	0.947
$1.4 \cdot 10^4$	0.544	0.606	0.929	0.949
$1.5 \cdot 10^4$	0.542	0.605	0.932	0.951
$1.6 \cdot 10^4$	0.540	0.604	0.933	0.953
$1.7 \cdot 10^4$	0.538	0.603	0.934	0.954
$1.8 \cdot 10^4$	0.536	0.602	0.935	0.956
$1.9 \cdot 10^4$	0.535	0.601	0.936	0.957
$2 \cdot 10^4$	0.534	0.600	0.937	0.958
$3 \cdot 10^4$	0.526	0.597	0.946	0.968
$4 \cdot 10^4$	0.522	0.595	0.952	0.973
$5 \cdot 10^4$	0.518	0.595	0.955	0.977
$6 \cdot 10^4$	0.516	0.595	0.956	0.980
$7 \cdot 10^4$	0.515	0.595	0.957	0.981
$8 \cdot 10^4$	0.513	0.595	0.958	0.983
$9 \cdot 10^4$	0.512	0.595	0.959	0.985
10^5	0.512	0.595	0.960	0.987
$2 \cdot 10^5$	0.507	0.595	0.960	0.991
$3 \cdot 10^5$	0.505	0.595	0.960	0.991

Note: For types A, C and E, $Re_d = Re_D$

10.5 FLOW STRAIGHTENERS

10.5.1 General

It should be noted that the discussion on flow straighteners in the following section is not only applicable to differential-type flow meters but applies also to other types.

Flow straighteners are devices installed within a fluid flow, upstream of a flow meter so as to reduce the total straight length required for a flow meter to give a predictable performance. They are made into a spool piece or designed to be clamped between flanges. They are available from some companies which manufacture flow meters or can be made in any suitable workshop to drawings such as those published in ISO 5167.

A flow straightener's function is to diminish or remove flow distortions and establish a desired fluid velocity and turbulence distribution.

The nature of the flow straightener's fluid dynamic characteristics, the limited information available and the form in which it is best presented, i.e. many graphs relating to different flow disturbances and flow meters, do not allow a few simple statements of advice on: "which straighteners to use in which application." A few comments only will therefore be made about some of the most commonly used straighteners, their principal characteristics and areas of use.

In the following, reference is made to the axially symmetrical flow distortion called "swirl". Swirl is uncommon in rectangular conduits but common in conduits of circular cross section. It is characterized by cork-screwing of the fluid through the pipe and higher forward-directed fluid velocities near the pipe wall than at the pipe's axis.

It can be formed by the flow passing down a pipe which goes through two closely positioned bends in different planes. It is the most persistent of all flow disturbances and often propagates over more than seventy pipe diameters. It causes considerable change in performance of many flow meters.

Non-axially symmetrical flow disturbances, such as are caused by a flow passing around a single bend or through a gate valve, usually decay to insignificant levels within 15 to 30 pipe diameters.

10.5.2 The installation of flow straighteners

Flow straighteners should be installed so that they completely fill the part of the pipe in which they are installed, i.e. there should be no gaps around them.

To make flow straighteners function effectively, they should be placed at a particular minimum distance upstream of the flow meter it serves.

The exact location depends on the type of flow disturbance to be removed, the location of the source, the type of straightener and the type of flow meter.

Flow meter manufacturers can often quote the particular distance upstream of one of their flow meters at which a particular type of straightener should be used to remove a particular disturbance, and this information should normally be used in preference to any other. If such information is not available, the advice is not to place the trailing edge of a straightener closer than ten pipe diameters upstream of the flow meter, nor the leading edge of the straightener closer than five pipe diameters downstream of the last flow disturber.

For orifice plates, Venturis or nozzles to be installed in accordance with ISO 5167 with no additional uncertainty in their performance (discharge coefficient) see (13.3.3), they must either meet the straight length of piping requirements (11.4) or be used with either the ISO 5167 specified tube bundle, a "Sprenkle" straightener or a "Zanker" straightener, located at least 20D downstream of the last flow disturber and 24D upstream of the flow meter.

10.5.3 The tube bundle flow straightener

One of the simplest to make and probably the most commonly used. It comprises a bundle of parallel tubes placed axially along the pipe. Fig. 10.1 shows the ISO 5167 specification for such a straightener, but some manufacturers have their own standard devices which contain fewer tubes.

Important features are that there should be more than six tubes and each tube should be at least ten times longer than its diameter.

Tube bundle flow straighteners containing a limited number of tubes have predominantly swirl-removing characteristics and do not introduce much pressure drop. As the number of tubes increases, more general flow conditioning aspects increase but so does the pressure drop. The straighteners are generally most effective if they create a pressure drop of about two velocity heads, i.e. pV^2 .

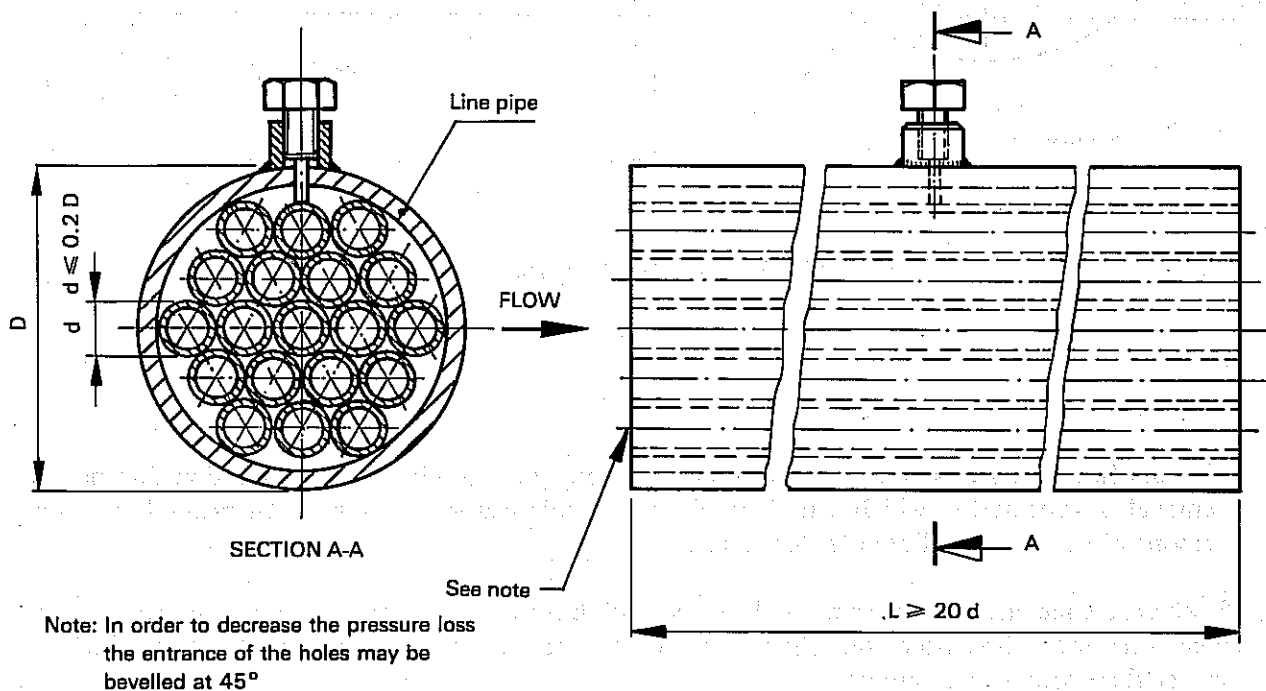


Fig. 10.1 ISO 5167 tube bundle flow straightener

Applications of tube bundle flow straighteners are:

- 1) With turbine meters. Turbine meters are very sensitive to swirl and should, unless preceded by a very long length, e.g. 100 pipe diameters of upstream pipe, be used with at least this type of straightener.
- 2) For any flow metering application in which strong swirl is known or thought to be present with the possible exception of the application using electromagnetic flow meters. Electromagnetic flow meters are typically insensitive to swirl.

10.5.4 Radial vanes

A flow straightener which can be simply made from pieces of flat plate.

They are usually made so as to have six or eight passages for the flow and to be at least two pipe diameters long (Fig. 10.2).

Radial vane straighteners have predominantly swirl-removing characteristics but, by introducing maximum obstruction to the flow near the pipe's axis, do less to condition the flow in preparation for a fully developed profile than does a tube bundle. They tend to flatten the flow profile, which can be used to linearize flow meters at low Reynolds Numbers. The usual constructions do not introduce much pressure drop.

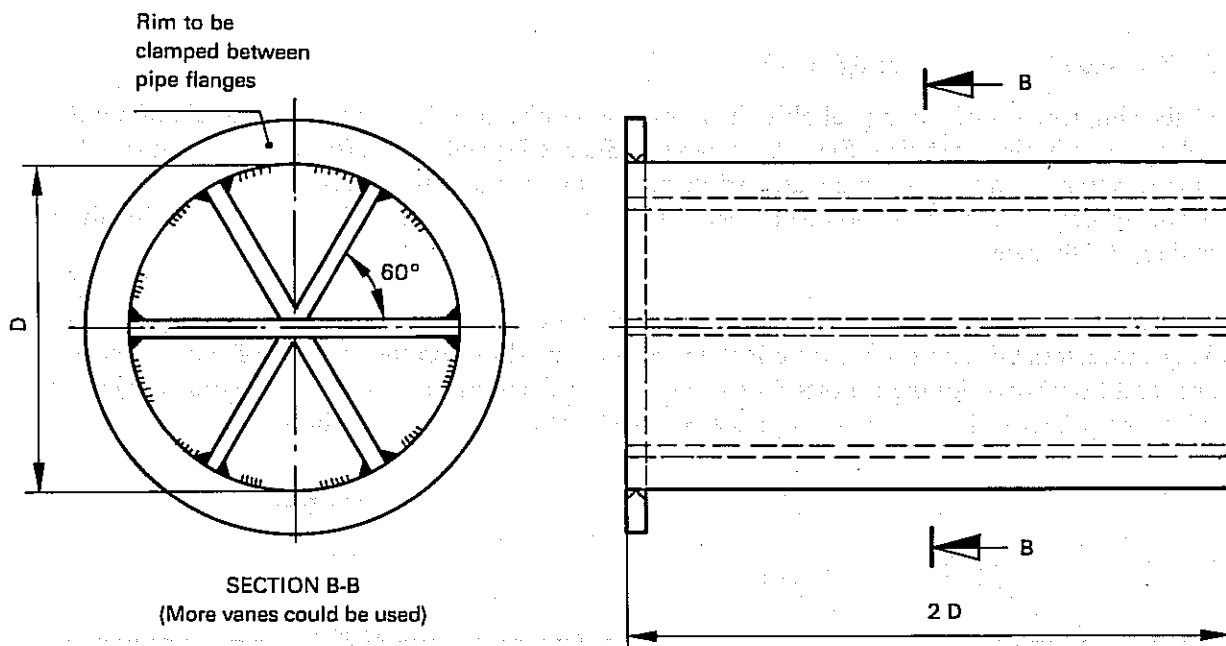


Fig. 10.2 Radial vane flow straightener

Applications of radial vanes are:

- 1) For any flow metering application in which the strongly predominant flow distortion that needs removal is swirl and in which a tube bundle type straightener cannot be implemented, e.g. for reasons of cost, availability of material, etc.
- 2) With vortex meters. There is some evidence that full-bore vortex meters perform more accurately when presented with a flow from which swirl has been removed with a radial vane flow straightener rather than with a tube bundle.

10.5.5 The "Sprenkle" flow straightener

A straightener which is difficult to fabricate. The Sprenkle design is fairly precisely defined (Fig. 10.3) and variations of it, such as fewer but larger drilled holes per plate or more plates, are not usually made since the design, as it is, has been optimized.

The Sprenkle straightener causes a fairly large pressure drop. It is intended as a general-purpose straightener designed to cater for all types of flow disturbances. It has considerable flow conditioning properties, i.e. prepares the flow to exhibit fully developed flow-like characteristics fairly rapidly.

Applications of "Sprenkle" flow straighteners are:

- 1) For any flow metering application in which a flow stream is known or thought to be fairly severely distorted and needs correction over the shortest possible distance before entering the flow meter.
- 2) For differential pressure flow meters, particularly those with a large β ratio, if the normally required upstream pipe lengths cannot be provided for accurate metering.

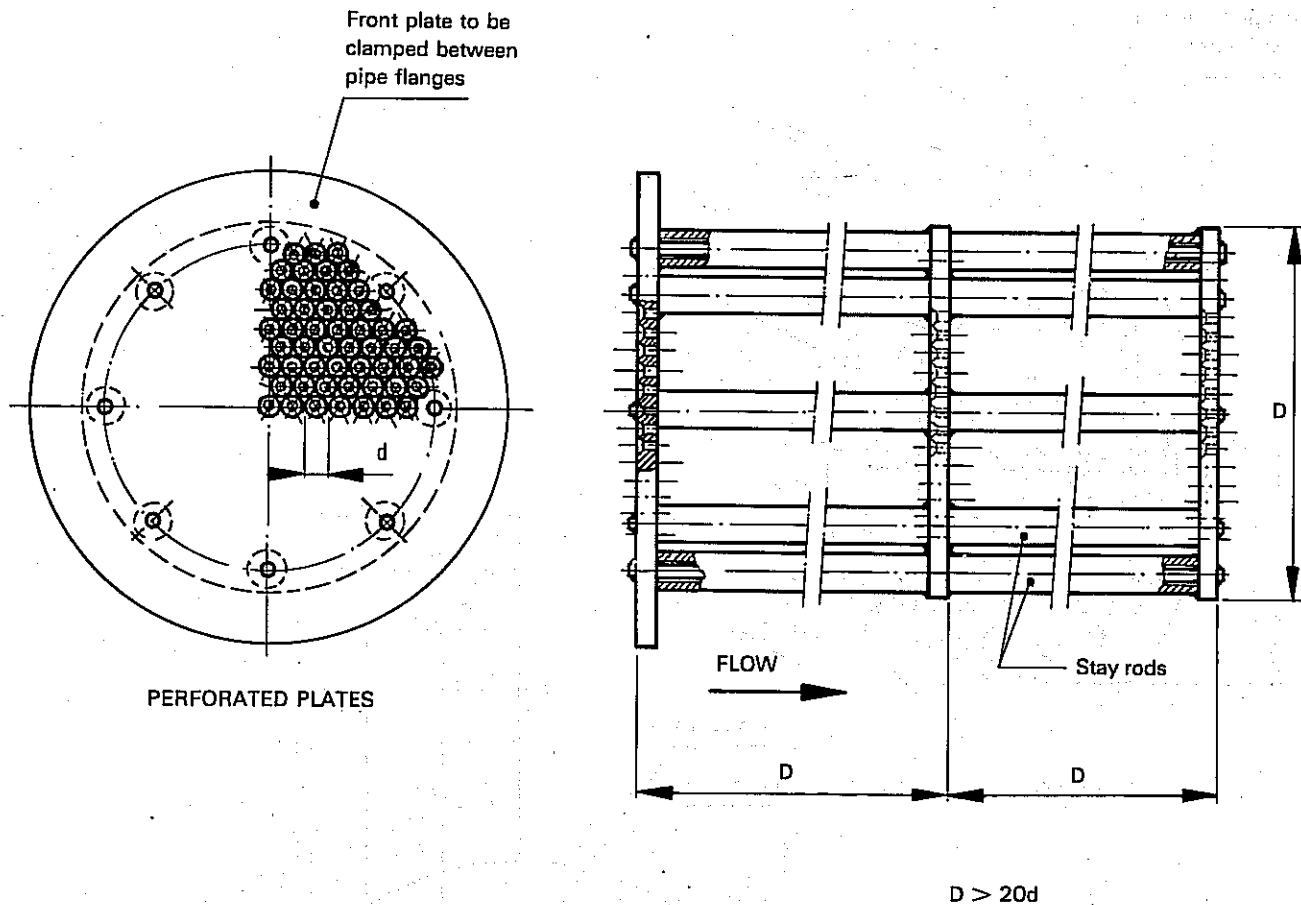


Fig. 10.3 "Sprenkle" flow straightener

10.5.6 The "Zanker" flow straightener

The most complicated to fabricate of all the straighteners. For a precisely defined design, see Fig. 10.4.

The Zanker straightener has been designed as a general-purpose straightener with the aim to compromise between good flow straightening characteristics for all types of flow distortion and maximum flow conditioning performance at as short a distance downstream of the straightener as possible and minimum pressure drop. It introduces a pressure drop of about two velocity heads.

Applications of "Zanker" flow straighteners are:

- 1) For any flow metering application in which a flow stream is known or thought to be distorted and needs correction, with the introduction of minimum additional pressure drop, in the shortest possible distance before entering the flow meter.
- 2) For differential pressure flow meters, particularly those with a large flow ratio, if the normally required upstream pipe lengths cannot be provided for accurate metering and only minimum additional pressure drop due to a straightener can be tolerated.

10.5.7 Reference

ISO 5167

Section 11. Flow meter installation and construction

11.1 General

11.2 Pipe orientation and flow direction

11.3 Orientation of the flow meter in relation to the pipe axis

11.3.1 Axial orientation of differential pressure flow meters

11.3.1.1 Location of pressure tapings

11.3.1.2 Location of the bleed hole in orifice plates

11.3.1.3 Location of a segmental orifice

11.3.1.4 Location of differential pressure transmitters

11.3.2 Axial orientation of Pitot tubes

11.4 Straight length requirements

11.4.1 General

11.4.2 Minimum length required for the orifice or nozzle flow meter

11.4.3 Minimum length required for a Venturi flow meter

11.4.4 Reference

11.5 Locally fabricated orifice meter runs

11.5.1 General

11.5.2 The selection of pipe

11.5.3 The preparation of pipes and orifice flanges

11.5.4 The preparation of orifice flanges

11.5.5 Fabrication of orifice meter runs

11.5.6 Measurement and recording of internal diameter

11.5.7 Assembling the orifice meter run

11.5.8 Reference

11.1 GENERAL

For a flow meter to perform predictably, i.e. so that the information presented in this handbook is useful for predicting its performance within narrowly defined uncertainty limits (13), three conditions shall be satisfied simultaneously. The flow meter shall be:

1. Properly made (e.g. as defined by the drawings in this handbook).
2. Used only under certain flow conditions (e.g. see for each flow meter type described in this handbook the subsections on "Limitations").
3. Properly installed (e.g. as described in this section).

Correct installation involves simultaneously satisfying all of the following four points:

1. Installation of the flow meter in a pipe in the correct orientation, e.g. vertically or horizontally and, in the case of vertical flow lines, ensuring that the flow is in the correct direction, e.g. up or down.
Conversely, the choice of the correct flow meter for a line of given orientation and flow direction (11.2).
2. Correct orientation of the flow meter in relation to the pipe axis (11.3).
3. The use of sufficient straight lengths of pipe, with the same bore as the flow meter, both upstream and downstream of the flow meter (11.4).
4. Adequate mechanical support of the flow meter and adequate surrounding free space to allow of maintenance and removal of the flow meter.

11.2 PIPE ORIENTATION AND FLOW DIRECTION

The reason why a particular flow meter should be mounted in a pipe with a particular or preferred orientation (11.3) is to avoid vapour or solids entrapment in liquid service and liquid entrapment in vapour or steam service, and/or to avoid undesirable loads on mechanical moving parts of flow meters susceptible to such loads.

In the following list of flow meters those marked with:

- H shall be mounted in horizontal pipes only
- V shall be mounted in vertical pipes only
- A may be mounted in pipes of any orientation.

Flow meters should not be inclined unless they can be mounted in any direction.

Preferred orientations are indicated in parentheses. If the requirements of a manufacturer of a particular proprietary flow meter differ from those indicated in the following list, the manufacturer's requirements should be followed.

Corner tapped orifice plate flow meter (with any plate)	H
Flange tapped orifice plate flow meter (with any plate)	A (pref. V)
Radius tapped orifice plate flow meter (with any plate)	A (pref. V)
Venturi tube	A (pref. V)
Flow nozzle	A (pref. V)
Pitot tubes (including Pitot Venturis)	A

For those flow meters mounted in a vertical pipe it is desirable, but not essential, that a wet gas or

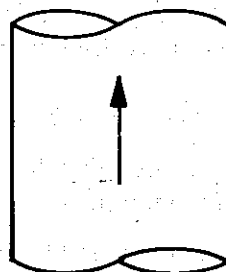
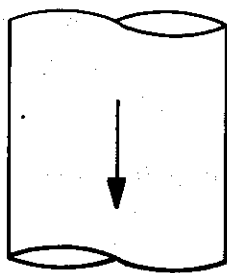


Fig. 11.1a Wet gas or saturated steam

Fig. 11.1b Vapour-containing liquid flow

saturated steam flow is downward through the flow meter (Fig. 11.1a) and a vapour-containing liquid flow is upward through the flow meter (Fig. 11.1b).

11.3 ORIENTATION OF THE FLOW METER IN RELATION TO THE PIPE AXIS

The correct orientation of a flow meter in relation to the pipe's axis is important in order to avoid vapour entrapment in liquid service, liquid entrapment in vapour or steam service to ensure self-cleaning action (if flows are dirty) and, for certain types of flow meter, the avoidance of undesirable loads on mechanical moving parts.

11.3.1 Axial orientation of differential pressure flow meters

Differential pressure flow meters have an axial orientation determined by the location of the pressure tapings, position of the vent hole (orifice plates only) and location of the throat/orifice for those flow meters (most commonly orifice plates) which have eccentric orifices.

11.3.1.1 Location of pressure tapings

Corner tapped orifice plate flow meters and flange tapped orifice plate flow meters should have their two pressure tapings to the differential pressure cell or switch at right angles to allow of free operation of the isolation valves. All other differential pressure flow meters may have these pressure tapings in the same plane (which is preferred) or at right angles to each other, whichever makes the installation of impulse lines easier.

For practical reasons flow meters in horizontal pipes normally have their pressure tapings at about 45° to the vertical. No flow meter in a horizontal pipe should have its pressure tapings lower than about 45° to the vertical in the flow meter's lower half – to avoid blockage by rust or other heavy extraneous matter – or above about 45° to the vertical in the upper half – to avoid entrapment of gas or vapour bubbles in the impulse lines.

Flow meters in horizontal pipes should have their pressure tapings above or below the flow meter's centre line according to the service and climatic conditions as indicated (Fig. 11.2a, 11.2b). The

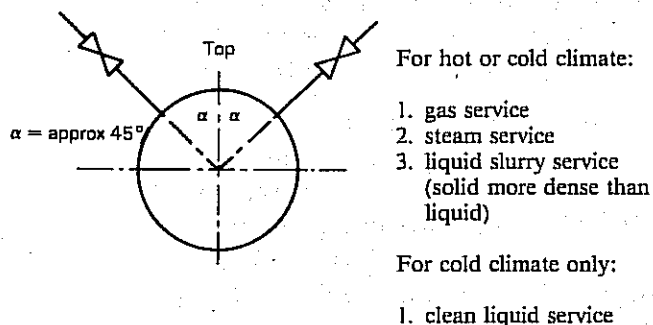
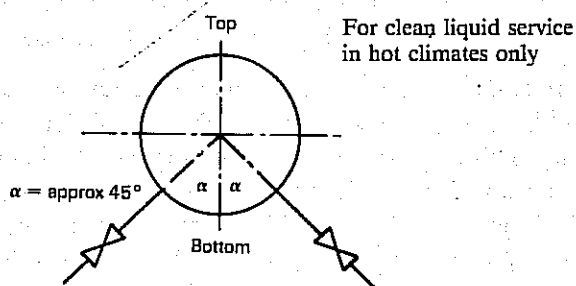


Fig. 11.2a



Note: Hot climate: sub-zero temperatures never reached
Cold climate: sub-zero temperatures are reached

Fig. 11.2b

recommended tapping orientation avoids water settlement out of the fluid and subsequent freezing-up of the pressure tapings. Other tapping orientations may be chosen avoiding excess settlement, blockage, freezing-up, etc., when the measured fluid may so require.

11.3.1.2 Location of the bleed hole in orifice plates

An orifice plate flow meter in a vertical line should not have a bleed hole. (If it does, it is best placed as far away as possible from pressure tapings).

An orifice plate flow meter in a horizontal line in liquid service should have the orifice plate positioned with the bleed hole (if there is one) at the top of the plate.

An orifice plate flow meter in a horizontal line in gas, vapour or steam service should have the orifice plate positioned with the bleed hole (if there is one) at the bottom of the plate.

If the orifice plate contains a bleed hole it is normally indicated by a small marker hole drilled either above or below the lifting eye. The position of the marker hole relative to the lifting eye corresponds to the position of the bleed hole relative to the orifice.

Note: Small orifice plates, especially those with a small beta ratio do not normally have bleed holes.

11.3.1.3 Location of a segmental orifice

Orifice flow meters with a segmental orifice shall be used on horizontal pipes only and be placed at the bottom of the pipe to allow of the easy passage of the secondary phase (Fig.11.3).

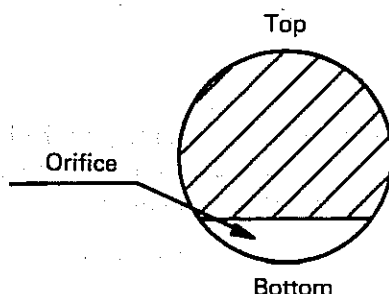


Fig.11.3

11.3.1.4 Location of differential pressure transmitters

To obtain accurate readings from differential pressure flow meters, it is necessary to install the differential pressure measuring instrument (i.e. the secondary device) and the impulse lines such as to avoid the possibility of unequal heads of liquid. In liquid service this necessitates avoiding air or vapour blocking the impulse lines; in gas service it necessitates preventing liquid from blocking the impulse lines. In vapour and steam applications it is assumed that liquid will condense out of the gas phase, so that the installation is suitably arranged for the liquid levels in the two impulse lines to be kept the same. This philosophy of balancing liquid heads within the impulse lines is also used for secondary devices installed with diaphragm seals, i.e. the liquid level between the sealing liquid and process liquid is kept to the same level by either diaphragms or pots. It should be realized that ensuring equal heads of liquid in liquid-filled impulse lines also requires that the liquid inside the impulse lines is of the same density. Difference in temperature between the lines can result in the liquid inside being of different density and hence, although of equal level, they can generate a significant difference in hydrostatic head. The problem is alleviated by keeping impulse lines short, running them over the same route, clipping them together, lagging them together and ensuring that the temperature difference over their length is small.

It is important that impulse lines are self-cleaning, i.e. that gas bubbles migrate continually upward to a chosen high point and that liquid bubbles and dense solids migrate continually downward to a chosen low point. This is usually ensured by using impulse lines of at least 10 mm (3/8") OD, laid over all parts of their length, with a gradient to the horizontal of at least 1:20. It is desirable to arrange the installation such that the chosen high and low points can never accumulate the unwanted phase. In doing so this removes the need for pots, i.e. local enlargement of impulse line diameter, to avoid line blockage, and avoids the need for venting valves to allow the unwanted, slowly produced accumulations to be released and also the need for regular manual attention to release the accumulation.

Following Fig. 11.4 shows a typical impulse line arrangement for orifice meter runs. Figure 11.5 shows a typical assembly for manifold and instrument.

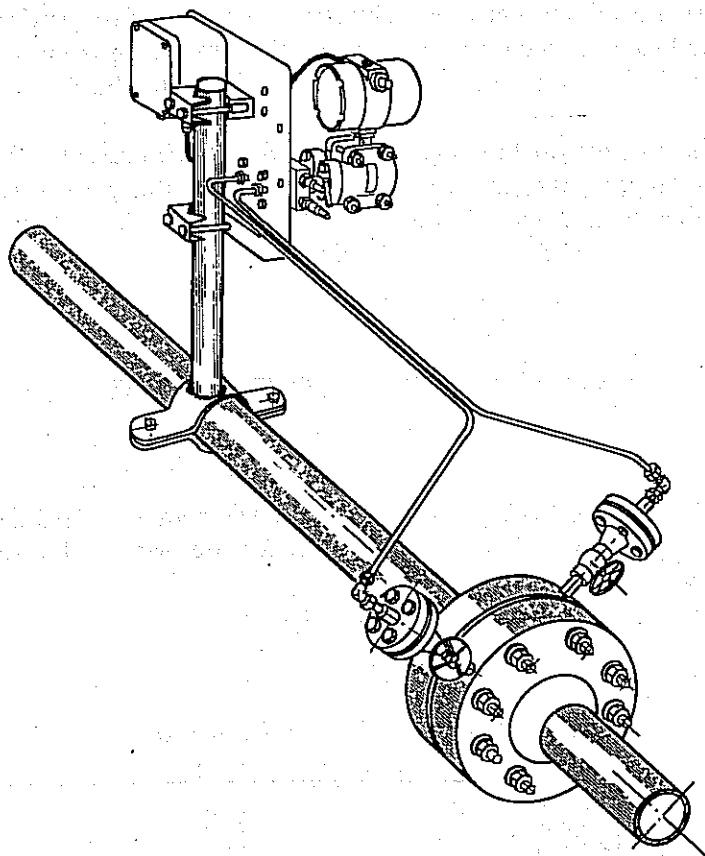


Fig. 11.4 Typical impulse line arrangement for a flow measurement

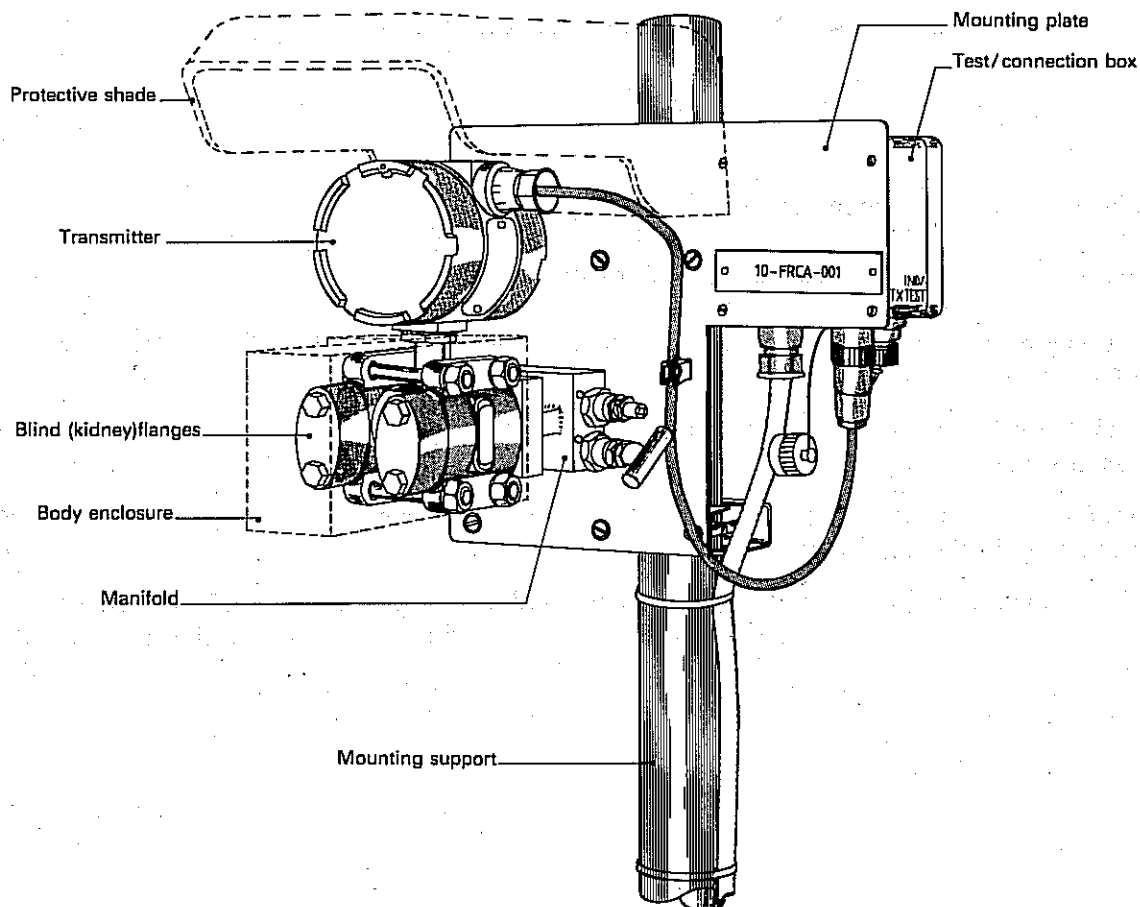


Fig. 11.5 Typical assembly for manifold and instrument

11.3.2 Axial orientation of Pitot tubes (including Pitot Venturi)

A Pitot tube is normally used to determine the velocity profile of a flowing fluid.

Pitot tubes used to obtain a single point velocity measurement as a means of measuring total flow should have the Pitot tube positioned such as to minimize the uncertainty resulting from possible flow profile distortions, and to minimize the length of the Pitot tube projecting into the flow.

Probes which use a separate static pressure tapping, i.e. one which is not included within the probe itself, should have the static pressure tapping positioned so as to minimize the static pressure head between the Pitot tube and the static pressure tapping used. For horizontal pipes the static pressure tapping should in such a case never be mounted on top or bottom of the line.

11.4 STRAIGHT LENGTH REQUIREMENTS

11.4.1 General

The minimum straight length requirements L_{U1} , L_{U2} and L_{D1} between various fittings located upstream or downstream of the primary device are given in Table 11.4.2 for the orifice plates and nozzles and in Table 11.4.3 for Venturi flow meters.

These straight length requirements are in accordance with ISO 5167.

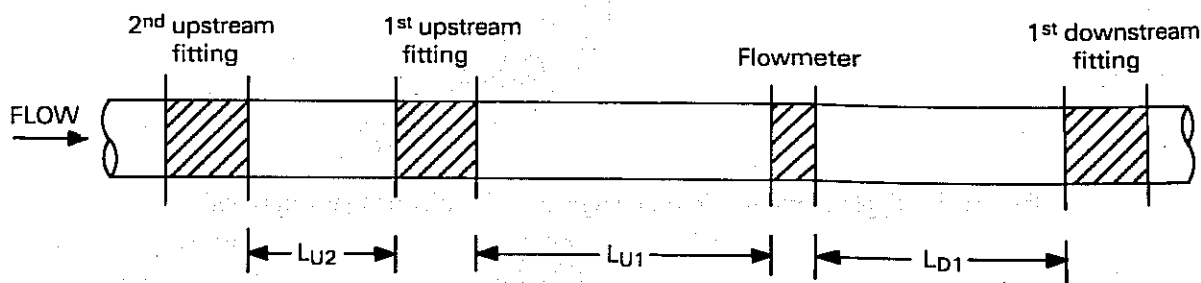


Fig. 11.4.1

- L_{U1} = distance between flow meter and first upstream fitting
- L_{U2} = distance between first upstream fitting and second upstream fitting
- L_{D1} = distance between flow meter and first downstream fitting

All straight lengths are expressed as multiples of the diameter D . They shall be measured from the upstream face of the primary device.

The unbracketed values are "zero additional uncertainty" values.

The bracketed values are " $\pm 0.5\%$ additional uncertainty" values.

The performance of orifice flow meters is greatly affected when not presented with a fully developed flow pattern specifically in the high β ratios.

It is strongly recommended to apply the figures corresponding to a β ratio of 0.7 thus obtaining the maximum flexibility in changing the orifice size at any time without affecting the zero additional uncertainty.

11.4.2 Minimum length required for the orifice or nozzle flow meter

Nature of first upstream fitting	L _{U1}														L _{U2}
	0.2	0.25	0.3	β ratio of the orifice or nozzle flow meter										For all β ratios	
Single 90° bend or tee flow from only one branch	10 (6)	10 (6)	10 (6)	12 (6)	14 (7)	14 (7)	14 (7)	16 (8)	18 (9)	22 (11)	28 (14)	36 (18)	46 (23)	14	
Two or more close 90° bends (radius of curvature D) in the same plane	14 (7)	14 (7)	16 (8)	16 (8)	18 (9)	18 (9)	20 (10)	22 (11)	26 (13)	32 (16)	36 (18)	42 (21)	50 (25)	18	
Two or more close 90° bends (radius of curvature D) in different planes	34 (17)	34 (17)	34 (17)	36 (18)	36 (18)	38 (19)	40 (20)	44 (22)	48 (24)	54 (27)	62 (31)	70 (35)	80 (40)	31	
Reducer 2D to D over a length of 3D	5	5	5	5	5	5	6 (5)	8 (5)	9 (5)	11 (6)	14 (7)	22 (11)	30 (15)	7	
Expander 0.5D to D over a length of 1.5D	16 (8)	16 (8)	16 (8)	16 (8)	16 (8)	17 (8)	18 (9)	20 (10)	22 (11)	25 (13)	30 (15)	38 (19)	54 (27)	15	
Globe valve (completely open)	18 (9)	18 (9)	18 (9)	18 (9)	20 (10)	20 (10)	22 (11)	24 (12)	26 (13)	28 (14)	32 (16)	36 (18)	44 (22)	16	
Gate valve (completely open)	12 (6)	12 (6)	12 (6)	12 (6)	12 (6)	12 (6)	12 (6)	14 (7)	14 (7)	16 (8)	20 (10)	24 (12)	30 (15)	10	
Abrupt symmetrical reduction from 2D to D	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	15	
Thermometer pocket dia. 0.3D	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	3	
Thermometer pocket dia. 0.03D to 0.13D	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	10	
Open space or large vessel, e.g. tank	30	30	30	30	30	30	30	30	30	30	30	30	30	30-L _{U1}	
L _{D1}															
For all above-mentioned fittings	4 (2)	4 (2)	5 (2.5)	5 (2.5)	6 (3)	6 (3)	6 (3)	6 (3)	7 (3.5)	7 (3.5)	7 (3.5)	8 (4)	8 (4)		

All straight lengths are expressed in multiples of the diameter D.

11.4.3 Minimum length for a Venturi flow meter

Nature of first upstream fitting	L _{U1}										L _{U2}
	β ratio of the Venturi flow meter										For all β ratios
	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	
Single 90° short radius bend radius of curvature D Note: 1	0.5 (*)	0.5 (*)	0.5 (*)	1.0 (0.5)	1.5 (0.5)	2.5 (0.5)	3.0 (1.0)	4.0 (1.5)	4.0 (2.0)	4.5 (3.0)	14
Two or more close 90° bends (radius of curvature D) in the same plane Note: 1	1.5 (0.5)	1.5 (0.5)	1.5 (0.5)	1.5 (0.5)	2.5 (1.5)	2.5 (1.5)	3.5 (2.5)	4.5 (2.5)	4.5 (2.5)	4.5 (3.5)	18
Two or more close 90° bends (radius of curvature D) in different planes Notes: 1, 2	(0.5)	(0.5)	(0.5)	(0.5)	(8.5)	(12.5)	(17.5)	(23.5)	(27.5)	(29.5)	31
Reducer 3D to D over a length of 3.5D	(0.5) (*)	1.5 (0.5)	2.5 (0.5)	4.5 (0.5)	5.5 (0.5)	6.5 (0.5)	8.5 (0.5)	9.5 (1.5)	10.5 (2.5)	11.5 (3.5)	7
Expander 0.75D to D over a length of D	1.5 (0.5)	1.5 (0.5)	1.5 (0.5)	2.5 (1.0)	2.5 (1.5)	3.5 (1.5)	3.5 (1.5)	4.5 (2.5)	5.5 (3.5)	6.5 (4.5)	15
Gate valve (completely open)	1.5 (0.5)	2.5 (0.5)	2.5 (1.5)	3.5 (1.5)	3.5 (1.5)	4.5 (2.5)	4.5 (2.5)	4.5 (2.5)	5.5 (3.5)	5.5 (3.5)	10
Abrupt symmetrical reduction	unknown				30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	30 (15)	15
Thermometer pocket dia. 0.03D	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	5 (3)	3
Thermometer pocket dia. 0.03D to 0.13D	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	20 (10)	10
Open space or large vessel, e.g. tank	30	30	30	30	30	30	30	30	30	30	30-L _{U1}
L _{D1}											
For all above-mentioned fittings	4	4	4	4	4	4	4	4	4	4	

Notes: 1) The radius of curvature of the bend shall be equal to or greater than the pipe diameter.

2) As the effect of these fittings may still be present after 40 D, no unbracketed values can be given in the table.

*) Since no fitting can be placed closer than 0.5 D to the upstream pressure tapping in the Venturi tube, the "zero additional uncertainty" value is only applicable in this distance.

All straight lengths are expressed in multiples of the diameter D.

11.4.4 Reference

ISO 5167.

11.5 LOCALLY FABRICATED ORIFICE METER RUNS

11.5.1 General

For meter runs with a longer upstream straight length requirement than 6 metres (typically for lines > DN 300), it becomes impracticable to have prefabricated meter runs (10.1) in view of transportation problems.

Note that a meter run comprises a specially selected pipe length carefully attached to orifice flanges. The meter run is made as long as possible within the confines of practical fabrication methods and handleability. It may or may not be long enough to fulfil the full straight length requirements (11.4). If it is not, a normal pipe quality joint is made between its own flanged ends and appropriate straight lengths of normal, not specially selected, plant pipe. Because the meter run includes the orifice flanges, certain aspects of these flanges must be considered part of the "pipe" specification.

11.5.2 The selection of pipe

A length of pipe to be used for the fabrication of the orifice meter run shall comply with the following requirements.

1. The pipe shall be a non-jointed, standard, random pipe length, typically about 6 metres long. It shall be of the required size, schedule and material and shall be straight and smooth by visual inspection.
2. For the upstream pipe any two measurements of the inside diameter of the pipe end which is to be welded to the upstream orifice flange, shall not differ by more than 1% or 2 mm, whichever is the smaller.

For the downstream pipe any two measurements of the inside diameter of the pipe end which is to be welded to the downstream orifice flange, shall not differ by more than 2% or 4 mm, whichever is the smaller.

The mean diameter of the pipe to be welded to the downstream orifice flange shall not differ by more than 2.5% from the mean diameter of the pipe end which is to be welded to the upstream orifice flange.

For compliance with these requirements, it may be convenient to take both the upstream and the downstream pipes from one pipe length. Alternatively, two separate pipes which also comply with the above requirements may be selected.

11.5.3 The preparation of pipes and orifice flanges

1. Select pipe in accordance with (11.5.2) and cut this to the required length (11.4), if appropriate. If the straight length as specified in Table 11.4.2 is longer than the approximately 6 metres of the selected length, the full (6 m) selected length is used as part of the meter run.
2. Prepare each pipe at both ends for butt welding in accordance with ANSI B16.25.
3. Measure the inside diameter at both ends of each pipe. At each pipe end measure four inside diameters spaced at approximately equal angles to each other, with an accuracy of 0.1%, and calculate the mean inside diameter of each end. The measurements shall be done in one circular plane not more than one pipe diameter away from the pipe end.
4. Selecting the pipe ends for welding to the flanges.

Select for welding to the upstream flange that end of the prepared upstream pipe which is nearest to complete roundness.

Mark the selected end with its mean inside diameter and the relevant instrument tag number followed by the letter (H).

Select for welding to the downstream flange that end of the prepared downstream pipe which has a mean inside diameter nearest to the mean inside diameter of the selected end of the upstream length.

Mark the selected end with its mean inside diameter and the relevant instrument tag number followed by the letter (L).

11.5.4 The preparation of orifice flanges

Orifice flanges according to the drawings given in this handbook shall be prepared for attachment to these lengths of pipe as follows:

1. Mark one orifice flange for upstream use with the relevant instrument tag number followed by the letter (H) and machine the bore to the calculated mean diameter of the selected end of the upstream pipe, within a tolerance of ± 0.2 mm.
2. Mark the other orifice flange for downstream use with the relevant instrument tag number followed by the letter (L) and machine the bore to the calculated mean diameter of the selected end of the downstream pipe, within a tolerance of ± 0.2 mm.
3. After machining, the holes for the pressure tapings in both flanges shall be sharp and free from burrs.

11.5.5 Fabrication of orifice meter runs

For the correct alignment of flanges and pipe, a trestle as shown in Fig. 11.6 or Fig. 11.7 or the equivalent, is recommended. The fabrication of the meter run should then take place in the following sequence.

1. Start at the longest part of the trestle.
2. Place the upstream pipe on the aligning trestle with the marked end at location (H).
3. Place the upstream orifice flange in front of the upstream pipe (at the marked end) with the flange bore as flush as possible with the inside of the pipe at all points, i.e. concentric, and with the pressure tapping as shown on the relevant isometric drawing.
4. Lightly tack-weld the flange to the pipe at two diametrically opposed points in the horizontal plane.
5. Repeat steps 2, 3 and 4 for the downstream pipe and orifice flange, except that tack welding shall now be in the vertical plane.
6. Bolt the upstream and downstream flanges together with the tapings in the correct position as shown on the relevant isometric drawing.
7. Ensure that the meter run lies fully supported along its whole length by the trestle.
8. Complete the tack welding and disconnect the flanges.
9. Weld the flanges to the pipe as prescribed for the relevant material, with weld metal fully penetrated on the inside.
10. Make a smooth internal transition between flange and pipe by carefully grinding away welding beads without unnecessary removal of material.

11.5.6 Measurement and recording of internal diameter

After the fabrication of the orifice meter run, at least two measurements shall be made of the inside diameter of the upstream flange.

The measurements of the diameter shall be at approximately equal angles to each other and be taken near to the front face of the flange.

Each measurement shall be accurate to better than 0.1%.

From the above measurements the mean diameter shall be calculated expressed in mm and recorded (by the instrument engineer).

The mean diameter of the upstream flange as determined above and the current year shall be stamped on the rim of the upstream flange, near the pressure tapping as in the following typical example:
 $D = 250.1 \text{ mm (1985)}$.

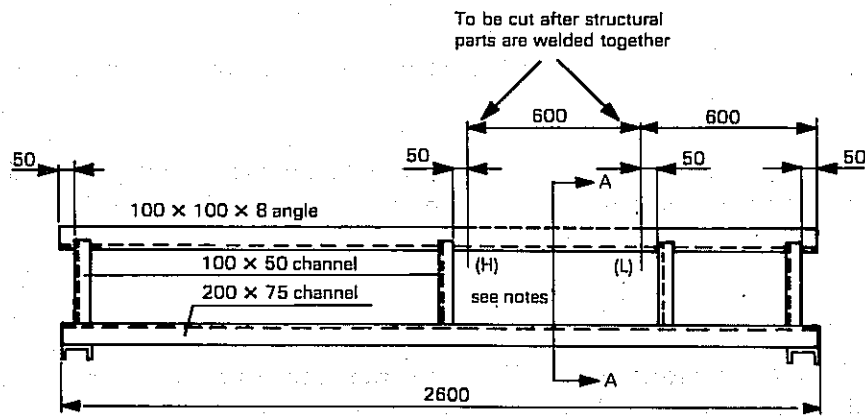
11.5.7 Assembling the orifice meter run

The upstream and downstream pieces of the orifice meter run shall be bolted together with the specified stud bolts, nuts, spiral-wound gaskets, the correct spacer in place and with the pressure tapplings in the correct position.

Before welding the orifice meter run into the piping system, the pressure tapplings shall be completed with the components of the assembly group, as specified on the relevant isometric drawing.

11.5.8 Reference

ANSI B 16.25



- Notes:
- 1) Dimensions in mm
 - 2) The trestle pipe support to be straight by visual inspection
 - 3) The letters (H) and (L) are for reference only

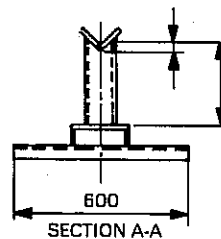
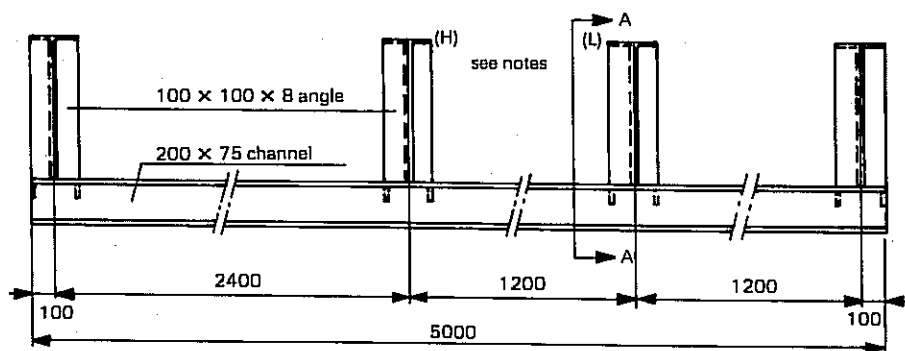


Fig. 11.6 Typical aligning trestle for nominal pipe size DN 150 and smaller



- Notes:
- 1) Weld structural parts rigidly together with alignment such that pipe pieces laid in the trestle will always be coaxial
 - 2) Dimensions in mm
 - 3) The trestle pipe support to be straight by visual inspection
 - 4) The letters (H) and (L) are for reference only

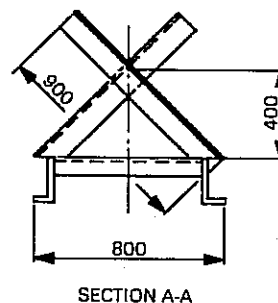


Fig. 11.7 Typical aligning trestle for nominal pipe size DN 200 and larger.

Section 12. General considerations

12.1 The principle of differential pressure flow measurement

- 12.1.1 The basic flow meter
- 12.1.2 Deriving the mass flow rate
- 12.1.3 Basic practical designs of the primaries
- 12.1.4 The range of general applications

12.2 Orifice plate designs

- 12.2.1 General
- 12.2.2 Square edge orifice plates
 - 12.2.2.1 ISO 5167 design requirements
 - 12.2.2.2 Recommended design
 - 12.2.2.3 Explanation of and comments on the recommended design and its relation to ISO 5167
- 12.2.3 Quarter of circle orifice plates
 - 12.2.3.1 BS 1042 (1964) design requirements
 - 12.2.3.2 Recommended design
 - 12.2.3.3 Explanation of and comments on the recommended design and its relation to BS 1042 (1964)
- 12.2.4 Conical entrance orifice plates
 - 12.2.4.1 BS 1042 (1964) design requirements
 - 12.2.4.2 Recommended design
 - 12.2.4.3 Explanation of and comments on the recommended design and its relation to BS 1042 (1964)
- 12.2.5 References

12.3 Orifice flange designs

- 12.3.1 General
- 12.3.2 Flange tapped orifice flanges
 - 12.3.2.1 ISO 5167 design requirements
 - 12.3.2.2 Recommended design
 - 12.3.2.3 Explanation of and comments on the recommended design and its relation to ISO 5167
- 12.3.3 Corner tapped orifice flanges
 - 12.3.3.1 ISO 5167 design requirements
 - 12.3.3.2 Recommended design
 - 12.3.3.3 Explanation of and comments on the recommended design and its relation to ISO 5167 and BS 1042
- 12.3.4 Radius tapped orifice flanges
 - 12.3.4.1 ISO 5167 design requirements
 - 12.3.4.2 Recommended design
 - 12.3.4.3 Explanation of and comments on the recommended design and its relation to ISO 5167
- 12.3.5 References

12.4 Specification of pipework upstream and downstream the flow meter

- 12.4.1 General
- 12.4.2 Pipework specification for orifice flow meters and nozzles
 - 12.4.2.1 ISO 5167 pipework specification
 - 12.4.2.2 The recommended pipework specification
 - 12.4.2.3 Explanation of the recommended pipework specification and its relationship to ISO 5167
- 12.4.3 Pipework specification for classical Venturi flow meters
 - 12.4.3.1 ISO 5167 design requirements
 - 12.4.3.2 The recommended pipework specification
 - 12.4.3.3 Explanation of the recommended pipework specification and its relationship to ISO 5167
- 12.4.4 References

- 12.5 Upstream and downstream straight lengths requirements**
- 12.5.1 General**
- 12.5.2 Recommended straight lengths for differential pressure type flow meters**
- 12.5.3 Straight length for the pipework between the second and subsequent upstream fittings and between the first and subsequent downstream fittings**
- 12.5.4 References**

12.1 THE PRINCIPLE OF DIFFERENTIAL PRESSURE FLOW MEASUREMENT

12.1.1 The basic flow meter

An orifice flow meter is basically of a design as shown in Fig. 12.1.

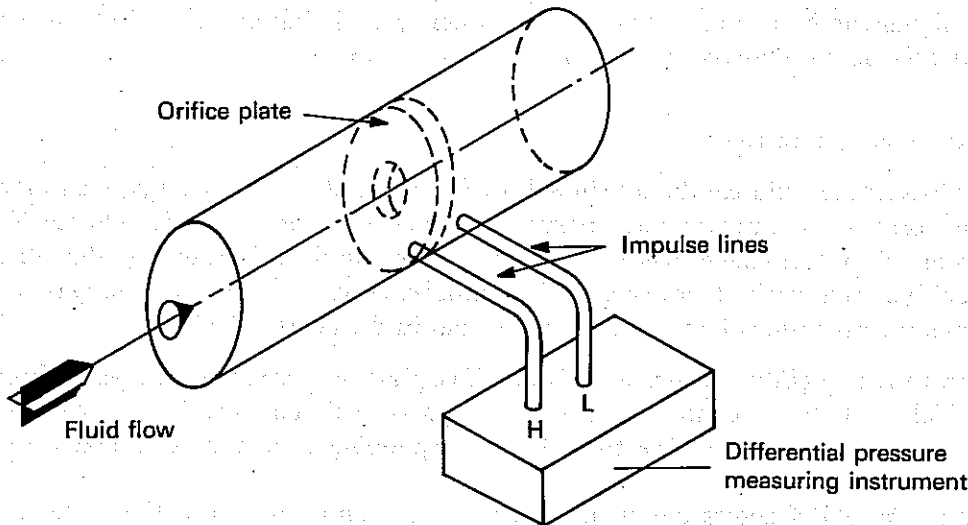


Fig. 12.1 Basic design of a flow meter

A thin metal plate with an orifice, the orifice plate, is mounted in a pipe perpendicular to the fluid flow. The orifice plate is usually held in position by clamping it with gaskets between two pipe flanges or, in the case of some commercial equipment, held in place by a specially designed ring or box.

As fluid passes along the pipe and through the orifice, the mean pressure within the fluid in the region of the plate assumes a characteristic form. This is roughly as shown in Fig. 12.2 at the pipe wall, where the pressure measurements for orifice flow metering are always obtained.

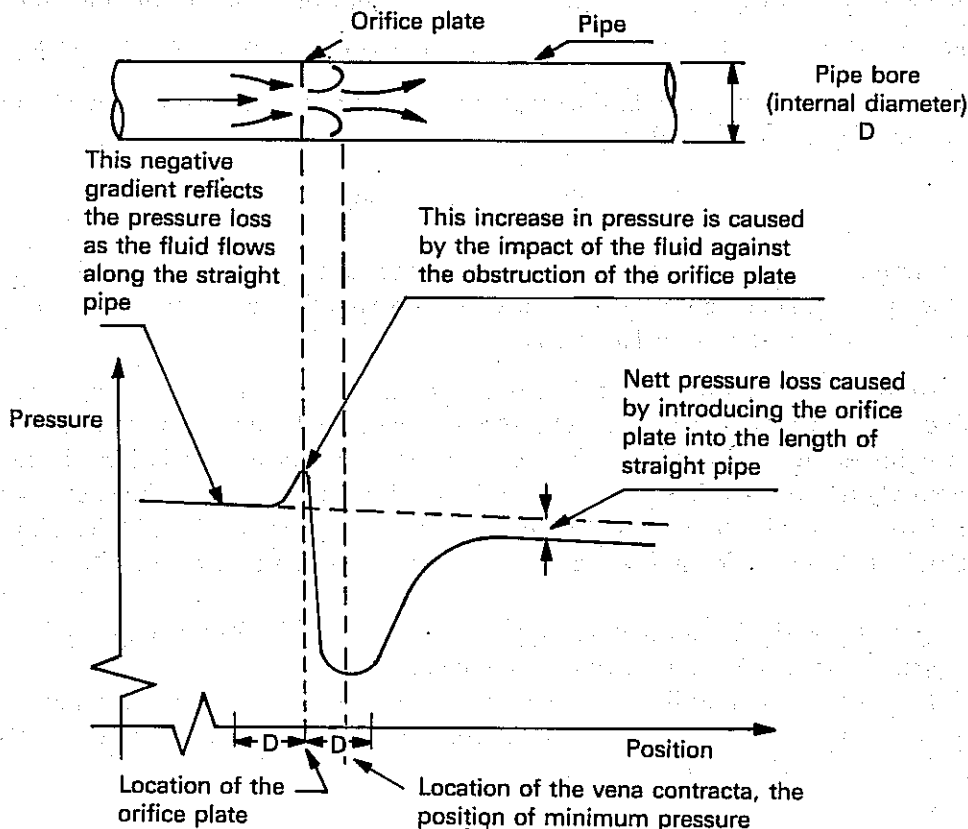


Fig. 12.2. Pressure drop across an orifice plate.

A pressure measuring instrument is used to measure the differential pressure between a point at the inside surface of the pipe wall slightly upstream of the orifice and one slightly downstream of the orifice. The differential pressure across the plate is a function of mean flow rate through the orifice and hence by measuring the differential pressure across the orifice plate the related flow rate can be derived. The differential pressure measuring instrument across the orifice plate acts as a transducer and either displays the change in differential pressure as the movement of pen or pointer or transmits it as an instrument signal.

The instrument signal can be a voltage or current, frequency or digital code, etc., provided that the relationship between the differential pressure and the signal is known.

12.1.2 Deriving the mass flow rate

Ignoring energy losses, the fluid can be attributed a fixed amount of total energy, part of which is potential energy stored as fluid pressure and part is kinetic energy stored as fluid velocity. The fluid travels with greater velocity and hence has greater kinetic energy in the orifice than in the unrestricted pipe. This greater kinetic energy is at the expense of potential energy, since the total energy is practically constant, and thus the pressure is lower at the orifice than in the upstream pipe.

The minimum pressure is slightly downstream of the orifice plate because the fluid squirts through the orifice in a jet which continues to contract to a minimum cross-sectional area, the vena contracta, at a point slightly downstream of the orifice plate before expanding in the unrestricted downstream pipe.

The differential pressure "dp" across the orifice plate corresponding to a mass flow rate q_m can be calculated, using Bernoulli's equation, to be:

$$q_m = \frac{\pi D^2}{4 \cdot 10^6} \sqrt{\frac{d^4}{D^4 - d^4}} \sqrt{2 \cdot 10^5 \rho dp} \quad (i)$$

which, simplified by writing $d/D = \beta$ gives:

$$q_m = 3.512 \cdot 10^{-4} \frac{d^2}{\sqrt{1 - \beta^4}} \sqrt{\rho dp} \quad (ii)$$

For orifice plates equation (ii) is a poor description of behaviour, mainly because the minimum cross-sectional area of the flow is not $\frac{\pi d^2}{4}$ at the orifice, as assumed in the derivation of the above, but about 35% less at the vena contracta. Making a rough allowance for this extra contraction by multiplying the above coefficient by $1 - 0.35 = 0.65$ gives:

$$q_m = 2.28 \cdot 10^{-4} \frac{d^2}{\sqrt{1 - \beta^4}} \sqrt{\rho dp} \quad (iii)$$

which, for any simple, concentric orifice plate flow meter using tappings near the plate, will give an answer correct to approximately $\pm 10\%$. This is a useful approximation as an initial rough estimation of the flow rate when starting iterative calculations.

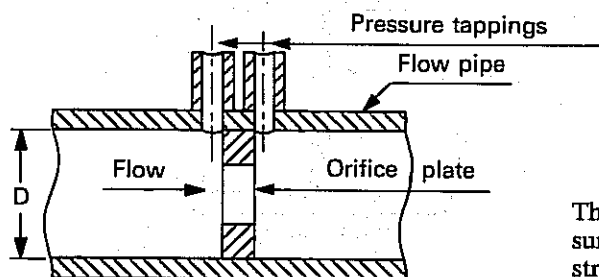
The reason equation (iii) is not more accurate is that its derivation does not take account of energy losses, changes in fluid density, orifice profile, exact size and location of pressure tappings, detailed flow pattern, pipe roughness, etc., all of which play a role in determining the exact relationship between flow rate and differential pressure. The influence of these factors is complicated and they need experimental determination. However, calibration of standard primary devices by means of liquids has shown that the discharge coefficient depends, for a given device in a given installation, on the Reynolds Number only.

By standardizing on a few significant features, e.g. orifice profile and pressure tapping locations, etc., sufficiently accurate empirical equations can be obtained.

It is the description of these standardized orifice flow metering arrangements and equations that forms the majority of information presented in this handbook. It allows flow rates to be calculated to an accuracy of about $\pm 0.8\%$ of reading, provided that the differential pressure measuring instrument is sufficiently accurate.

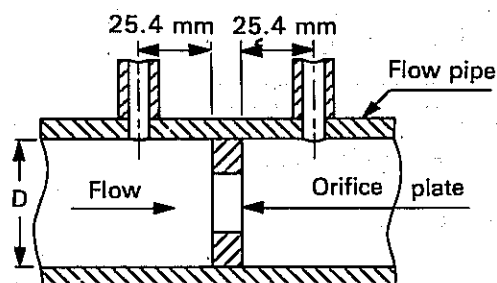
12.1.3 Basic practical designs of the primaries

The most common practical design of an orifice plate flow meter features an orifice plate clamped with gaskets between two pipe flanges. In practice, the pressure from upstream and downstream of the orifice plate is taken in different configurations referred to as corner tapplings, flange tapplings and radius tapplings, as shown in Figs. 12.3a, b and c respectively.



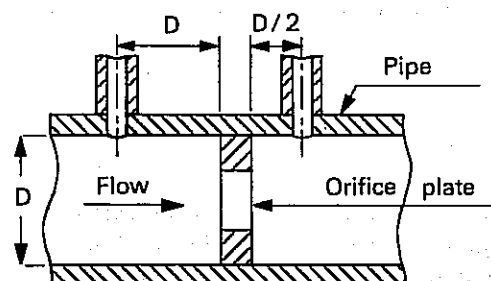
The pressure tapplings take the pressure directly upstream and downstream of the orifice plate.

Fig. 12.3a Orifice flow meter primary with corner tapplings



Take the pressure 25.4 mm from the nearest face of the orifice plate. Hence, in practice, the tapplings pass straight through the flanges which clamp the orifice plate.

Fig. 12.3b Orifice flow meter primary with flange tapplings



The upstream and downstream pressure tapplings are placed at distances D and $D/2$ respectively, measured from the upstream face of the orifice plate.

Fig. 12.3c Orifice flow meter primary with radius tapplings

Orifice plates with three different upstream profiles, called square edge, quarter of circle and conical entrance, are widely used. Figs. 12.4a, b and c below show the profiles of these three types of orifice plates and the recommended shaping of the identification tab which enables them to be readily identified even when they are installed.

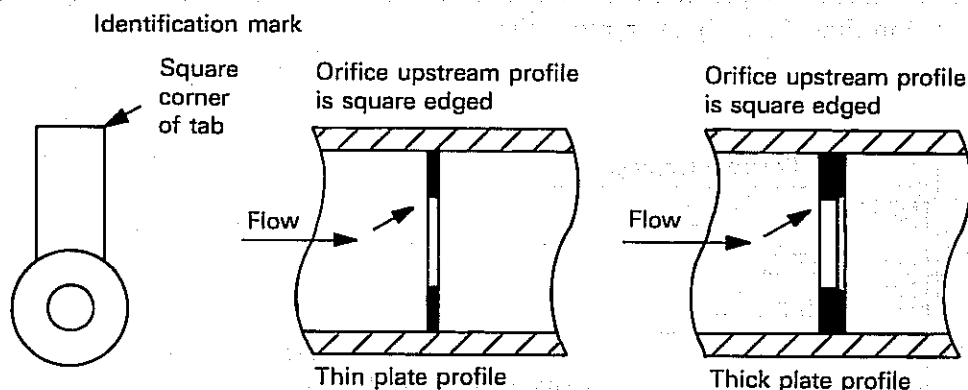


Fig. 12.4a Square edge orifice plate, "S" Type

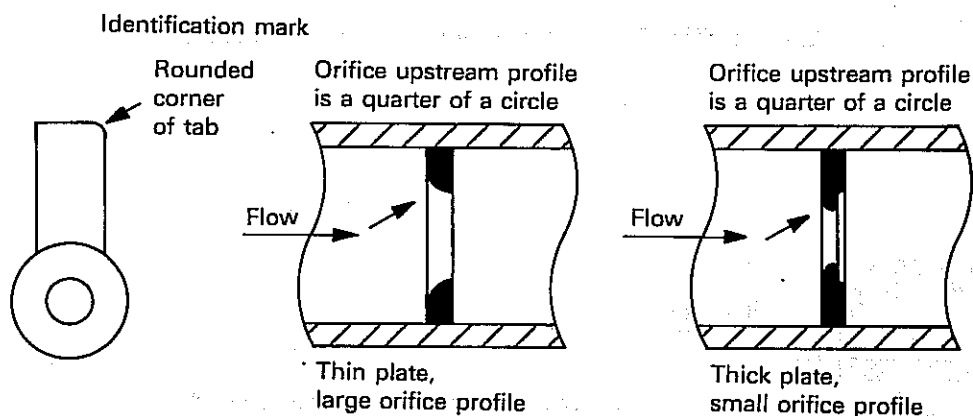


Fig. 12.4b Quarter of circle orifice plate, "Q" Type

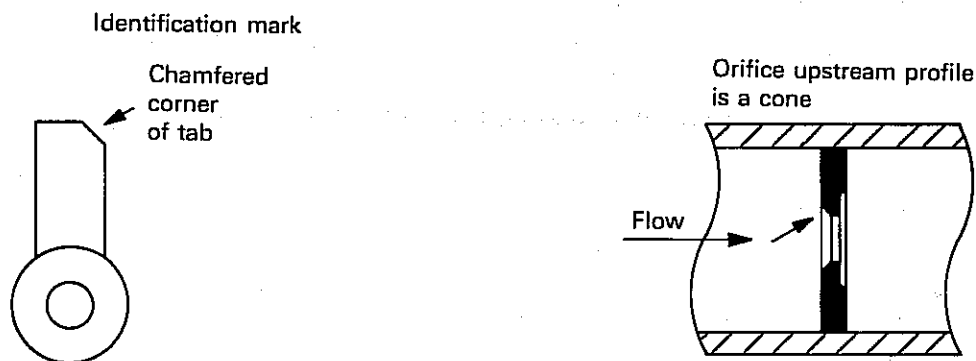


Fig. 12.4c Conical entrance plate, "C" Type

12.1.3 The range of general applications

Orifice flow meters can be used for metering the flow of gases, vapours or liquids which are non-abrasive and non-corrosive for the materials from which the instrument is made, provided the fluid flow shall be within certain Reynolds Number limits. Experiments suggest that there is no fundamental upper pipe size limit for which the technique can be used, but limited data for the larger sizes sometimes preclude general use.

There is a minimum pipe size limit which is imposed by a combination of negative effects.

For industrial applications the minimum pipe size limit is often governed by practical manufacturing and installation tolerances. It is partly for this reason that the ISO 5167 does not specify square edge orifice flow meters for a pipe with a bore of less than 50 mm.

If an orifice flow meter for a pipe size smaller than 50 mm is used, it results in a much larger uncertainty in its flow metering accuracy than calculated from its dimensions. These flow meters can perform accurately and be fairly linear after square root extraction, if carefully made and individually calibrated, but their calibration is very sensitive to minute changes in the absolute dimensions of their internal parts—caused for example by erosion and corrosion. They normally need to be recalibrated after each (re)assembly.

12.2 ORIFICE PLATE DESIGNS

12.2.1 General

In this section reference is made to ISO 5167, BS 1042 (1981), BS 1042 (1964) and ASME (1971) as appropriate.

Both ISO 5167 and BS 1042 (1981) specify identical requirements for the design of square edge orifice plates, without allowance for a bleed hole.

ASME (1971) specifies requirements for the design of eccentric orifice plates, also without allowance for a bleed hole. BS 1042 (1964) specifies quarter of circle and conical entrance orifice plates with allowance for a bleed hole.

The orifice plate designs are made to suit flanges using spiral-wound gaskets fitted in DN 15 to DN 600 pipes. The designs for DN 15 to DN 40 pipes are to fit the orifice flanges of Fig. 10.1.9. The designs for DN 50 to DN 600 pipes are to fit the corner tapped orifice flanges of Fig. 3.2.9 or the flange tapped flanges of Fig. 3.1.9. The DN 200 to DN 600 plates will fit ANSI B16.5 pipe flanges for use with radius tappings. In all cases, if the plates are stainless steel 316 and the flanges of low alloy carbon steel, the plates can be used up to 450 °C and a maximum differential pressure of 2 bar.

Orifice plates of sizes DN 50 to DN 600 should have a bleed hole if mounted in horizontal pipes. The presence of the bleed hole introduces an extra uncertainty in flow measurement because of the uncertainty of flow through it. BS 1042 (1964) defines this as equivalent to 100% of the estimated flow through the bleed hole. In accordance with this and BS 1042 (1964) computational methods, this extra uncertainty is defined as:

$$- 55 \left[\frac{y}{\beta \cdot D} \right]^2 \% \text{ of measured flow}$$

in which: D = the pipe bore (schedule number allowed for)

y = the bleed hole diameter

and should be added arithmetically to the flow meter's basic uncertainty when a bleed hole is applied.

Because of tolerances and the standardization of a bleed hole position for pipes of different schedule number, the bleed hole can be located between approximately 0.01D to 0.1D from the inner wall of the pipe. This can result in an almost 0.1D height of liquid or gas (the second phase) accumulation between pipe wall and bleed hole, so that effectively the pipe does not "run full" as required by ISO 5167.

The extra uncertainty becomes larger for smaller pipe diameters, therefore orifice plates for pipes < DN 50 shall not contain a drain hole in order to avoid the introduction of an extra unacceptable uncertainty.

Horizontally installed orifice flow meters in liquid applications unavoidably have a gas pocket introduced when first assembled. This pocket initially bleeds through the orifice plate's bleed hole until it is of a size bounded by bleed hole and pipe wall. Thereafter the pocket compresses under the influence of pipe pressure. In some orifice flow metering installations second phase accumulations extending from pipe wall to bleed hole will still occur, even after the fluid medium is stabilized.

Because the presence of a second phase accumulation and its volume are very dependent on a flow meter's operational and installation condition, the effect is not calculable and hence in general ignored as contributory to the basic uncertainty in flow measurement. It should be realized however that an extra uncertainty will exist in many circumstances.

For the orifice plate designs given in this handbook, e.g. (3.1.8), the orifice seating area has a surface finish suitable for spiral-wound gaskets.

Note that if an orifice plate is used with radius tapped orifice flanges with compressed asbestos fibre (CAF) gaskets, the plate's gasket seating area must have a stock finish.

12.2.2 Square edge orifice plates

12.2.2.1 ISO 5167 design requirements

The ISO 5167 design requirements are comprehensive and cannot be summarized for quick reference, without loss of accuracy. Therefore these are not included in the handbook, for details see section 7.1 of ISO 5167.

12.2.2.2 Recommended design

For pipes up to DN 600, the recommended design for the square edge orifice plates is given in (3.1.8).

For pipes larger than DN 600, no recommended design is given.

The same holds for ring-type joint (RTJ) orifice flanges.

12.2.2.3 Explanation of and comments on the recommended design and its relation to ISO 5167

1) Orifice plates for pipes $< \text{DN } 50$

Provided that the beta ratio and orifice diameter of the square edge orifice plate fall within the ISO 5167 limits, the design of the orifice plates for the nominally DN 15, DN 20, DN 25 and DN 40 pipe meets the ISO 5167 requirements on all points except for thickness and edge sharpness. The plates are made 1.5 mm thick, so that the orifice flanges made for these small sizes tighten on to the orifice plate and not on to the centering ring. For these small diameter plates, 1.5 mm is much thicker than allowed of by ISO 5167.

The effect of the greater thickness is a shift in position of the downstream pressure tapping with respect to the metering edge of the orifice. However, considering this shift with respect to differences in tapping position between the flange and corner tapped orifice plate and their discharge coefficient, suggests that the extra uncertainty is negligible.

Good machining methods can produce an orifice "sharp edge" radius of about 5 micrometres or μm . This is greater than the maximum $0.0004 d$ allowed of by ISO 5167 if the orifice diameter is smaller than 12.5 mm, i.e. if the beta ratios are less than 0.8 for DN 15, 0.74 for DN 20, 0.6 for DN 25, and 0.4 for DN 40 pipes.

A rounded "sharp edge" will result in an increase of the flow meter's discharge coefficient. However, a slightly raised "wire-like" edge is as likely and will produce the opposite flow metering effect. The additional uncertainty can be approximated by an equation for all beta ratios, and should be added to the basic uncertainty of the flow coefficient (i.e. 0.6%).

In total, ignoring second-phase hold-ups, a rough guide for orifice flow meters using orifice plates

made in accordance with Fig. 3.1.8 is that an uncertainty of $\pm 0.3 \left[\frac{12.5}{d} \right] \%$ should be added to the basic uncertainty to account for deficiencies of the edge sharpness.

2) Orifice plates for pipes $\geq \text{DN } 50$

The designs for orifice plates for DN 50 to DN 600 sizes meet ISO 5167 requirements on all points, except perhaps "sharp edge" specification for beta ratios less than 0.3 in DN 50 sizes, provided that they do not contain a bleed hole. If they contain a bleed hole they still meet BS 1042 (1964) requirements.

The accumulation of the second phase (e.g. liquid in gas) affects the flow meter's velocity of approach factor $(1 - \beta^4)^{-1/2}$. Accumulation up to the depth of the bleed hole may affect this term, and hence flow metering accuracy, by up to 20% for large beta ratios. For smaller accumulations and/or smaller beta ratios the effect will be less. Second-phase accumulations will make the flow meter read lower than true. The latter effect is, however, ignored in the uncertainty calculations.

In total, ignoring second-phase hold-ups, a rough guide for orifice flow meters using orifice plates made in accordance with Fig. 3.1.8 is that an uncertainty of $-55 \left[\frac{y}{d} \right]^2$ % should be added to the basic uncertainty, if a bleed hole is used (12.2.1).

It should be noted that the plate thickness of the square edge orifice plate as per Fig. 3.1.8 is a calculated figure.

If a thickness is chosen for the orifice plate of a material with a standard commercial plate thickness, the thickness of the orifice plate shall be less than 0.05D.

12.2.3 Quarter of circle orifice plates

12.2.3.1 BS 1042 (1964) design requirements

ISO 5167 and BS 1042 (1981) do not specify quarter of circle orifice plates, therefore designs recommended in this handbook are based on the specification given by BS 1042 (1964).

The BS 1042 (1964) requirements are comprehensive. For details see clause 74 and Figs. 43 and 44 of BS 1042 (1964).

For the design of the plate, the following applies:

The radius r of the upstream profile shall be not less than 3.175 mm, and shall lie between 0.101 d and 0.208 d inclusive. Within these limits, the radius r expressed as a fraction of d shall be determined by the ratio d/D in accordance with the table given in (4.1.3) within limits of $\pm 0.05 r$.

The thickness of the orifice plate shall be not less than 2.54 mm and not exceed 0.1D.

12.2.3.2 Recommended design

The recommended design for quarter of circle orifice plates is given in Fig. 4.1.9.

The thickness "N" of the orifice plates for DN 15 to DN 40 pipes is selected to fit into the orifice flange assembly as shown in Fig. 10.1.9.

The thickness "N" of the orifice plates for DN 50 to DN 600 pipes shall be calculated as follows:

$N = (0.1) \text{ (Nominal pipe bore)}$, taking into account the pipe schedule number.

The radius r of the upstream profile is calculated in accordance with Fig. 44 of BS 1042 (1964). From a theoretical point of view there are no restrictions for a minimum radius.

12.2.3.3 Explanation of and comments on the recommended design and its relation to BS 1042 (1964)

Provided that the beta ratio and orifice diameter of the quarter of circle orifice plate fall within the BS 1042 (1964) limits, the orifice plates will meet the BS 1042 (1964) requirements on all points except that they might be slightly thicker than 0.1D because the plate thickness is based on the nominal pipe bore instead of the actual internal diameter. This deviation is of minor importance and hence it is ignored in the uncertainty estimates.

Because of tolerances and the standardization of bleed hole position for pipes of different schedule number, the bleed hole can range from about 0.02D to 0.2D from the inner wall of the pipe. This can result in almost 0.2D of second-phase accumulation (gas or liquid) between pipe wall and bleed hole, so that effectively the pipe does not "run full" as required by BS 1042 (1964).

The accumulation of this second-phase affects both the effective cross-sectional area of the flow at the upstream pressure tapping and the fluid's velocity of approach factor $(1 - \beta^4)^{-1/2}$. Because the maximum beta ratio for a quarter of circle orifice plate is limited to 0.6, the second-phase accumulations are never likely to affect flow metering accuracy by more than 5%. This effect is ignored in the calculations for the uncertainty.

In summing up, ignoring second-phase hold-ups, a rough guide is that orifice flow meters using orifice plates made in accordance with Fig. 4.1.9 should have $-55 \left[\frac{y}{d} \right]^2$ % extra uncertainty added arithmetically to the basic uncertainty of the flow coefficient because of flow through the bleed hole (12.2.1).

12.2.4 Conical entrance orifice plates

12.2.4.1 BS 1042 (1964) design requirements

ISO 5167 and BS 1042 (1981) do not specify conical entrance orifice plates, therefore the designs in this handbook are based on the specification given by BS 1042 (1964).

The BS 1042 (1964) requirements are comprehensive and can be found in clause 69 and Fig. 42 of this standard.

12.2.4.2 Recommended design

The recommended design for conical entrance orifice plates is given in Fig. 4.2.9.

The thickness "N" of the orifice plates for DN 15 to DN 40 pipes is given in Fig. 4.2.9. The thickness "N" of the orifice plates for DN 50 to DN 600 shall be calculated as follows:

$N = (0.1) \text{ (Nominal pipe bore)}$, taking into account the pipe schedule number

12.2.4.3 Explanation of and comments on the recommended design and its relation to BS 1042 (1964)

Provided that the beta ratio and orifice diameter of the conical entrance plate fall within the BS 1042 (1964) limits, the orifice plates will meet the BS 1042 (1964) requirements on all points except that they might be slightly thicker than $0.1D$ because the plate thickness is based on the nominal pipe bore instead of the actual internal diameter. This deviation is of minor importance and hence it is ignored in the uncertainty estimates.

A second-phase accumulation affects both the effective cross-sectional area of the flow at the upstream pressure tapping and the fluid's velocity of approach factor $(1 - \beta^4)^{-1/2}$. Because the maximum beta ratio for a conical entrance orifice plate is limited to 0.316, the second-phase accumulations are never likely to affect flow metering accuracy by more than 5%, provided that there is a bleed hole.

In summing up, ignoring second-phase hold-ups, a rough guide is that orifice flow meters using orifice plates made in accordance with Fig. 4.2.9 should have $-55 \left[\frac{y}{d} \right]^2$ % extra uncertainty added arithmetically to the basic uncertainty of the flow coefficient because of the drain hole (12.2.1).

12.2.5 References

ISO 5167
BS 1042 (1964)
BS 1042 (1981)
Fluid meters, their Theory and Application, ASME (1971)
ANSI B 16.5

12.3 ORIFICE FLANGE DESIGNS

12.3.1 General

General orifice flange designs are intended to meet ISO 5167 requirements for all orifice plate flow meters, although the ISO standard applies only to square edge orifice plates.

The ISO standard has been chosen because it is internationally widely recognized.

Moreover it covers, and in some cases is more stringent than BS 1042 (1964) and ASME (1971) for quarter of circle and conical entrance plates. The practical realization of the recommendation with regard to geometry, method and operating conditions of ISO 5167, is given in this handbook. It shows recommended designs, and where the handbook deviates from the ISO standard, the reasons for the deviation are given.

The recommended flange designs covered in this section are those for flange tapped, corner tapped and radius tapped flanges.

Flanges of the welding neck type are recommended as a standard. Therefore, slip-on and ring-type joint flanges are not considered.

Radius tappings are considered only for existing installations, where the type of flange has already been chosen.

The alignment of the orifice plate within the pipe is determined by the location of the orifice plate within the flange's bolt circle. To keep the plate as near concentric as possible within the pipe, the plate's outer diameter is made as large as possible within the limits allowed by tolerances and differential expansion. Allowances are made for bolt hole tolerances, bolt tolerances, the number of bolts in the bolt circle – which affect the way the plate rests – pitch circle diameter tolerances and orifice plate diameter tolerances. The differential expansion of flange and plate allowed for is based on a stainless steel plate and low alloy carbon steel pipe components up to a temperature of 450 °C.

The result of these considerations is that at a temperature T °C an offset of about

$2.8 + \left[\frac{1.70}{600} \right] \cdot \left[\frac{450 - T}{430} \right]$ mm can exist between orifice centre line and the centre line of the upstream and downstream pipework. The actual eccentricities may vary slightly with pipe size and schedule number.

Comparison of the ISO 5167 orifice plate eccentricity e_x criteria, i.e. $e_x \leq \frac{0.005D}{(0.1 + 2.3 \beta^4)}$ and the difference between the discharge coefficients of the ISO 5167 flange tapped, concentric, square edge orifice plates and the ASTM flange tapped, eccentric orifice, indicates a rough linear change in discharge coefficient with orifice displacement over the full radius of the pipe. This simple linearity is perhaps particularly likely to be true for small ISO 5167 allowable displacements near the centre. On this basis, using the ISO 5167 recommendation when:

$\frac{0.0005D}{(0.1 + 2.3 \beta^4)} < e_x \leq \frac{0.005D}{(0.1 + 2.3 \beta^4)}$, a $\pm 0.3\%$ extra uncertainty should be added to the uncertainty in the flow meter's flow coefficient and noting the possible orifice plate eccentricity:

$$2.8 + \left[\frac{1.70}{600} \right] \cdot \left[\frac{450 - T}{430} \right]$$

it can be shown that the extra uncertainty due to orifice plate eccentricity is:

$$\pm \left[\frac{28}{D} + \left[\frac{17}{258\,000} \right] (450 - T) \right] (0.6 + 13.8 \beta^4) \%$$

This formula is based on a stainless steel orifice plate and low alloy carbon steel pipe and flanges for sizes $> DN\ 50$.

12.3.2 Flange tapped orifice flanges

12.3.2.1 ISO 5167 design requirements

These are covered in the following sections of ISO 5167:

6.5.3 "Location of primary device and rings"

6.5.4 "Fixing and gaskets"

7.2 "Pressure tapplings"

Fig. 3 "Spacing of pressure tapplings for orifice plates with D and D/2 or flange tapplings"

12.3.2.2 Recommended design

For pipes DN 50 to DN 600, the recommended design for flange tapped orifice flanges is given in Fig. 3.1.9.

This design is for welding neck, raised face flanges to fit pipework of schedule 20 to 160, as given in Table 14.2.1.

For pipes smaller than DN 50, the corner tapped flange shall be used only (12.3.3.2), otherwise the inaccuracy due to positioning of the tapplings becomes too large.

For pipes larger than DN 600, the design for flange tapped flanges could be based on BS 3381 or API 605 flanges using spiral-wound gaskets.

12.3.2.3 Explanation of and comments on the recommended design and its relation to ISO 5167

The design is suitable for flanges made of carbon steel, low alloy steel or stainless steel and fitted to carbon steel, low alloy steel or stainless steel pipework of schedule 20 to 160, with or without corrosion allowance.

The diameter of the pressure tapplings and their position with respect to the orifice plate are within ISO 5167 requirements. Note that the position of each pressure tapping is the sum of the distance between its centre line and the front of the flange's raised face, 22.0 mm (+0.2 mm, -0.0 mm) and the thickness of the compressed spiral-wound gasket 3.4 ± 0.25 mm. In total this is 25.4 mm (+0.45 mm, -0.25 mm).

The pressure seal is provided by the spiral-wound gaskets, which typically has an inner ring and outer ring.

The rings are 3.2 mm thick and the diameter of these standard rings is such that, considering tolerances on the rings, bolt circle, bolt holes and bolts, it may be so eccentrically positioned as to protrude into the pipe bore by up to 7% of the bore diameter.

The possible protrusion is partly dependent on pipe size and schedule number.

This gasket protrusion into the pipe affects the flow as if part of the orifice plate. The effective large discontinuity constitutes an orifice plate non-flatness and vastly exceeds ISO 5167 allowances.

Considering misalignment tolerances, the edge of an orifice with a beta ratio of 0.75 can be within approximately 0.105 D from the inner wall of the pipe. If a gasket protrudes 0.07 D, the distance between the edge of the gasket and the orifice throat is only 0.035 D, i.e. 3.5 mm on a 100 mm pipe.

A protrusion on the upstream side will alter the effective position of the upstream pressure tapping with respect to the orifice plate, the pressure build-up against the plate produced by velocity head and the profile of the flow through the orifice. A protrusion on the downstream side will probably not greatly affect flow metering.

As a rough estimate the uncertainty in the flow reading that will be caused by the upstream gasket's inner ring on a concentric orifice plate equals $\pm \beta^4\%$.

In summing up, orifice flow meters with flange tapplings made in accordance with Fig. 3.1.9 should have

$$\pm \left[\frac{28}{D} + \left[\frac{17}{258\,000} \right] (450 - T) \right] (0.6 + 13.8 \beta^4) + \beta^4 \% \text{ extra uncertainty added arithmetically to the basic}$$

flow coefficient uncertainty, because of practical limitations of the orifice flange design in meeting ISO 5167 requirements.

12.3.3 Corner tapped orifice flanges

12.3.3.1 ISO 5167 design requirements

These are covered in the following sections of ISO 5167:

6.5.3 "Location of primary device and rings"

6.5.4 "Fixing and gaskets"

7.2 "Pressure tapings"

Fig. 4 "Corner tapings"

12.3.3.2 Recommended design

For pipes smaller than DN 50, the recommended design for corner tapped orifice flanges is given in Fig. 10.1.9. Pipes smaller than DN 50 are not covered by ISO 5167, but the rules as given for pipes >DN 50 are followed as closely as possible.

The above design, using welding neck type flanges, is a complete meter run to give better control over tolerances on the small dimensions.

For pipes DN 50 to DN 600, the recommended design for corner tapped orifice flanges is given in Fig. 3.2.9.

The design is for welding neck type flanges to fit pipework of schedule 20 to 160, see Table 14.2.

Corner tapped flanges for pipes larger than DN 600 could be based on BS 3381 or API 605 flanges using spiral-wound gaskets.

12.3.3.3 Explanation of and comments on the recommended design and its relation to ISO 5167 and BS 1042 (1964)

1) Corner tapped orifice flanges for pipes smaller than DN 50, Fig. 10.1.9

The range of pipe sizes to which the flanges are fitted falls below the specified minimum of ISO 5167, i.e. those with a bore of 50 mm for the use of square edge orifice plates. A design for 40 mm pipework is still, as regards the pipe diameter, within BS 1042 (1964) limits if used with quarter of circle or conical entrance orifice plates.

In order to meet the ISO 5167 requirements as closely as possible, the flanges are designed with attached pipework as a meter run and made from stainless steel for better control of tolerances on the small dimensions.

Other non-corrosive material may have to be applied depending on the composition of the fluid medium.

The flow meters are made as prefabricated meter runs, rather than just flanges to be attached to pipework at site, to allow a boring through from flange to pipework.

This establishes a smooth, circular and step-free bore with a clearly defined dimension over more than the 10 diameters upstream and 5 diameters downstream of the flow meter, specified in ISO 5167/BS 1042 (1964).

Orifice plate and flange alignment is achieved by using a centering ring as detailed in item 8 of Fig. 10.1.9. This design deviates from ISO 5167 requirements on the position tolerances of the orifice plate.

The practical tolerances governing the position of the orifice plate are such that 0.5 mm can exist between the orifice centre line and the centre line of either the upstream or downstream pipework. This represents an eccentricity of 4.2% D, 2.9% D, 2.4% D or 1.6% D for DN 15, DN 20, DN 25 or DN 40 nominal diameter pipes respectively.

An extra uncertainty has to be added to the basic uncertainty as explained in section (12.3.1).

For a stainless steel meter run and a stainless steel orifice plate, which is recommended as a standard, no temperature effects have to be considered.

For the small diameter meter runs, the bore limits of the tapping holes as defined in 7.2.4.3 of ISO 5167 are too small.

By using a greater bore an additional uncertainty has to be added.

Therefore an approximation formula of $55\beta^9 \left[\frac{1.5}{D} \right] \%$ has been used to correct the influence of the tapping.

In summing up, it is estimated that orifice flow meters made according to Fig. 10.1.9 should have:

$\pm \left[\frac{5}{D} (0.6 + 13.8 \beta^4) + 59\beta^9 \left[\frac{1.5}{D} \right]^{1/2} \right] \%$ extra uncertainty added arithmetically to the basic flow coefficient uncertainty owing to failure of the orifice flange design to meet ISO 5167 requirements.

2) Corner tapped orifice flanges for pipes DN 50 to DN 600, Fig. 3.2.9

The design is suitable for the flanges to be made from carbon steel, low alloy steel or stainless steel and fitted to carbon steel, low alloy steel or stainless steel pipework of schedule 20 to 160, with or without corrosion allowance.

To provide a single pressure tapping right through each flange to the bore, as illustrated by ISO 5167, is impractical.

To provide a pressure tapping with an annular slot dimensioned as per ISO 5167/BS 1042 (1964) is not possible within the free metal available in each flange. Note that the flange designs to ANSI B 16.36, prohibit machining from the flange face into the body of the flange any deeper than 6.4 mm of the raised face. The ISO 5167 and BS 1042 annular slot dimensions could be achieved if a carrier ring were provided, but doing so would require considerable extra expense and complexity of construction which is not considered worthwhile.

The pressure tapping arrangement used approaches the ISO 5167 and BS 1042 (1964) annular slot design within the very limited material available in the flange's raised face. The design is aimed at being fairly cheap and simple to make, yet not easily fouled or modified by corrosion.

Since the width of the slot as it breaks through into the inside of the flange complies with ISO 5167, it probably does not cause a calibration shift. The inadequacy of the annular slot might produce noisy signals which, because of exponential averaging by the time constant of the impulse lines and the differential pressure transmitter, might cause some slight shifts in calibration. However, no extra uncertainty in measurement is attributed to this.

In summing up, orifice flow meters with corner tapings made in accordance with Fig. 3.2.8 should

have $\pm \left[\frac{28}{D} + \left[\frac{17}{258\,000} \right] (450 - T) \right] (0.6 + 13.8 \beta^4) \%$ extra uncertainty added arithmetically to the basic flow coefficient uncertainty, because of failure of the orifice flange design to meet ISO 5167 requirements.

12.3.4 Radius tapped orifice flanges

12.3.4.1 ISO 5167 design requirements

The upstream pressure tapings shall be at a distance $D \pm 0.1D$ from the upstream face of the orifice plate.

The downstream pressure tapping shall be at a distance $0.5D \pm 0.02D$ from the upstream face of the orifice plate when $\beta \leq 0.6$, or $0.5D \pm 0.01D$ from the upstream face of the orifice plate when $\beta > 0.6$.

The centre line of the pressure tapping shall be at a right angle to the pipe centre line.

At the point of breakthrough into the inside of the pipe, the pressure tapping shall be circular. The edges shall be flush with the internal surface of the pipe wall and be as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, a minimum rounding shall be permitted but it shall be kept to less than 10% of the pressure tapping diameter. No irregularity shall appear inside the connecting hole, on the edges of the hole drilled in the pipe wall, or on the pipe wall close to the pressure tapping.

The upstream and downstream pressure tapings shall have the same diameter.

The pressure tapings shall have diameters less than 12 mm, but not smaller than 6 mm.

The pressure tapings shall be cylindrical over a length of at least 2.5 times the diameter of the tapping measured from the inner wall of the pipe.

12.3.4.2 Recommended design

There is no drawing showing a recommended pressure tapping arrangement.

Recommended design follows the ISO 5167 requirements referred to above together with additional special requirements specified below:

- 1) In horizontal pipes the upstream and downstream pressure tapings shall be at the same height with regard to the horizontal.
- 2) Radius tapings shall not be used on pipes smaller than DN 200 if the flanges are of the slip-on type.
- 3) Radius tapings shall not be used on pipes smaller than DN 400 if the flanges are of the welding neck type.
- 4) If the pipework already contains pipe flanges which are to be used to hold the orifice plate needs to be shortened before it can accept the orifice plate and extra gasket, it shall be shortened at a plane at least 4D downstream of the chosen orifice plate position.

12.3.4.3 Explanation of and comments on the recommended design and its relation to ISO 5167

Whether the orifice plate is held by slip-on or welding neck flanges, the upstream pressure tapping is located at a distance "a" from the upstream neck of the flange, and the downstream pressure tapping at a distance "b" from the downstream neck of the flange. Since the upstream tapping is at a distance D from the orifice plate and the downstream tapping at a distance D/2 from the plate, "b" is always smaller than "a". The minimum pipe sizes on which radius tapings can be used in practice is determined by the need to keep "b" large enough for the welding around the pressure tapping nipple not to interfere with the welding at the end of the flange. For this reason this tapping arrangement can be used only on DN 200 and larger pipe if slip-on flanges are used and only on DN 400 and larger pipe if welding neck flanges are used.

If the pipe flanges used to hold the orifice plate were sealed with compressed asbestos fibre (CAF) gaskets before the orifice plate was introduced, it still needs sealing with CAF gaskets at both ends of the plate when the plate is installed. The maximum gasket thickness of 1 mm needs allowing for when positioning the pressure tapings. CAF gaskets do not interfere with the performance of the flow meter.

It should be noted that the non-shaded area of the orifice plate shall have the same finish as the flanges in order to allow of the use of CAF gaskets.

If the pipe flanges used to hold the orifice plate were sealed with spiral-wound gaskets, a standard orifice plate can be used (3.1.8).

The 3.2 mm thickness of spiral-wound gasket rings needs to be taken into account when considering positioning of the pressure tapings. The gasket is positioned by the flange bolt circle. With tolerances on the ring, bolt circle, bolt holes and bolts the gasket can be so eccentrically positioned that its inner ring can protrude into the pipe bore by up to 7% of the bore diameter (12.3.2.3).

Gaskets protruding into the pipe are presented to the flow as if part of the orifice plate. The effective large discontinuity which they produce on the faces of the orifice plate constitutes orifice plate non-flatness.

A protrusion on the upstream side of the plate alters the effective position of the pressure tapping, but the tapping is so far upstream of the region of plate impact pressure build-up as to make no difference to the accuracy of metering. Gaskets protrusion on the downstream side of the plate has probably also no significant effect on metering accuracy.

The close proximity of the inner ring to the orifice will affect metering. It will affect the flow profile as it passes through the orifice. As a rough estimate the uncertainty in the flow reading that will be caused by spiral-wound gaskets with inner ring equals $\pm \beta^4\%$.

In summing up, orifice flow meters using radius tapings as described in section (3.3) should have

$$\pm \left[\frac{28}{D} + 0.7 + \left[\frac{17}{258\,000} \right] (450 - T) \right] (0.6 + 13.8 \beta^4) + \beta^4 \% \text{ extra uncertainty added arithmetically to the}$$

basic flow coefficient uncertainty, because of failure of the design to meet ISO 5167 requirements.

12.3.5 References

ISO 5167

BS 1042 (1964)

Fluid meters, their Theory and Application, ASME (1971)

BS 3381

API 605

ANSI B 16.36

12.4 SPECIFICATION OF PIPEWORK UPSTREAM AND DOWNSTREAM THE FLOW METER

12.4.1 General

ISO 5167 specifies that the pipework upstream and downstream of the flow meters should meet certain conditions of smoothness, circularity and consistency of bore diameter and length. The requirements for the various types of ISO 5167 flow meters are different, as are the requirements for BS 1042 (1964) types.

The specification of pipe generally used in plants is in certain aspects so unpredictable that achieving formal flow metering requirements, such as those of ISO 5167, is very difficult. However, experience has shown that adequate metering for a given application can often be achieved by coming close to, but not quite meeting, the standard requirements. As a consequence, in the interest of cost effectiveness many flow metering installations are installed of which the straight lengths do not quite meet these conditions over the whole length.

Where necessary, e.g. for custody transfer applications, the full standard requirements should of course be fulfilled accepting the high cost involved in meeting these stringent requirements.

12.4.2 Pipework specification for orifice flow meters and nozzles

12.4.2.1 ISO 5167 pipework specification

The actual straight length required upstream and downstream of differential pressure flow meters for a particular type of flow meter of given beta ratio, is stated in section (11.4).

The minimum ISO 5167 acceptable conditions of circularity, smoothness and consistency of pipe bore for the "straight length" pipework installed are given below.

Strictly speaking, the ISO 5167 conditions for orifice plates apply only to the use of square edge types, but they can be taken as the minimum "ideal requirement" for the use of quarter of circle and conical entrance plates as well. The reason for this is that ISO 5167, which does not cover quarter of circle and conical entrance plates, is much more specific in this aspect than BS 1042 (1964). Also in practice it is not unthinkable that any quarter of circle or conical entrance plate may be replaced by a square edge plate at a later stage. It is therefore desirable that the pipework should meet the requirements of that latter condition.

The following ISO 5167 rules apply:

- 1) The length of the upstream pipe section adjacent to the orifice plate shall be cylindrical for a length of at least $2D$.

The pipe is said to be cylindrical when no diameter in any plane differs by more than 0.3% from the value of D as used in the computation of diameter ratio.

The mean value of D used for computation of diameter ratio is the mean of the internal diameter of the pipe over a length of $0.5D$ from of the upstream pressure tapping. The mean diameter D is the arithmetic mean of the measurements at four diameters at least, distributed in each of at least three cross sections being at distances $0 D$ and $0.5D$ from the upstream tapping.

- 2) Beyond $2D$ from the orifice plate to the upstream limit of the straight length measured from the orifice plate, (11.4), the pipe can be made of one or more sections, but the following shall be taken into account:

If a step (h) between any two sections of pipe does not exceed $\pm 0.003 D$, the step size is within the limits of ISO 5167 acceptability, and no "additional" uncertainty in the discharge coefficient (C) has to be considered when calculating the overall uncertainty of flow measurement of the flow meter (13).

If the step (h) between any two sections exceeds $\pm 0.003 D$ but is less than or equal to

$0.002D \left[\frac{s/D + 0.4}{0.1 + 2.3 \beta^4} \right]$ with a maximum of $\pm 0.05 D$, where s is the distance of the step from the upstream pressure tapping, the step size is within the limits of ISO 5167 acceptability, but an "additional uncertainty" of $\pm 0.2\%$ in the discharge coefficient (C) has to be accounted for when calculating the overall uncertainty of flow measurement of the flow meter.

If the step (h) is larger than the requirements stated above, the metering installation is outside the limits prescribed by ISO 5167. (See section 6.5.1.3 of ISO 5167.)

- 3) No diameter of the downstream straight length, considered over a length of at least $2D$ from the upstream face of the orifice plate, shall differ from the mean bore D by more than $\pm 0.3\%$. This can be judged by the check of a single diameter of the downstream straight length.
- 4) The acceptable roughness of the pipe depends on the pressure tapping configuration and beta ratio of the orifice plate (sections 6.6.2, 7.3.1 and 8.1.6.2 of ISO 5167).

12.4.2.2 The recommended pipework specification

The flanges and pipework, which combined form upstream and downstream the "straight lengths" of the flow meter, are usually made from standardized commercially available parts. The standards to which these parts are made, are produced to fulfill pipe requirements and so specify dimensions much more loosely than is required for ISO 5167 types of flow meter, in particular orifice flow meters.

Pipes are in general made to the American National Standards Institute (ANSI) for which, depending slightly on pipe size and class, the tolerance on the reference outside diameter is about $\pm 1\%$, including out-of-roundness, and the tolerance on pipe wall thickness is about $+15\%$, -12.5% .

Tolerances of other standards, e.g. DIN, are similar.

From the ANSI specification it is clear that finding a length of pipe that meets the ISO 5167 maximum out-of-roundness condition of $\pm 0.3\%$ for the orifice flow meters, will involve a long search through stock. Meeting the ISO 5167 maximum allowable step in the pipe's inside wall condition appears to be somewhat easier, since choosing a close to worst case example of 4 inches, schedule 160 pipe, the maximum step that can occur resulting from the ANSI tolerances is about $+4.9\%$. Such a step is within ISO 5167 limits if placed far enough away, about $24 D$ upstream, $8 D$ downstream, from even the most step-sensitive orifice plate – a square edge type of 0.8 beta ratio.

The principal difficulty is providing straight lengths with no larger than ISO 5167 acceptable steps in the pipe bore, when welding neck flanges are used. The upstream pipe/flange joint occurs in a very sensitive region where the ISO 5167 specification is highly restrictive because of the close proximity to the orifice plate and, for flange and corner tapplings, the close proximity to the pressure tapplings. When radius tapplings are used the downstream pressure tapplings are also in a very sensitive position namely just downstream of the downstream flange/pipe joint.

If slip-on flanges were to be used, the problem would hardly exist because the joint between flange and pipe only breaks into the bore right up against the orifice plate. However, the location of this joint and weld prevents the use of corner tapplings and in addition in many cases has proved to be potentially dangerous because of corrosion between flange and pipe caused by fluid from the pressure tapping where it breaks through the pipe. Because of this and the desirability of standardizing on the use of welding neck flanges, slip-on flanges are not promoted and hence not further discussed in this handbook.

The overall smoothness, or roughness, of ANSI specified pipe is usually within ISO 5167 specified limits.

From the above it is evident that making orifice flow meters with straight lengths within the limits of circularity and smoothness as specified by ISO 5167 cannot be done from parts randomly selected from ANSI line pipes and flanges. In general, a compromise has to be made between the cost of a flow meter and the need for it to be accurate. This compromise is reflected in the recommendations as laid down below.

The requirements for orifice flow meters fall within one of the following designs, depending on pipe size and application.

1) Pipes smaller than DN 50

The pipe specification is governed by the standard specification for the piping class and material, usually ANSI.

For a typical assembly of the small-diameter meter run, see (10.1.9).

Orifice flow meters smaller than DN 50 are used only for general applications, not for custody transfer applications.

Nozzles should not be used in pipes smaller than DN 50.

2) Pipes of DN 50 and larger for custody transfer applications

The pipe specification is governed by ISO 5167. It is recommended to buy meter runs made by specialist manufacturers to meet these requirements.

3) Pipes of DN 50 to DN 300 for general applications, see (10.1.10)

In order to obtain meter runs within or close to the ISO specification for pipes DN 50 to DN 300, it is recommended to buy pipes for these sizes complete with orifice flanges made by specialist manufacturers.

Considering price, transportation and ISO tolerances for out-of-roundness and maximum step in D, the length of the upstream pipe is set at 24D with a maximum of 6 m (standard length of pipe) and the length of the downstream pipe is set at 8D.

4) Pipes larger than DN 300 for general applications

For pipes of DN 300 and larger it will usually be more practical to have the meter runs fabricated locally, selecting pipe with the highest roundness figure, as available in stock, and fabricated as described in (11.5).

12.4.2.3 Explanation of the recommended pipework specification and its relationship to ISO 5167

1) Pipes smaller than DN 50

The meter run of (10.1.9) covers about 33D upstream and 13D downstream from the orifice plate. Up to about 30D upstream and 10D downstream from the plate the bore is uniform and in accordance with ISO 5167. It is then coned up at 20 degrees, just before the plant flanges, to match the nominal bore of plant pipework. The cones, equivalent to the reducers and expanders specified in ISO 5167 are at an ISO 5167 acceptable distance from the plate, so do not require a modification to the basic uncertainty of the flow meter's discharge coefficient.

Beyond the limits of the meter run, the pipe bore is covered by the standard pipe specification, usually ANSI, and the accuracy with which the pipe is flanged for the meter run. The tolerances on these are within ISO 5167 requirements because they are sufficiently far removed from the orifice plate.

2) Pipes of DN 50 and larger for custody transfer applications

It is recommended to follow the ISO 5167 requirements.

3) Pipes of DN 50 to DN 300 for general applications

It is recommended to follow the ISO 5167 requirements for the pipework of 24D upstream with a maximum of 6 m and 8D downstream.

4) Pipes larger than DN 300 for general applications

Section (11.5) describes how a meter run could be prepared locally.

This practical specification relates to ISO 5167 requirements as follows:

The upstream straight lengths as recommended by this handbook, shall be in agreement with ISO 5167, starting from the orifice plate. For the length of the upstream flange, the upstream "pipe" is bored out as specified in the relevant drawing and meets ISO 5167 requirements. Unfortunately for

flow metering the flange extends only between about $D/3$ and $2D$ from the orifice plate, depending on pipe size and piping class so that a joint has to be made to a piece of pipe within this distance.

The fabrication procedure should control this joint to the best practical limit but it can still result in an ISO 5167 unacceptable step of up to $\pm 0.01 D \pm 0.2 \text{ mm}$ in the "pipe" bore at this point and an excessive roughness resulting from the weld.

It is assumed that a piece of standard pipe can be selected locally (11.5), which is smooth inside and has a maximum out-of-roundness of $\pm 1\%$. The smoothness will usually meet ISO 5167 requirements but the out-of-roundness may not (Note: ISO 5167 specifies a maximum out-of-roundness of $\pm 0.3\%$). The length of "Section 2" as shown in Fig. 12.5 shall be as long as possible up to a maximum of 6 metres taking into account the handleability in the workshop and transportation.

The length of pipe described as "Section 1" in Fig. 12.5 needs only to comply with the specification of standard pipework, e.g. the ANSI specification, for the relevant piping class at the distance $8D$ from the orifice plate. This is within the ISO 5167 requirements.

The possible magnitude of the step at joint marked $1/2$ is governed by the standard pipework specification and, depending on pipe size and piping class, can be up to about $0.05 D$. Such a step can just be allowed within the limits of ISO 5167 if placed far enough away from the orifice plate.

The length of "Section 2" (Fig. 12.5) as laid down in (11.4) can for practical reasons not be great enough to fulfil all straight length conditions but, if the length of "Section 2" has been made as large as possible, the more commonly encountered smaller steps that may occur at the joint $1/2$ can be accommodated.

The actual situation governing whether the possible step at joint marked $1/2$, resulting from pipe tolerances, will or will not meet ISO 5167 requirements is a complicated function of orifice plate, beta ratio (11.4), pipe size, pipe specification (e.g. ANSI B 16.36) and schedule number (e.g. ANSI B 16.36).

Considering the downstream straight length (11.4), the ISO 5167 tolerance on the "pipework" is sufficiently large that the practical requirements embodied in the relevant flange drawing, pipe code, and the fabrication procedure of (11.5) fulfil all aspects.

It should be noted that the procedure of (11.5) describes the fabrication of meter runs which for some applications will completely fulfil the full straight length requirements (11.4). In such situations the possible unacceptability of joints marked $1/2$ and $5/6$ (Fig. 12.5) in accordance with ISO 5167 as commented on above do not apply of course.

Most of the generally specified orifice flow meter installations encountered in practice may have straight lengths of pipework which fail to meet in full the ISO 5167 conditions.

This will almost always be so because of the joint marked $2/3$ and the circularity of "Section 1" (Fig. 12.5), but may also be so because of joints marked $1/2$ and $5/6$, (Fig. 12.5).

The provision of straight lengths for general application as described in this section limits this discrepancy as far as thought practically possible, but the consequence in terms of metering accuracy and repeatability, is unknown in precise terms. General experience, however, suggests that the discrepancy does not cause much difference in metering.

The ISO 5167 specifies that an extra uncertainty of $\pm 0.2\%$ in the flow coefficient should at least be added in the flow calculations. This to account for what shall generally be assumed to be greater than the minimum allowed irregularities at joints marked $1/2$, $2/3$ and $5/6$ (Fig. 12.5). Particularly at joint marked $2/3$, these irregularities may even be larger than those allowed by ISO 5167.

To allow for the fact that in practice orifice plates and nozzles made for general use to the specification as described in this section fall short of the ISO 5167 requirement for circularity and regularity, an extra $\pm 0.4\%$ uncertainty should be added to the basic flow coefficient uncertainty.

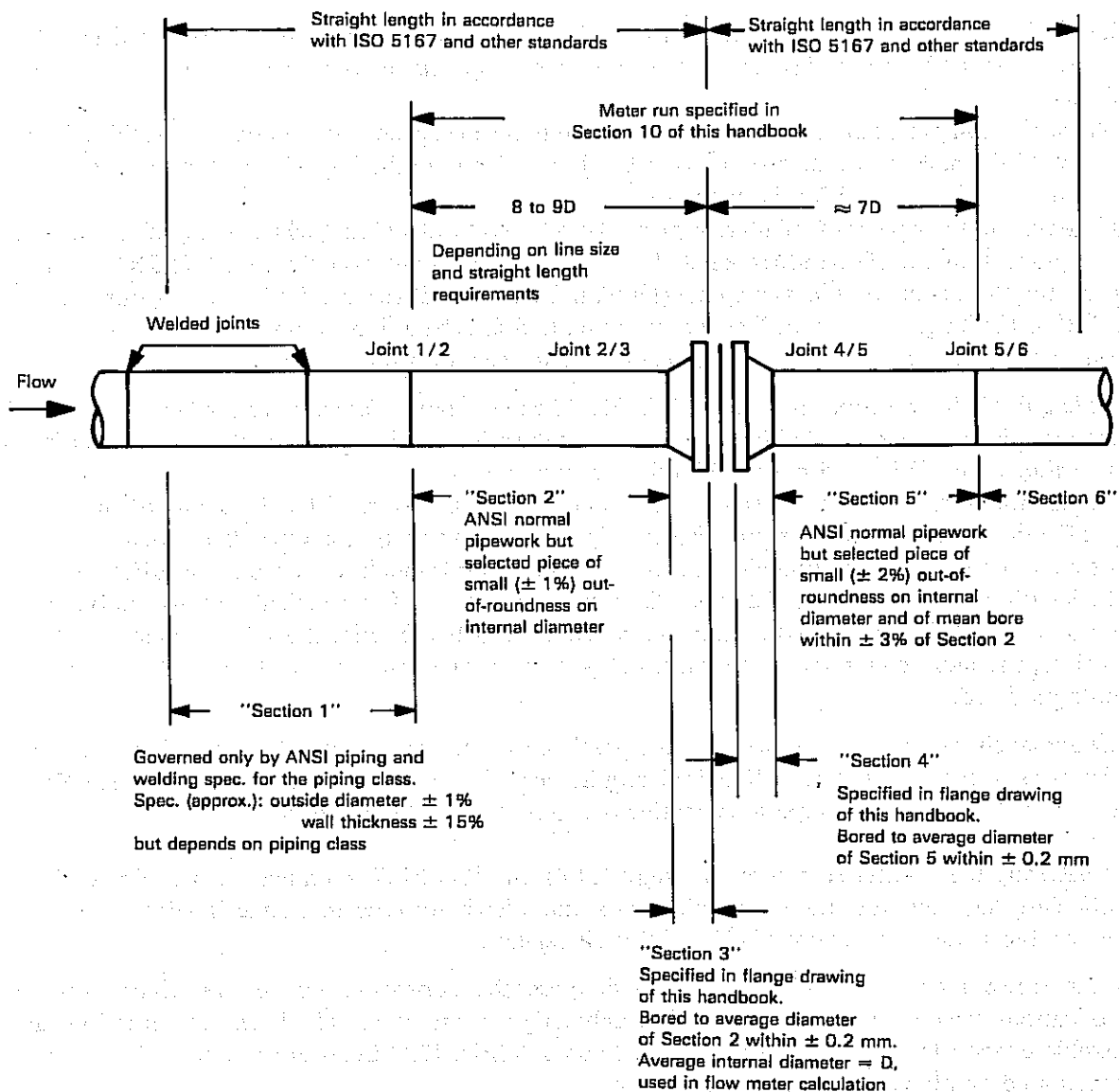


Fig. 12.5

12.4.3 Pipework specification for classical Venturi flow meters

12.4.3.1 ISO 5167 design requirements

The minimum ISO 5167 acceptable conditions of circularity, smoothness and consistency of pipe bore for the "straight length" pipework installed upstream and downstream of the Venturi tube are given below. The straight lengths required for a given beta ratio and disturbing influence are given in (11.4).

The ISO 5167 requirements are as follows:

- 1) Over an upstream length of at least $2D$ measured from the upstream end of the entrance cylinder of the Venturi tube, the pipe shall be cylindrical.
The pipe is said to be cylindrical if no individual measurements of diameter differ by more than $\pm 2\%$ from the mean of many measurements of diameter.
- 2) The mean diameter of the upstream pipework, where it joins the Venturi tube, shall be within $\pm 1\%$ of the Venturi's entrance cylinder diameter.
The mean diameter is calculated as per (12.4.2.1) item 1.

- 3) The mean diameter of the downstream pipework, where it joins the Venturi tube, shall not be less than 90% of the end of the Venturi's divergent outlet.
- 4) The upstream pipe shall have a roughness of $k/D \leq 10^{-3}$ over a length of at least $2D$ measured upstream from the Venturi tube.
- 5) The difference between the centre lines of the upstream pipe and of the Venturi tube as measured in the connecting plane of the upstream pipe shall be less than $0.005D$
- 6) The angular alignment uncertainty of the upstream pipe centre line with respect to the Venturi tube centre line shall be less than 1 degree.
- 7) The sum of the offset (see 5 above) and half the range of the individual measurements of diameter of the upstream pipework shall be less than $0.0075D$.

12.4.3.2 *The recommended pipework specification*

The ANSI pipe specification, but with smoothing of the internal diameter of the pipe/flange joints, satisfies the pipe requirements for the upstream and downstream length for a Venturi tube.

The pipe specification is governed by:

- 1) The standard specification for the piping class and material, usually ANSI B 31.3.
- 2) The standard specification for pipe preparation for welding and welding of pipe and flanges, e.g. B 16.25 and ANSI B 31.3.

The ability to follow the ISO 5167 requirements more closely for a classical Venturi than for a field fabricated orifice meter run should be an advantage for contractual arrangements. However, the Venturi meter cannot easily be adapted to changing parameters in the flow conditions and is therefore less practical.

12.4.3.3 *Explanation of the recommended pipework specification and its relationship to ISO 5167*

The bore of the pipe flange which bolts to the upstream side of the flow meter, and the flow meter's entrance cylinder, both of which are made to the nominal bore of the pipe (schedule number accounted for), will meet within the $\pm 1\%$ required by ISO 5167. The tolerance on standard pipe, typically $\pm 1\%$ on mean outside diameter, $\pm 1\%$ on ellipticity and $\pm 15\%$ on wall thickness, will mean that individual measurements of diameter near the neck of the flange and the end of the pipe will not always meet within $\pm 2\%$ of the flange bore. Since welding neck flanges vary in length relative to pipe bore from about $2D$ to $D/8$, the ISO 5167 requirement for a cylindrical section of conduit for $2D$ upstream of the flow meter will hardly ever be fulfilled. The case will usually be worse for the large-diameter, and higher schedule pipes. If the bore is not smoothed out, it is estimated that an extra $\pm 0.2\%$ uncertainty should be added arithmetically to the flow meter's uncertainty of discharge coefficient for failure to meet these conditions.

12.4.4 References

ISO 5167
 BS 1042 (1964)
 ANSI B 31.3
 ANSI B 16.25
 ANSI B 16.36

12.5 UPSTREAM AND DOWNSTREAM STRAIGHT LENGTHS REQUIREMENTS

12.5.1 General

Fluid flow through a pipe has different velocities at different points across the cross section of the pipe.

Almost an infinite variety of velocity patterns of the fluid elements may exist. A flow meter installed in the pipe to measure the total flow, responds in a different way to every one of them. For a flow meter to be useful it should be designed to be maximally sensitive to the total mean flow velocity through the conduit and minimally sensitive to the individual velocity components of the different fluid elements. However, for most of the flow meters the physical limitations are such that this design objective cannot be achieved very well. It is therefore important to define specifically the flow velocity distribution over the cross section of the pipe for which the flow meter has been designed in terms of velocity, range linearity, velocity angle, etc., in order to meet a specific repeatability and accuracy.

All flow meters described in this handbook are designed and specified for use on fully developed regular flow patterns which occur in a fluid after it has passed through a long straight length of conduit of uniform cross section and roughness. The performance of some flow meters, e.g. large β ratio orifice flow meters, changes considerably if not presented with a fully developed flow pattern.

The performance of other types of flow meters, e.g. positive displacement meters, are hardly affected at all.

Any deviation from a long straight conduit of uniform cross section and roughness will disturb the flow. It takes time, following a disturbance, for the flow to regain its fully developed state. Since this time interval is generally inversely proportional to the fluid's mean flow velocity along the conduit, the flow dependent time interval can be interpreted as a particular fixed distance downstream of the disturbing influence.

It is difficult to predict how far downstream the effects of a disturbing influence are still reflected in a deviation of the flow from a fully developed condition. The distance depends on:

- how much of the total flow was affected by the disturbance (e.g. a bend affects the total flow, a thermowell affects only part of it)
- the nature of the disturbance (e.g. swirling, as produced by two bends in different planes, or jetting, as produced by flow through a partially closed gate valve)
- the physical nature of the flowing fluid (e.g. its viscosity, density) etc.

The effects of a disturbing influence decrease in a roughly exponential way, so that there is a difficulty in defining at what point the disturbance can be said to have ceased.

Given that it is not always possible to present a flow meter with a fully developed flow, the question of interest to a flow meter user is to what extent the performance of the instrument he wishes to use deviates from that in an ideal installation. The main difficulty, as described above, is to define the fluid dynamic disturbances which result from a disturbing influence, how long these take to decay to an acceptable level, and the flow meter's different sensitivity to different types of disturbance.

For the "every-day user" this is solved by applying the "required minimum straight pipe lengths" necessary to achieve the flow profile in accordance with the flow meter's specification for use on fully developed flow. Shorter minimum straight length requirements may also be available for which the flow meter will perform with a specified reduced accuracy and repeatability.

The "required minimum straight lengths" refer to the necessary length of pipe of constant cross section and roughness upstream and downstream a particular flow meter to meet its stated performance. The pipe's cross section shall be the same as the entrance to the flow meter and no obstructions, e.g. misaligned pipe sections, protruding gaskets, oversized pressure tappings, nozzles or thermowells within these lengths of pipe should be allowed to disturb a flow's tendency to become or stay fully developed.

All minimum straight length requirements are based on experimental measurements and for the greater part they have only been tested in practice for a few single fixtures, e.g. a single gate valve by a particular manufacturer in close proximity to a few particular types of flow meter. The result of this is, for example,

that installing a particular design of orifice flow meter at the book-stated distance downstream of a half open gate valve is no guarantee that the flow meter will perform as specified. It does, however, greatly increase the probability that it will do so.

Besides the weaknesses of these fairly directly proven requirements, there is the question of how much the influence of disturbances upstream of the one before the flow meter, has an effect on the flow meter's performance. Only a few tests have been done in this field and so correspondingly, the rules which have been formulated to predict whether or not good flow metering can be obtained by using a particular configuration, are even less precise.

The result is that incomplete, sometimes conflicting rules are formulated in the standards, which need a careful consideration and cannot be applied without knowledge of the underlying data.

To alleviate this problem tables have been included (11.4.2 and 11.4.3) showing, based on ISO 5167, the minimum straight length requirements for different types of differential pressure flow meters expressed in multiples of D.

The values without brackets are values for a "zero additional uncertainty".

The values between brackets are values for an "additional uncertainty of $\pm 0.5\%$ ".

It is highly recommended to use the values related to a $\beta = 0.7$ in order to obtain full flexibility for re-sizing the orifice plate at a later stage.

The requirements for other types of flow meters, e.g. vortex, electromagnetic, ultrasonic, etc., differ considerably from one manufacturer to another, so that it is not easy to offer general comments. For each proprietary product the manufacturer's installation instructions must be followed – firstly because they should be correct and secondly because he "guarantees" the performance of his instrument to the specification he quotes only if his installation instructions are complied with.

Some very general comments on the straight length requirements of the different types of flow meters are given below.

(These comments should take second place to manufacturer's advice.)

Vortex meters: Usually have straight length requirements very roughly like those of a 0.4 beta ratio orifice plate.

Electromagnetic flow meters: Are usually satisfied by very short straight lengths, e.g. 5D upstream, 2D downstream.

They are designed by using a symmetrical electromagnetic field to be very insensitive to axially symmetric flow distortions, e.g. swirling flows, such as produced by two 90° bends in different planes.

Ultrasonic leading: Single-beam types usually have straight length requirements similar to those of a 0.75 beta ratio orifice plate.

Double-beam types usually require straight lengths similar to those of a 0.5 beta ratio orifice plate.

4-beam types usually require straight lengths similar to those of a 0.2 beta ratio orifice plate.

Turbine meters: They are very sensitive to swirl and should preferably be used with a swirl removing type flow straightener, e.g. a tube bundle placed at least 10D upstream.

Positive displacement meters: Do not require straight pipe upstream or downstream of the meter since they are usually insensitive to flow profiles.

Coriolis flow meters: Do not require straight pipe upstream or downstream of the meter since they are usually insensitive to flow profiles.

Insertion flow meters
(of any type; e.g.
Pitot annubar,
Pitot Venturi,
vortex, Agar turbine)
for total flow
measurement:

Should generally be given at least the same straight lengths as a 0.8 beta ratio orifice plate.

The more of the total flow the flow meter samples, the more accurate and repeatable should be the inference of the total flow.

Thus, in a large pipe a 100 mm insertion vortex meter should give better results than a Pitot tube. The smaller the flow meter relative to pipe diameter, the greater the need for long straight lengths.

12.5.2 Recommended straight lengths for differential pressure type flow meters

The tables in section (11.4) give the minimum recommended straight lengths for:

- 1) A square edge orifice flow meter with corner, flange, radius, or pipe tapings.
A quarter of circle orifice flow meter with corner or flange tapings.
A conical entrance orifice flow meter with corner tapings.
- 2) Eccentric orifice flow meter.
- 3) Segmental orifice flow meter.
- 4) ISA 1932 nozzle.
- 5) Long radius nozzle.
- 6) Venturi nozzle.

The following shall be taken into account:

- 1) For all orifice flow meters, except those used with pipe tapings, the distances shall be measured from the upstream face of the orifice plate.
- 2) For orifice flow meters used with pipe tapings, the upstream distance shall be measured from the upstream pressure tapping (i.e. 2.5D upstream of the orifice plate) and the downstream distance from the downstream pressure tapping (i.e. 8D downstream of the orifice plate).
- 3) For nozzles the upstream and downstream distances shall be measured from the upstream face of the nozzle.
- 4) For beta ratios that lie between adjacent values in the table, the straight lengths required for the higher of the two flanking values shall be used.
- 5) For installations in which both upstream and downstream straight lengths are equal to or, preferably, greater than the unbracketed values shown in the table, no additional uncertainty needs to be added to the uncertainty in the flow meter's discharge coefficient C.
- 6) For installations in which either the upstream or downstream straight length is equal to or, preferably, greater than an unbracketed value shown in the table but the other straight length is less than the unbracketed value but equal to or, preferably, greater than the bracketed value, an additional uncertainty of $\pm 0.5\%$ shall be added to the uncertainty in the flow meter's discharge coefficient C.
- 7) If both the upstream and downstream straight lengths are equal to or less than the bracketed values shown in the table, the metering installation fails to meet ISO 5167. The uncertainty of the discharge coefficient C cannot be predicted then with certainty and depends on the deviation from the ISO 5167 requirements.

12.5.3 Straight length for the pipework between the second and subsequent upstream fittings and between the first and subsequent downstream fittings

On the upstream side of the flow meter, this means the distances L_{U3} , L_{U4} , etc. and on the downstream side of the flow meter the distances L_{D2} , L_{D3} , etc. (see Fig. 12.6 below).

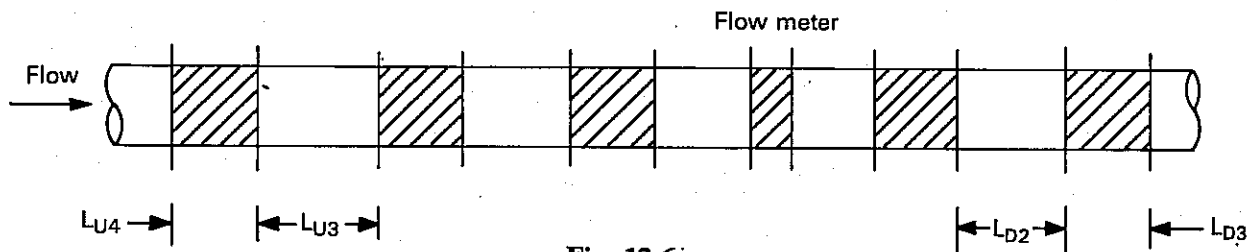


Fig. 12.6

It is a logical extension of the arguments given in (12.4.2.2) to say that the straight lengths between the second and subsequent upstream fittings L_{U3} , L_{U4} , etc., and the first and subsequent downstream fittings L_{D2} , L_{D3} , etc., should be specified.

However, national or international standards do not specify these lengths, so, although in reality inadequacy of these lengths should influence the flow reading, no official guidance is given and in fact no reliable experimental results are available to quantify the matter.

In spite of this, a general consideration of fluid dynamics and plant pipework can allow of the formulation of the following guiding requirements to aid the installation of all types of differential pressure in real plants:

1) At the downstream side of the flow meter:

Any fitting or group of fittings can be placed at any spacing L_{D2} , L_{D3} , etc., downstream of the first downstream fitting without influencing the uncertainty of the flow meter's discharge coefficient C .

The justification for this is implied in ISO 5167 for the specification of the downstream length L_{D1} to the first fitting, which is dependent only on the flow meter's beta ratio and not on the type of fitting. In general, any fluid dynamic disturbance affects only a flow for a short distance upstream.

2) At the upstream side of the flow meter:

If two or more fittings exist within $50D$ or less upstream of the first upstream fitting, an additional uncertainty of $\pm 0.5\%$ should be added to the uncertainty of the flow meter's discharge coefficient C .

The justification for this is implied in the BS 1042 (1964) specification for distance between the first and second upstream fittings.

Two or more fittings upstream of the first constitute "any other fitting" in terms of Table 8 of clause 47 of BS 1042 (1964).

As a general rule, if there are several fittings which should be placed in the vicinity of the second upstream fitting, they should be kept as far upstream as possible from it. If plant conditions dictate that they cannot be placed far upstream of the second upstream fitting, then every reasonable attempt should be made to allow as long a length of pipework as possible for the distance L_{U2} between the first and second upstream fitting, and L_{U1} between the flow meter and first upstream fitting.

12.5.4 References

ISO 5167
BS 1042 (1964)

Section 13. Uncertainties

- 13.1 Understanding a differential pressure flow meter's output reading
- 13.2 The accuracy of differential pressure flow meters over their meter range
- 13.3 The uncertainty of flow measurement
 - 13.3.1 General discussion
 - 13.3.2 Estimation of uncertainties in the measurement of flow rates using differential pressure flow meters in accordance with ISO 5167 and BS 1042 (1964)
 - 13.3.3 Discharge coefficient C for orifice and nozzle flow meters
 - 13.3.3.1 Installation in accordance with ISO 5167 and BS 1042 (1964)
 - 13.3.3.2 Installation as per recommended design
 - 13.3.3.2.1 $\delta C / C$ for square edge orifice plates
 - 13.3.3.2.2 $\delta C / C$ for quarter of circle and conical entrance orifice plates
 - 13.3.3.2.3 $\delta C / C$ for nozzle flow meters
 - 13.3.4 Discharge coefficient C for Venturi flow meters
 - 13.3.4.1 Installation in accordance with ISO 5167
 - 13.3.4.2 Installation as per recommended design
 - 13.3.5 Expansion factor
 - 13.3.6 Upstream D
 - 13.3.7 Throat d
 - 13.3.8 Differential pressure (dp)
 - 13.3.9 Density
- 13.4 Typical uncertainties
- 13.5 Guide to the effects of a departure from the standards
- 13.6 References

13.1 UNDERSTANDING A DIFFERENTIAL PRESSURE FLOW METER'S OUTPUT READING

The output signal of a flow meter, measuring the differential pressure across the flow measuring device, becomes meaningful only when the accuracy is known with which this output signal corresponds to a particular flow rate. One procedure for obtaining this knowledge is to note the output reading, calculate the corresponding flow rate q taking into account all relevant factors, and to estimate the likely uncertainty δq in the calculated flow rate by taking account of the uncertainty with which each factor is known.

This procedure is tedious and holds for one output value only.

The number of factors that influence a flow measurement are many since in practice the output reading of a flow meter is affected by each element of the installation, such as orifice plates, impulse lines, differential pressure measuring instruments, square-root extractor (if used), signal transmission system (if used) and output display, and also the dynamic properties of the fluid. It is almost impractical to include in an estimate of the flow meter's accuracy, terms relating to all these quantities. A more handsome solution is to specify design tolerance limits and installation conditions. If obeyed, they ensure, within a high probability, that all flow meters designed and installed in accordance with the specification are at least within calculable limits of uncertainty. In such cases the residual differences between individual instruments can be attributed to a few quantities which greatly affect the flow meter's performance or depend on unspecified aspects of its use. For example, the pipe bore and orifice or throat diameters are of overwhelming importance and can be specified as part of the design. How the fluid's density, expansibility and the flow meter's differential pressure output are determined is not specified, nor how the accuracy of their determination also affects the overall accuracy of the flow reading.

When the flow meter and its installation are as specified, the flow rate q and a good estimate of the uncertainty in flow rate δq provide the estimate of the flow rate as: $q \pm \delta q$.

It should be stressed that, although it is common practice to quote a flow rate as q (kilograms per second or tons per day), this is in fact meaningless unless also accompanied by an estimate of the probable uncertainty δq .

13.2 THE ACCURACY OF DIFFERENTIAL PRESSURE FLOW METERS OVER THEIR METER RANGE

Although in practice the flow rate q through a differential pressure flow meter is taken as directly proportional to the square root of the differential pressure:

$$q = K \sqrt{dp} \quad (K = \text{constant}),$$

is this statement not strictly valid, even if the specification of design and range of application are carefully chosen. The ISO 5167 recommendation which includes design tolerances to give a calculable estimate of uncertainty in the flow rate, assumes that $K = K' \cdot C \cdot \epsilon$, where C and ϵ can themselves both be functions of the flow rate and K' is constant. In particular square edge orifice and nozzle flow meters (for which the discharge coefficient is a function of the Reynolds Number) and any differential flow meter working on gas (for which ϵ is a function of differential pressure) do not exhibit simple proportionality. These devices when used in combination with a dp cell and square root extractor have a calibration curve as shown in Fig. 13.1. Venturi flow meters, quarter of circle and conical entrance orifice flow meters, which all have discharge coefficients independent of the Reynolds Number, do approach the ideal calibration curve as shown in Fig. 13.1 if used on liquids.

According to the flow metering standards, each flow rate through a flow meter should be determined by evaluating the corresponding values of discharge coefficient, expansibility and differential pressure. Flow computers are capable of doing this, but in practice most differential pressure flow meters are not

provided with such a sophistication. The only calculating capability provided is a square root extractor and further a constant meter factor is assumed.

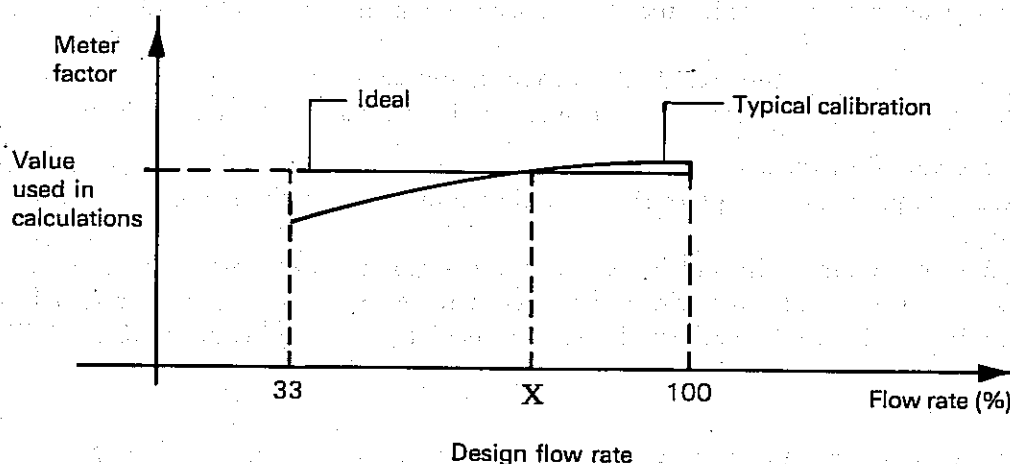


Fig. 13.1 Optimum sizing of a differential pressure flow meter (using a square root extractor)

The flow charts presented earlier in this handbook calculate the flow factor at only one point on the above curve. This point is so chosen in order to minimize the errors resulting from a flow meter over its whole workable range, see Fig. 13.1. In general, the evaluation point "X" is taken close to the normal reading, i.e. the design flow rate.

The flow meter reads true only at this flow rate. Higher on the scale it reads slightly higher than true, lower on the scale it reads slightly lower than true. Fig. 13.1 illustrates this situation.

13.3 THE UNCERTAINTY OF FLOW MEASUREMENT

13.3.1 General discussion

Many factors, including engineering tolerances in the flow meter primary and secondary parts, variations in fluid characteristics, etc., contribute an element of uncertainty to the flow rate indicated by a flow meter in relation to the actual, true rate of flow through the device.

It is therefore necessary to estimate the uncertainty of the measurement. The more realistic the estimate, the more useful the measurement.

The uncertainty in a flow measurement can be expressed in either absolute or relative terms as follows:

absolute rate of flow = $q \pm \delta q$ (flow units)

relative rate of flow = q (flow units) $\pm (\delta q/q) \times 100\%$.

The causes of the uncertainty δq are of such a nature that one cannot say with absolute certainty that a flow meter will indicate a flow rate q within the band $q \pm \delta q$. The criterion for determining δq for any flow meter should be such that, meaningful information is conveyed to the user. The usual criterion is that there is a 95% probability that the flow meter's output reading will agree with the true reading within the limits $q \pm \delta q$. To arrive at an overall δq with reference to the total flow meter's performance, it is common to assume that the component errors have a "normal" (or "gaussian") distribution. In reality this is seldom exactly true but the closeness to this distribution and the mathematical simplification achieved by the assumption, are well worth accepting the slight error in the error calculation.

Manufacturers of proprietary flow meter designs also provide accuracy figures for their products. For example, the manufacturer of a vortex meter, a basically pulse-producing device, may quote the

accuracy of the uncalibrated flow meter's output signal as $\pm 0.5\%$ of reading $+ 0.2\%$ of full scale output. When so specified, the 0.5% accounts for the uncertainties in the flow meter's calibration as affected by manufacturing tolerances. The influencing factors are the accuracy with which the flow meter's bore is machined, the dimensional and locational accuracy of the vortex-shedding bluff body, etc.. The 0.2% accounts for the accuracy with which the electronics can convert the frequency signal into a current signal.

Again it is an overall figure which takes into account many separately identifiable component uncertainties in the operation of the electronics, such as amplifier linearity, thermal compensation, etc.

Differential pressure flow meters, particularly orifice plate flow meters, are made of an assembly of different parts, e.g. piping, orifice plate, differential pressure cell, which may originate from different manufacturers.

To determine the uncertainty with which the total product can meter, the tolerances on the component parts and the way they affect the metering accuracy have to be considered. An internationally accepted method, described in ISO 5167, has been devised to calculate the metering uncertainty of differential pressure flow meters.

13.3.2 Estimation of uncertainties in the measurement of flow rates using differential pressure flow meters in accordance with ISO 5167 and BS 1042 (1964)

The practical working formula for the uncertainty δq_m of the mass rate of flow q_m is given in ISO 5167, section 10.2.2, which can be expressed as follows:

$$\left[\frac{\delta q_m}{q_m} \right] = \left[\left[\frac{\delta C}{C} \right]^2 + \left[\frac{\delta \epsilon}{\epsilon} \right]^2 + 4 \left[\frac{\beta^4 \cdot (1 - \beta^4)^{\frac{1}{2}}}{C} \right] \left[\frac{\delta D}{D} \right]^2 + 4 \left[1 + \frac{\beta^4 \cdot (1 - \beta^4)^{\frac{1}{2}}}{C} \right] \left[\frac{\delta d}{d} \right]^2 + \frac{1}{4} \left[\frac{\delta dp}{dp} \right]^2 + \frac{1}{4} \left[\frac{\delta \rho}{\rho} \right]^2 \right]^{\frac{1}{2}}$$

The uncertainty δq gives the range of values for q_m within which the true value of the measurement is estimated to lie within a 95% probability.

The true value can be expressed as either:

$$\text{rate of flow} = q_m \pm \delta q_m$$

$$\text{or} \quad \text{rate of flow} = q_m \text{ within } \pm \left[\frac{\delta q}{q} \right] \times 100\%$$

where the uncertainty δq_m must have the same dimensions as q_m .

To evaluate the above basic equation for the estimation of uncertainty, the following should be considered:

- 1) q_m is computed for the device of interest according to the methods described in sections (2-8).
- 2) $\frac{\delta C}{C}$ depends on the type of primary device, the dimensions and tolerances of its manufacture and the piping conditions in which it is installed.

For custody transfer applications, the flow meter and adjacent pipework should meet the requirements of the relevant, preferably most stringent specification of the flow metering standards. It can be met only through highly specialized manufacturing methods.

In the following sections, the values of $\frac{\delta C}{C}$ are given for two different categories of installation for each type of device. These categories are:

- 1) installation in accordance with ISO 5167
- 2) installation as per recommended design as given in section 12.

13.3.3 Discharge coefficient C for orifice and nozzle flow meters

13.3.3.1 Installation in accordance with ISO 5167 and BS 1042 (1964)

The uncertainties of the discharge coefficient C as given in sections (3, 4 and 7) are:

for square edge orifice plate: $\frac{\delta C}{C} = \pm 0.6\%$ if $\beta \leq 0.6$

$$\frac{\delta C}{C} = \pm \beta\% \quad \text{if } \beta > 0.6$$

for quarter of circle orifice plates: $\frac{\delta C}{C} = \pm 2.5\%$ if $\beta \leq 0.316$

$$\frac{\delta C}{C} = \pm 2.0\% \quad \text{if } \beta > 0.316$$

for conical entrance orifice plates: $\frac{\delta C}{C} = \pm 0.6\%$

for ISA 1932 nozzle: $\frac{\delta C}{C} = \pm 0.8\%$ if $\beta \leq 0.6$

$$\frac{\delta C}{C} = \pm (2\beta - 0.4) \quad \text{if } \beta > 0.6$$

for long radius nozzle: $\frac{\delta C}{C} = 2.0\%$

The above is assumed to be true provided that:

1. The straight length L_{U1} , L_{D1} and L_{U2} (11.4.1) equal or exceed the unbracketed values quoted in Table 11.4.2.

If any two of the three straight lengths L_{U1} , L_{D1} and L_{U2} equals or exceeds unbracketed values and the third exceeds a bracketed value but not the unbracketed value, then the installation meets ISO 5167 requirements provided that $\pm 0.5\%$ is added arithmetically to the basic uncertainty of $(\delta C/C)$.

2. Any step between adjacent sections of pipe used to fabricate the upstream straight length L_{U1} shall not exceed 0.3% from D.

If any step with a height h at a distance s from the orifice plate, within straight length L_{U1} , exceeds 0.3% from D but complies with the relationships:

$$\frac{h}{D} \leq 0.002 \left[\frac{s/D + 0.4}{0.1 + 2.3\beta^4} \right] \quad \text{and} \quad \frac{h}{D} \leq 0.05$$

an additional uncertainty of $\pm 0.2\%$ shall be added arithmetically to the basic uncertainty of $(\delta C/C)$.

3. The distance between the centre line of the orifice and the centre lines of the pipe on the upstream and downstream sides shall be less than or equal to:

$$\frac{0.0005D}{0.1 + 2.3\beta^4}$$

If the distance between the centre line of the orifice and the centre lines of the pipe on the upstream and downstream sides is more than:

$\frac{0.0005D}{0.1 + 2.3\beta^4}$ but less than $\frac{0.005D}{0.1 + 2.3\beta^4}$ an additional uncertainty of $\pm 0.3\%$ shall be added arithmetically to the basic uncertainty of $(\delta C/C)$.

13.3.3.2 Installation as per recommended design

The uncertainties in flow coefficient ($\delta C/C$) used for general orifice flow metering should of course relate to the real mechanical installations used in the field.

In sections (12.2), (12.3), (12.4) and (12.5) approximation expressions are given for the effects which can be expected on the uncertainty of the factor C for orifice flow meters as a result of tolerances in the pipe work, flanges and orifice plates, in addition to the uncertainty figures given by ISO 5167 and/or BS 1042 (1964).

Table 13.3.3.2.1 reflects the various effects which can be expected for the C factor for the square edge orifice plates in the configuration with flange tapplings, corner tapplings and radius tapplings.

Table 13.3.3.2.2 reflects the same effects for the quarter of circle and conical entrance orifice plates.

For nozzle flow meters, Table 13.3.3.2.3, the value of ($\delta C/C$) should be provided by the manufacturer.

In the absence of such information rough estimates can be based on the assumptions that the general piping quality as defined in (12.4) and nozzle/pipe bore alignment as defined by a stainless steel nozzle, held within the bolt circle of a carbon steel orifice flange like an orifice plate is used and the straight lengths, are in accordance with Table 11.4.2, see (13.3.3.2.3).

13.3.3.2.1 $\delta C/C$ for square edge orifice plates

	Values to be added to calculate the uncertainty of the discharge coefficient $\frac{\delta C}{C}$	SQUARE EDGE ORIFICE PLATES							
		flange tappings		corner tappings			radius tappings		
		DN > 50		DN < 50	DN > 50		slip on DN > 200		w.neck DN > 400
		$\beta \leq 0.6$	$\beta > 0.6$	none	$\beta \leq 0.6$	$\beta > 0.6$	$\beta \leq 0.6$	$\beta > 0.6$	$\beta \leq 0.6$ $\beta > 0.6$
basic uncertainty ISO 5167 (13.3.3.1)	see value per type	0.6	β	0.6	0.6	β	0.6	β	0.6 β
uncertainty due to pipe joints (12.4.2.3)	see value per type	0.4	0.4		0.4	0.4	0.3	0.4	0.6 0.6
square edge DN < 50 (12.2.2.3)	$0.3 \cdot \frac{12.5}{d}$			x					
corner tappings DN < 50 (12.3.3.3)	$55 \cdot \beta^9 \left[\frac{1.5}{D} \right]^{\frac{1}{2}}$			x					
flange tappings (12.3.2.3)	β^4	x	x						
radius tappings (12.3.4.3)	β^4						x	x	x x
eccentricity all tappings DN > 50 (12.3.1)	$\frac{28}{D} (0.6 + 13.8\beta^4) + T_{\text{comp}}$	x	x		x	x	x	x	x x
eccentricity corner tappings DN < 50 (12.3.3.3)	$\frac{5}{D} (0.6 + 13.8\beta^4)$			x					
bleed hole compensation DN > 50 (12.2.3.3)	$-55 \left[\frac{y}{d} \right]^2$	x	x		x	x	x	x	x x

Notes:

- 1) x = applicable to calculations for this type.
- 2) The expressions as stated in the above table do not include terms to allow of pipework straight lengths less than those quoted in Table 11.4.2 and/or pipe irregularities.
If any two of the three straight lengths L_{U1} , L_{D1} and L_{U2} , see Table 11.4.2, equal or exceed unbracketed values, and the third exceeds a bracketed value but not the unbracketed value, then an extra $\pm 0.5\%$ needs to be added arithmetically to the values determined from the equations in (13.3.3.1).
- 3) For temperature compensation, the following formula (12.3.1) shall be used:

$$T_{\text{comp}} = \left[\frac{17}{258\,000} \right] \cdot (450 - T) \cdot (0.6 + 13.8\beta^4)$$

13.3.3.2.2 $\delta C/C$ for quarter of circle and conical entrance orifice plates

	Values to be added to calculate the uncertainty of the discharge coefficient $\frac{\delta C}{C}$	QUARTER OF CIRCLE				CONICAL ENTRANCE	
		flange tappings		corner tappings		corner tappings	
		DN > 50		DN $\leq$ 50		DN $\leq$ 50	DN > 50
		$\beta \leq 0.316$	$\beta > 0.316$	$\beta \leq 0.316$	$\beta > 0.316$		
basic uncertainty ISO 5167 (13.3.3.1)	see value per type	2.5	2	2.5	2	2	2
uncertainty due to pipe joints (12.4.2.3)	see value per type	0.4	0.4				0.4
quarter of circle DN < 50	$\frac{19.2}{d} - 1$			x	x		
conical entrance DN < 50	$\frac{10.0}{d} - 1$					x	x
corner tappings DN < 50 (12.3.3.3)	$55 \cdot \beta^9 \left[\frac{1.5}{D} \right]^{\frac{1}{2}}$			x	x	x	
flange tappings (12.3.2.3)	β^4	x	x				
eccentricity all tappings DN > 50 (12.3.1)	$\frac{28}{D} (0.6 + 13.8\beta^4) + T_{\text{comp}}$	x	x				x
eccentricity corner tappings DN < 50 (12.3.3.3)	$\frac{5}{D} (0.6 + 13.8\beta^4)$			x	x	x	
bleed hole compensation DN > 50 (12.2.3.3)	$-55 \left[\frac{y}{d} \right]^2$	x	x				x

- Notes:
- 1) x = applicable to calculations for this type.
 - 2) The expressions as stated in the above table do not include terms to allow of pipework straight lengths less than those quoted in Table 11.4.2 and/or pipe irregularities.
If any two of the three straight lengths L_{U1} , L_{D1} and L_{U2} , see Table 11.4.2, equal or exceed unbracketed values and the third exceeds a bracketed value but not the unbracketed value, then an extra $\pm 0.5\%$ needs to be added arithmetically to the values determined from the equations in (13.3.3.1).
 - 3) For temperature compensation, the following formula (12.3.1) shall be used:

$$T_{\text{comp}} = \left[\frac{17}{258\,000} \right] \cdot (450 - T) \cdot (0.6 + 13.8\beta^4)$$

13.3.3.2.3 $\delta C/C$ for nozzle flow meters

	Values to be added to calculate the uncertainty of the discharge coefficient $\frac{\delta C}{C}$	ISA 1932 NOZZLE		LONG RADIUS NOZZLE
		corner tappings		corner tappings
		DN > 50		DN > 50
		$\beta \leq 0.6$	$\beta > 0.6$	none
basic uncertainty ISO 5167 (13.3.3.1)	see value per type	0.8	$2\beta - 0.4$	2
uncertainty due to pipe joints (12.4.2.3)	see value per type	0.4	0.4	0.4
eccentricity all tappings DN > 50 (12.3.1)	$\frac{28}{D} (0.6 + 13.8\beta^4) + T_{\text{comp}}$	×	×	×

Notes:

- 1) × = applicable to calculations for this type.
- 2) The expressions as stated in the above table do not include terms to allow of pipework straight lengths less than those quoted in Table 11.4.2 and/or pipe irregularities.
If any two of the three straight lengths L_{U1} , L_{D1} and L_{U2} , see Table 11.4.2, equal or exceed unbracketed values and the third exceeds a bracketed value but not the unbracketed value, then an extra $\pm 0.5\%$ needs to be added arithmetically to the values determined from the equations (13.3.3.1).
- 3) For temperature compensation, the following formula (12.3.1) shall be used:

$$T_{\text{comp}} = \left[\frac{17}{258\,000} \right] \cdot (450 - T) \cdot (0.6 + 13.8\beta^4)$$

13.3.4 Discharge coefficient C for Venturi flow meters

13.3.4.1 Installation in accordance with ISO 5167

The uncertainties for all types of classical Venturis as given in section (6) are:

rough cast convergent $\frac{\delta C}{C} = \pm 0.7\%$

machined convergent $\frac{\delta C}{C} = \pm 1.0\%$

rough cast, welded sheet iron convergent $\frac{\delta C}{C} = \pm 1.5\%$

The above is assumed to be true provided that:

1. The straight lengths L_{U1} , L_{U2} and L_{D1} equal or exceed the unbracketed values quoted in Table 11.4.3.
If any two of the three straight lengths L_{U1} , L_{U2} , and L_{D1} , see Table 11.4.3, equal or exceed unbracketed values and the third exceeds a bracketed value but not the unbracketed value, then the installation meets ISO 5167 requirements provided that $\pm 0.5\%$ is added arithmetically to the basic uncertainty ($\delta C/C$).
2. The items 1–7 of (12.4.3.1) are met.

13.3.4.2 Installation as per recommended design

All types of classical Venturis.

The uncertainties for the classical Venturi as per recommended design are estimated as:

rough cast convergent $\frac{\delta C}{C} = \pm 0.9\%$

machined convergent $\frac{\delta C}{C} = \pm 1.2\%$

rough cast, welded sheet iron convergent $\frac{\delta C}{C} = \pm 1.7\%$

Note that for the rectangular Venturis (6.2.9) the relevant value of $(\delta C/C)$ is estimated as:

rectangular Venturi $\frac{\delta C}{C} = \pm 10\%$

rectangular Venturi $\frac{W}{H} = \frac{w}{h} = 1$ $\frac{\delta C}{C} = \pm 5\%$

The above uncertainties are valid when the observations as discussed in section (12.4.3.3) are taken into consideration.

13.3.5 Expansion factor

The uncertainty of the expansion factor depends on the type of device and its β ratio.

The following table gives the uncertainty of ϵ with the limitation for β , as given in the sections (3, 4, 6, 7 and 8).

	β limitation	uncertainty of $\delta\epsilon/\epsilon$
Square edge orifice plate	$\beta \leq 0.75$	$\pm 4 \frac{dp}{p} \%$
	$0.75 < \beta \leq 0.8$	$\pm 4 \frac{dp}{p} \%$
Quarter of circle orifice plate	$0.245 < \beta < 0.6$	$\pm 33 (1-\epsilon) \%$
Conical entrance orifice plate	$0.1 < \beta < 0.316$	$\pm 33 (1-\epsilon) \%$
Classical Venturi tube type A, B and C	$0.3 < \beta < 0.75$	$\pm (4 + 100\beta^8) \frac{dp}{p} \%$
Rectangular Venturi	$0.44 < \frac{wh}{WH} < 0.74$	$\pm (4 + 100\beta) \frac{dp}{p} \%$
ISA 1932 nozzle	$0.3 < \beta < 0.8$	$\pm 2 \frac{dp}{p} \%$
Long radius nozzle	$0.2 < \beta < 0.8$	$\pm 2 \frac{dp}{p} \%$

13.3.6 Upstream D

D is the internal diameter of the flow meter in the plane of its upstream pressure tapping. It should be determined by taking the average of measurements across at least four different, equi-spaced, diametrical lines within this plane. If, as is sometimes the case for an orifice plate flow meter, direct measurement is impractical, the nominal bore of the pipe at the upstream pressure tapping can be that quoted in the tables specifying the dimensions of the relevant piping class.

$\delta D/D$ is the uncertainty in the value of D.

When D has been determined by direct measurement, it includes the uncertainty in the measurement due to the limited accuracy of the measuring device (e.g. internal micrometer), the skill with which the measuring device is used, the number of readings taken and the non-circularity of the pipe in the plane of the upstream pressure tapping. D is ideally the root-mean-square (rms) of these individual terms. In practice it is usually sufficient to equate D to the rms of the differences between each overall reading and the mean (11.5.6).

For example, if six measurements to determine D are:

49.5, 48.5, 49.0, 49.3, 48.8 and 48.9 mm, then the mean $D = 49.0$ mm.

The deviations from the mean D are: +0.5, -0.5, 0, +0.3, -0.2 and -0.1 mm so that

$$\delta D = \pm \left[\frac{(+0.5)^2 + (-0.5)^2 + (0)^2 + (+0.3)^2 + (-0.2)^2 + (-0.1)^2}{6} \right]^{\frac{1}{2}} = \pm 0.3 \text{ mm.}$$

When, for orifice plate flow meters, the value of D has been determined from piping class tables, the δD should also be determined from such tables.

13.3.7 Throat d

d is the flow meter's throat diameter, i.e. for orifice plate flow meters the diameter of the orifice. This dimension is usually stamped on the body of the flow metering device. Orifice plate flow meters usually have it stamped on the orifice plate's tab. If the dimension is not pre-stamped it should be determined by taking the average of measurements across at least four different, equi-spaced, diametrical lines.

$\delta d/d$ is the uncertainty in the value of d. As for δD (see above) it should really be evaluated considering several different component uncertainties, but in practice it is usually sufficient to equate it to the rms of the differences between each reading and the mean d.

For example, if four measurements to determine d are:

20.05, 20.02, 19.95 and 19.98 mm, then the mean $d = 20.00$ mm.

The deviations from the mean d are: +0.05, +0.02, -0.05, -0.02 mm so that:

$$\delta d = \pm \left[\frac{(0.05)^2 + (0.02)^2 + (-0.05)^2 + (-0.02)^2}{4} \right]^{\frac{1}{2}} = 0.04 \text{ mm.}$$

13.3.8 Differential pressure (dp)

dp is the differential pressure registered by the differential pressure measuring device at a certain flow for which the uncertainty of flow measurement is being determined. For general applications the dp used for these estimates can be the differential pressure range (DP) of the transmitter.

$\delta (dp)/dp$ is the uncertainty in the differential pressure measurement.

For a mercury manometer or Barton-type recorder in which, within a single instrument, a differential pressure input is converted directly into a visual indication of flow rate, the instrument manufacturers description of the overall accuracy of the transmitter should be used for $\delta (dp)$, typically ± 0.2 to $\pm 0.5\%$ of the full scale.

Notes:

- 1) When a transmitter is used, some other device, e.g. pressure gauge or current meter or flow computer, has also to be used to obtain a read-out of the flow rate. The inaccuracy of the performance of such a device should be accounted for in the error analysis.
- 2) Differential pressure measuring instruments, whether including self-contained read-out or being only a transmitter, have an accuracy which is a function of their range, i.e. full-scale deflection (fsd). As such they are only half as accurate at half range, as the value given at fsd.

When considering the uncertainty of reading from a differential pressure transmitter, care should be taken to include the effects of its temperature and static pressure coefficient over the range of temperatures and the static pressures for which the instrument will be used.

13.3.9 Density

ρ_1 is the fluid density at the flow meter.

δ_1/ρ_1 is the uncertainty in the fluid density at the flow meter.

On-line densitometers are often used when a flow computer is applied which is specially designed to provide compensation, thereby effectively reducing the $\delta\rho_1$ of the densitometer. In such cases the effective $\delta\rho_1$ may be used in the calculation. If a resonant cylinder-type densitometer is used with a frequency-to-analogue converter, the inaccuracy of this converter should be added to that of the density measuring device itself.

If the density is determined in an off-line situation, e.g. in the laboratory, both the actual ρ_1 (at pipe conditions and upstream tapping) and the $\delta\rho$ should be carefully evaluated.

The laboratory evaluations are normally carried out at ambient conditions. The actual ρ is subsequently calculated using tables or correlation functions; both can have a significant impact on the uncertainty of the ρ_1 , e.g. light products which are in gaseous form at ambient conditions.

13.4 TYPICAL UNCERTAINTIES

Orifice diameter			± 0.05 %
Internal pipe diameter D			
if D is not measured but taken from tables			± 0.50 %
if D is measured			± 0.10 %
Differential pressure dp, including transmission and reading			
for a reading of approximately 3	on a 0-10 square scale		± 5.00 %
5	on a 0-10 square scale		± 2.00 %
7.5	on a 0-10 square scale		± 1.00 %
10	on a 0-10 square scale		± 0.50 %
Density of liquid			
for constant composition (molar mass) and constant temperature (°C)			± 0.03 %
for 1 % variation in molar mass and 1 % variation in temperature			± 1 %
5 %	5 %		± 5 %
10 %	10 %		± 10 %
1 %	5 %		± 1 %
1.5 %	5 %		± 1.5 %
1 %	10 %		± 1.3 %
5 %	1 %		± 5 %
10 %	1 %		± 10 %
Density of steam			
for constant pressure (bar) and constant temperature (°C)			± 0.02 %
for 1 % variation in pressure and 1 % variation in temperature			± 0.5 %
5 %	5 %		± 3 %
10 %	10 %		± 6 %
1 %	5 %		± 1.5 %
1 %	10 %		± 3 %
5 %	1 %		± 2.5 %
10 %	1 %		± 5 %
Density of gas			
for constant composition (molar mass), pressure (bar) and constant temperature (°C)			± 0.05 %
for 1 % variation in molar mass 1 % in pressure and 1 % variation in temperature			± 1 %
5 %	5 %	5 %	± 4 %
10 %	10 %	10 %	± 8 %
1 %	5 %	5 %	± 3 %
1 %	10 %	10 %	± 5.5 %
5 %	1 %	5 %	± 3 %
10 %	1 %	10 %	± 5.5 %
5 %	5 %	1 %	± 4 %
10 %	10 %	1 %	± 8 %
1 %	1 %	5 %	± 1 %
1 %	1 %	10 %	± 1.5 %
1 %	5 %	1 %	± 3 %
1 %	10 %	1 %	± 5.5 %
5 %	1 %	1 %	± 3 %
10 %	1 %	1 %	± 5.5 %

13.5 GUIDE TO THE EFFECTS OF A DEPARTURE FROM THE STANDARDS

The following information is intended to indicate the degree of some known effects of non-compliance on the requirements for flow meter installations. At the same time, those users who may not be able to comply with the requirements, e.g. for existing installations, are enabled to assess roughly the magnitude and direction of the resulting errors.

It should be noted that:

- A positive error will cause a meter to give a reading higher than normal (a decrease in the flow coefficient will give rise to such a reading).
- The following list is by no means complete but represents a summary of information extracted from available literature.

Defects in primary measuring element	Primary element	β	Order of the error to be expected $\frac{\text{actual reading} - \text{true reading}}{\text{true reading}} \times 100$
Rounding of upstream edge	Square edge orifice		$-450 \times \frac{\text{radius edge}}{d} \%$
	Segmental orifice		$-175 \times \frac{\text{radius edge}}{\text{height segment opening}} \%$
Orifice edge too thick	Square edge orifice/corner, radius and vena contracta tappings	0.2	-1% for twice the correct thickness
Orifice plate too thick	Square edge orifice/corner tappings	<0.7	<+1% for twice the correct thickness
Pressure tapping position	Square edge orifice/corner tappings	<0.67	-0.1% if distance 0.05D from corner -1.2% if distance 0.5D from corner
	Nozzles	<0.6	-0.5% if distance 0.05D from corner -2.6% if distance 0.5D from corner
	Square edge orifice/radius tappings	0.7	-1% if downstream tapping 0.1D too far downstream or +1% if downstream tapping 0.1D too far upstream
Excessive size of pressure tapping hole	Orifices/flange tappings		Positive
Burrs around pressure tappings	All differential pressure devices		From -30% up to +30%
Carrier ring dia. too small	Square edge orifice/corner tappings	0.7	From -2% to +5% for 10% discrepancy
	Nozzles	0.75	From -6% to +1% for 10% discrepancy
Eccentric or too small a gasket between carrier ring and flange	Orifices and nozzles		From -60% up to +60%
Position of device not concentric	Orifices and nozzles	0.8	From -1% to +1% if eccentricity 0.015D max <5%
Inlet cone angle of convergence incorrect	Venturi tubes		+2% if angle 12° instead of 15°
Outlet cone angle of divergence incorrect	Venturi tubes		None, only affects pressure loss
Radius between cone and throat incorrect	Venturi tubes		Up to +1.5% if incorrect
Roughness upstream side of primary element	Orifices	0.5	Negative error for increasing roughness -3% for water if $Re_D = 20\,000$ and $d / \text{roughness plate} = 80$ -2% for water if $Re_D = 20\,000$ and $d / \text{roughness plate} = 620$

(Continued)

Defects in primary measuring element	Primary element	β	Order of the error to be expected $\frac{\text{actual reading} - \text{true reading}}{\text{true reading}} \times 100$
Increasing roughness	Venturi tubes		Positive error
Bending of orifice	Orifices		Unpredictable
Too short an upstream straight length after:			
a. single bend	All differential pressure devices		Error varies with plane of tapping and straight length
b. double bend in one plane	Square edge orifice/corner tappings	0.55 0.75	<+0.5% if straight length > 4D <+3 % if straight length > 4D
c. three bends at right angles	Square edge orifice/corner tappings	<0.75	<-5 % if straight length > 4D
d. open globe valve	Square edge orifice/corner tappings	0.55 0.75	<+1.5% if straight length > 4D <+5 % if straight length > 8D
	Square edge orifice with flange or radius tappings	<0.75	<+2 % if straight length > 6D
	Pipe bend		<+3 % if straight length > 8D
e. divergent taper piece (from 0.5D to D over 1.8D)	Square edge orifice/corner tappings	0.40 0.70	-10 % if no straight length at all -50 % if no straight length at all
f. convergent taper piece (from 1.25D to D over D)	Square edge orifice/corner tappings	0.40 0.70	From -0.5% to +0.5% if no straight length at all +2% if no straight length at all
g. thermowell	Orifices		<+2% if dia. well > 0.04D and straight length < 15D
h. change in internal pipe dia. (weld between 2 pipe sections of different schedule)	Orifices		Negligible if dia. change < 20% and straight length > 7D
Too short a downstream straight length after:			
a. single bend	Square edge orifice/corner tappings		Error varies with plane of tapping
b. double bend in one plane	Square edge orifice/corner tappings	0.55 0.75	<-2 % if straight length > 1D <-3 % if straight length > 1D
c. three bends at right angles	Square edge orifice/corner tappings	0.55 0.75	<-2 % if straight length > 1D <-2.5% if straight length > 1D
d. open globe valve	Square edge orifice/corner tappings	0.55 0.75	<-0.5% if straight length > 1D <-1 % if straight length > 1D
No downstream straight length between device and taper piece (from D to 0.5D over D)	Square edge orifice/corner tappings	<0.4 0.7	+1% -1%
Error in measured D	Square edge orifice	0.74	> -4% if D = D+5%
Abnormal roughness	Square edge orifice/any tapping	<0.3	Negligible
Following data for roughness = 6 mm	Square edge orifice/corner tappings (For other tappings and device error magnitude most likely smaller)	0.5 0.7 0.5 0.7	+ 9% if D = DN 80 +40% if D = DN 80 + 2% if D = DN 300 + 8% if D = DN 300 + 1% for D = DN 300 if cleaned over 5D upstream + ½% if cleaned over 7D upstream Negligible if cleaned over 15D upstream + 2% for D = DN 80 if cleaned over 5D upstream + 1% if cleaned over 15D upstream Negligible if cleaned over 30D upstream

(Continued)

Defects in primary measuring element	Primary element	β	Order of the error to be expected $\frac{\text{actual reading} - \text{true reading}}{\text{true reading}} \times 100$
	Venturi tubes		Negative
Foreign matter in bore of device	All differential pressure devices		Positive, increasing magnitude for higher β
Foreign deposits on upstream side of device	Orifice any tapping		Negative, increasing magnitude for higher β
Pulsating flow	Any device		Usually positive and very high
Excessively low pipe Reynolds Number	Square edge orifice/flange or vena contracta tappings	0.3	-7.5% at $Re_D = 1000$, up to -17% at $Re_D = 250$
		0.6	-19% at $Re_D = 1000$, up to -26% at $Re_D = 250$
	Square edge orifice/corner or radius tappings	0.3	-2.5% at $Re_D = 1000$, up to -14% at $Re_D = 100$
		0.6	-20% at $Re_D = 1000$, up to -25% at $Re_D = 200$

13.6 References

ISO 5167

BS 1042 (1964)

Section 14. General data

14.1 Reynolds Number and viscosity

14.2 Standard pipe diameters ANSI and DIN

14.2.1 Values of D of ANSI sizes DN 50 to DN 600 (2" to 24")

14.2.2 Values of D of DIN sizes 50 to 500 mm

14.3 Pipe wall roughness

14.4 Steam quality correction factor

14.1 REYNOLDS NUMBER AND VISCOSITY

To express the characteristics of a flow, a dimensionless quantity, the Reynolds Number is used.

The pipe Reynolds Number $Re_D = \rho V_D D / \eta = 1000 V_D D / \nu$

The orifice or throat Reynolds Number $Re_d = \rho V_d d / \eta = 1000 V_d d / \nu$

where:

ρ	= density	(kg/m ³)
V_D	= mean velocity in the pipe	(m/s)
V_d	= mean velocity in the orifice or throat	(m/s)
η	= absolute or dynamic viscosity	(mPa·s)
ν	= kinematic viscosity	(mm ² /s)
D	= internal pipe diameter	(mm)
d	= orifice or throat diameter	(mm)

while $Re_D = \beta Re_d$ and $\nu = 1000 \eta / \rho$

In this handbook the pipe Reynolds Number Re_D is used in accordance with the ISO 5167 recommendation, as its value can be calculated before the orifice diameter has been determined.

The calculation of one pipe Reynolds Number at design flow is usually sufficient for practical applications. When calculating the Reynolds Number for gas or steam flows it is usually more convenient to use the absolute viscosity (independence of pressure).

For calculation, the following practical formula can be used for liquid and gas:

$$Re_D = 1.2732 \times 10^6 q / \eta D$$

where:

Re_D	= pipe Reynolds Number at flow q	
q	= mass flow rate	(kg/s)
D	= internal pipe diameter	(mm)
	(the substitution of the nominal pipe size is usually accurate enough for practical purposes)	
η	= absolute or dynamic viscosity under operating conditions	(mPa·s)

If the calculated pipe Reynolds Number at design flow is close to the prescribed limits, it will be necessary to check Re_D at minimum flow and/or maximum flow.

14.2 STANDARD PIPE DIAMETERS ANSI AND DIN

14.2.1 Values of D of ANSI sizes DN 50 to DN 600 (2" to 24")

Ref. ANSI B 36.10.

Nominal pipe size	Pipe schedule	Internal dia. D (in.)	Internal dia. D (mm)
DN 50 (2 inch)	40	2.067	52.50
	80	1.939	49.25
	160**	1.689	42.90
DN 80 (3 inch)	40	3.068	77.93
	80	2.900	73.66
	160**	2.624	66.70
DN 100 (4 inch)	40	4.026	102.26
	80	3.826	97.18
	120**	3.624	92.05
	160**	3.438	87.33
DN 150 (6 inch)	40	6.065	154.1
	80	5.761	146.3
	120**	5.501	139.7
	160**	5.189	131.8
DN 200 (8 inch)	20	8.125	206.4
	30	8.071	205.0
	40	7.981	202.7
	60	7.813	198.5
	80	7.625	193.7
	120**	7.189	182.6
DN 250 (10 inch)	30	10.136	257.5
	40	10.020	254.5
	60	9.750	247.7
	80	9.564	242.9
DN 300 (12 inch)	30	12.090	307.1
	40	11.938	303.2
	60	11.626	295.3
	80	11.376	289.0
DN 350 (14 inch)	30	13.250	336.6
	40	13.124	333.4
	60	12.814	325.5
	80**	12.500	317.5
DN 400 (16 inch)	30	15.250	387.4
	40	15.000	381.0
	60	14.688	373.1
	80**	14.314	363.6
DN 450 (18 inch)	20	17.376	441.4
	30	17.124	435.0
	40	16.876	428.7
	60**	16.500	419.1
	80**	16.126	409.6
DN 500 (20 inch)	20	19.250	488.9
	30	19.000	482.6
	40	18.814	477.9
	60**	18.376	466.8
	80**	17.938	455.6
DN 600 (24 inch)	20	23.250	590.6
	30	22.876	581.1
	40	22.626	574.7
	60**	22.064	560.4
	80**	21.564	547.7

*) Use these figures as a guide in design only; always measure the actual diameter.

**) For the high value of the standard metric orifice diameter, the upper β limit of 0.70 will be exceeded when using this pipe.

14.2.2 Values of D of DIN sizes 50 to 500 mm

Pipe size DN (Nennweite)*	PN (Nenndruck)*	Internal dia. D (mm)
50	25	52.3**
	25/40, 64	52.3**
	100	51.3**
80	25	80.9
	25/40	80.9
	64	78.9
	100	77.7
100	25	106.3
	25/40, 64	103.1
	100	98.3
150	25	158.3
	25/40	155.7
	64	154.1
200	25	209.1
	25/40	204.9
	64	203.1
250	25	261.8
	25/40	258.8
	64	255.4
300	25	311.3
	25/40	307.9
	64	301.9
350	25	341.4
	25/40	338.0
	64	330.6
400	25	390.4
	25/40	386.4
	64	378.0
500	25	490.4
	25/40	483.0
	64	473.0

*) Nenndruck (PN) is translated by "nominal pressure", Nennweite (DN) is translated by "nominal size".

**) Use the figure as a guide in design only; always measure the actual diameter.

Note: Internal diameter D is in accordance with TUV with a corrosion allowance of 1 mm.

14.3 PIPE WALL ROUGHNESS

The value of k is a uniform equivalent of the pipe wall roughness, expressed in length units, and examples are given in the table below.

Pipes with greater relative roughness may be used if the roughness for at least 10D upstream of the primary device is within the limits given.

Examples of values of the pipe wall roughness, k

Material	Condition	k (mm)
brass, copper, aluminium, plastic, glass	smooth, without sediments	< 0.03
steel	new, seamless cold-drawn	< 0.03
	new, seamless hot-drawn	0.05 to 0.10
	new, seamless rolled	0.05 to 0.10
	new, welded longitudinally	0.05 to 0.10
	new, welded spirally	0.10
	slightly rusted	0.10 to 0.20
	rusty	0.20 to 0.30
	encrusted	0.50 to 2
	with heavy incrustations	> 2
	bituminized, new	0.03 to 0.05
cast iron	bituminized, normal	0.10 to 0.20
	galvanized	0.13
	new	0.25
	rusty	1.0 to 1.5
asbestos cement	encrusted	> 1.5
	bituminized, new	0.03 to 0.05
asbestos cement	insulated and not insulated, new	< 0.03
	not insulated, normal	0.05

14.4 STEAM QUALITY CORRECTION FACTOR

For superheated and dry saturated steam, the correction factor F_s is equal to 1.

For steam quality 95% and above, the following table gives the steam quality correction factor.

steam quality %	water % wt	F_s
99	1	1.007
98	2	1.015
97	3	1.022
96	4	1.030
95	5	1.037

or $F_s = 1 + 0.0074 \text{ wt } \%, \text{ for } \%H_2O \geq 5\%$

Appendix A

Flow meter sizing

- 1 Sizing form for square edge orifices with flange tappings
- 2 Sizing form for square edge orifices with corner tappings
- 3 Sizing form for square edge orifices with radius tappings
- 4 Sizing form for quarter of circle orifices with flange tappings
- 5 Sizing form for conical entrance orifices with corner tappings
- 6 Sizing form for Venturi tubes (A, B and C)
- 7 Sizing form for rectangular Venturi tubes
- 8 Sizing form for ISA 1932 nozzles
- 9 Sizing form for long radius nozzles

Note:

For the computer program in Basic as given in the following sheets, the accuracy of the calculation depends on the type of computer used, and the type of variable. The listings are written with single-position variables, double-position will increase the accuracy.

APPENDIX A-1

SIZING FORM FOR SQUARE EDGE ORIFICES WITH FLANGE TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.2 \leq \beta \leq 0.75$	
Bleed hole size y	mm	$1260 \beta^2 D \leq Re_D \leq 10^8$	
Ratio of specific heats $\kappa = C_p/C_v$			
1. $D = D_m [1 + \alpha_{\text{pipe}} (T - T_0)]$		$D =$ mm	
2. $(Re_D)_{\text{des}} = \frac{1.2732 \cdot 10^6 (q_m)_{\text{des}}}{\eta D}$		$(Re_D)_{\text{des}} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)_{\text{des}}^2}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{\text{des}}^2} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)_{\text{des}}} \right]^{0.75} +$ $+ \left[\frac{2.286}{D} \right] \beta^4 \cdot (1 - \beta^4)^{-1} - \left[\frac{0.85598}{D} \right] \beta^3$		$C =$	
Note: If $D < 58.615$ mm use 0.0390 as coefficient of $\beta^4 (1 - \beta^4)^{-1}$			
7. $\beta = \left[\frac{28470.5 (q_m)_{\text{des}} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. $d = \beta D$		$d =$ mm	
9. $d_m = d [1 - 0.55 (y/d)^2] [1 + \alpha_{\text{plate}} (T - T_0)]^{-1}$		$d_m =$ mm	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR A-1

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM
   [ kg/s];QM
30 INPUT "Viscosity under operating conditions";N
   [ m Pa·s];N
40 INPUT "Operating temperature";T
   [ °C];T
50 INPUT "Density under operating conditions";R
   [ kg/m3];R
60 INPUT "Operating pressure";P
   [ bar];P
70 INPUT "Internal pipe diameter at To";DM
   [ mm];DM
80 INPUT "Transmitter range";DP
   [ bar];DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH
   [ mm];DH
110 INPUT "Linear expansion coeff. pipe";AP
   [ /°C];AP
120 INPUT "Linear expansion coeff. orifice";AO
   [ /°C];AO
130 INPUT "Ambient temperature";TO
   [ °C];TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
   [ %];W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated β)
590 B = (QM^2 / (4.6 * 10^-8 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (calculate discharge coefficient)
640 C = 0.5959 + 0.0312 * B^2.1 - 0.184 * B^8 + 0.0029 * B^2.5 *
   (1000000 / RED)^0.75 - 0.85598 * B^3 / D
650 IF D < 58.615 THEN C = C + 0.039 * B^4 / ( 1 - B^4 ) : GOTO 670
660 C = C + 2.286 * B^4 / (D * (1 - B^4))
670 REM STEP 8 (calculate new β)
680 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
690 REM check if calculated β agrees with previous β within 0.01%
700 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 600
710 REM STEP 9 (calculate d orifice at line temp)
720 DO = B1 * D
730 REM STEP 10 (calculate d orifice at ambient temp)
740 DOM = DO * (1 - 0.55 * (DH / DO)^2) / (1 + AO * (T - TO))
750 REM the following lines will print the output and restart the program
760 PRINT "Orifice diameter at To";DOM
   [ mm];DOM
770 PRINT "Beta ratio";B1
780 PRINT "Reynolds Number";RED
790 INPUT "A new calculation Y/N";A$
800 IF A$="Y" GOTO 10
810 END

```

APPENDIX A-2

SIZING FORM FOR SQUARE EDGE ORIFICES WITH CORNER TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.23 \leq \beta \leq 0.80$	
Bleed hole size y	mm	$5000 \leq Re_D \leq 10^6$ for $0.23 \leq \beta \leq 0.45$	
Ratio of specific heats $\kappa = C_p/C_v$		$10\,000 \leq Re_D \leq 10^6$ for $0.45 < \beta \leq 0.77$	
		$20\,000 \leq Re_D \leq 10^6$ for $0.77 < \beta \leq 0.80$	
1. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
2. $(Re_D)_{des} = \frac{1.2732 \cdot 10^6 (q_m)_{des}}{\eta D}$		$(Re_D)_{des} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)_{des}^2}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{des}^2} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)_{des}} \right]^{0.75}$		$C =$	
7. $\beta = \left[\frac{28\,470.5 (q_m)_{des} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. If $Re_D \geq 10^6$ then $Z_{Re_D} = Z_0$, otherwise $Z_{Re_D} = (Z_0 - 1) [\log (Re_D)/6]^2 + 1$		$Z_{Re_D} =$	
9. $\beta = \beta (Z_{Re_D})^{-0.5}$		corrected $\beta =$	
10. $d = \beta D$		$d =$ mm	
11. $d_m = d [1 - 0.55 (y/d)^2] [1 + \alpha_{plate} (T - T_0)]^{-1}$		$d_m =$ mm	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR A-2

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM
30 INPUT "Viscosity under operating conditions";N
40 INPUT "Operating temperature";T
50 INPUT "Density under operating conditions";R
60 INPUT "Operating pressure";P
70 INPUT "Internal pipe diameter at To";DM
80 INPUT "Transmitter range";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH
110 INPUT "Linear expansion coeff. pipe";AP
120 INPUT "Linear expansion coeff. orifice";AO
130 INPUT "Ambient temperature";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated  $\beta$ )
590 B = (QM^2 / (4.6 * 10^-8 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (calculate discharge coefficient)
640 C = 0.5959 + 0.0312 * B^2.1 - 0.184 * B^8 + 0.0029 * B^2.5 * (1000000 / RED)^0.75
650 REM STEP 8 (calculate new  $\beta$ )
660 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
670 REM check if calculated  $\beta$  agrees with previous  $\beta$  within 0.01%
680 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 600
690 REM STEP 9 (check on roughness correction factor)
700 PRINT "Beta ratio";B1
710 INPUT "Roughness correction factor Zo";ZO
720 IF RED >= 1000000 THEN ZRED=ZO ELSE ZRED = (ZO-1)*(LOG(RED/1000000))^2 + 1
730 REM STEP 10 (calculate corrected  $\beta$ )
740 B1 = B1 / ZRED^0.5
750 REM STEP 11 (calculate d orifice at line temp)
760 DO = B1 * D
770 REM STEP 12 (calculate d orifice at ambient temp)
780 DOM = DO * (1 - 0.55 * (DH / DO)^2) / (1 + AO * (T - TO))
790 REM the following lines will print the output and restart the program
800 PRINT "Orifice diameter at To";DOM
810 PRINT "Beta ratio";B1
820 PRINT "Reynolds Number";RED
830 INPUT "A new calculation Y/N";A$
840 IF A$="Y" GOTO 10
850 END

```

APPENDIX A-3

SIZING FORM FOR SQUARE EDGE ORIFICES WITH RADIUS TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.2 \leq \beta \leq 0.75$	
Bleed hole size y	mm	$1260 \beta^2 D \leq Re_D \leq 10^4$	
Ratio of specific heats $\kappa = C_p/C_v$			
1. $D = D_m [1 + \alpha_{\text{pipe}} (T - T_0)]$		$D = \dots\dots\dots \text{mm}$	
2. $(Re_D)_{\text{des}} = \frac{1.2732 \cdot 10^6 (q_m)_{\text{des}}}{\eta D}$		$(Re_D)_{\text{des}} = \dots\dots\dots$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s = \dots\dots\dots$	
4. $\beta = \left[\frac{(q_m)_{\text{des}}^2}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{\text{des}}^2} \right]^{0.25}$		estimated $\beta = \dots\dots\dots$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon = \dots\dots\dots$	
6. $C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)_{\text{des}}} \right]^{0.75} + 0.039 \beta^4 (1 - \beta^4)^{-1} - 0.015839 \beta^3$		$C = \dots\dots\dots$	
7. $\beta = \left[\frac{28\,470.5 (q_m)_{\text{des}} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta = \dots\dots\dots$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. $d = \beta D$		$d = \dots\dots\dots \text{mm}$	
9. $d_m = d [1 - 0.55 (y/d)^2] [1 + \alpha_{\text{plate}} (T - T_0)]^{-1}$		$d_m = \dots\dots\dots \text{mm}$	
Calculated by: Date: Sign.:			

COMPUTER PROGRAM IN BASIC FOR A-3

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM
30 INPUT "Viscosity under operating conditions";N
40 INPUT "Operating temperature";T
50 INPUT "Density under operating conditions";R
60 INPUT "Operating pressure";P
70 INPUT "Internal pipe diameter at To";DM
80 INPUT "Transmitter range";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH
110 INPUT "Linear expansion coeff. pipe";AP
120 INPUT "Linear expansion coeff. orifice";AO
130 INPUT "Ambient temperature";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ) )
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated  $\beta$ )
590 B = (QM^2 / ( 4.6 * 10^-8 * D^4 * DPN * R + QM^2 )) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (calculate discharge coefficient)
640 C = 0.5959 + 0.0312 * B^2.1 - 0.184 * B^8 + 0.0029 * B^2.5 * (1000000 / RED)^0.75 +
    + 0.0039 * B^4 ( 1 - B^4 )^ - 1 - 0.015839 B^3
650 REM STEP 8 (calculate new  $\beta$ )
660 B1 = (2847.05 * QM / ( D^2 * E * FS * C * ( 1 - B^4 )^-0.5 * (DPN * R)^0.5 ))^0.5
670 REM check if calculated  $\beta$  agrees with previous  $\beta$  within 0.01%
680 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 600
690 REM STEP 9 (calculate d orifice at line temp)
700 DO = B1 * D
710 REM STEP 10 (calculate d orifice at ambient temp)
720 DOM = DO * ( 1 - 0.55 * (DH / DO)^2 ) / ( 1 + AO * ( T - TO ) )
730 REM the following lines will print the output and restart the program
740 PRINT "Orifice diameter at To";DOM
750 PRINT "Beta ratio";B1
760 PRINT "Reynolds Number";RED
770 INPUT "A new calculation Y/N";A$
780 IF A$="Y" GOTO 10
790 END

```

SIZING FORM FOR QUARTER OF CIRCLE ORIFICES WITH FLANGE TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diam. d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Orifice r	mm	Linear expansion coeff. α_{plate}	/°C
Internal pipe dia. D_m at T_0	mm	Ambient temp. T_0	°C
Transmitter range DP	bar	Limitations: $0.245 \leq \beta \leq 0.6$	
Indication X of q_m on scale (0-10)		$1000\beta + 9.4 \cdot 10^6 (\beta - 0.24)^3 \leq Re_D \leq 10^5 \beta$	
Bleed hole size y	mm		
Ratio of specific heats $\kappa = C_p/C_v$			
1. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$	mm
2. $(Re_D)_{des} = \frac{1.2732 \cdot 10^6 (q_m)_{des}}{\eta D}$		$(Re_D)_{des} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)_{des}^2}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{des}^2} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $C = 0.73823 + 0.3309 \beta - 1.1615 \beta^2 + 1.5084 \beta^3$		$C =$	
7. $\beta = \left[\frac{28\,470.5 (q_m)_{des} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. $d = \beta D$		$d =$	mm
9. $d_m = d [1 - 0.55 (y/d)^2] [1 + \alpha_{plate} (T - T_0)]^{-1}$		$d_m =$	mm
10. $r = \frac{(0.0757141 \beta - 0.06253143) d}{\beta - 0.6828572}$		$r =$	mm
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR A-4

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM [ kg/s];QM
30 INPUT "Viscosity under operating conditions";N [ m Pa·s];N
40 INPUT "Operating temperature";T [ °C];T
50 INPUT "Density under operating conditions";R [ kg/m3];R
60 INPUT "Operating pressure";P [ bar];P
70 INPUT "Internal pipe diameter at To";DM [ mm];DM
80 INPUT "Transmitter range";DP [ bar];DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH [ mm];DH
110 INPUT "Linear expansion coeff. pipe";AP [ /°C];AP
120 INPUT "Linear expansion coeff. orifice";AO [ /°C];AO
130 INPUT "Ambient temperature";TO [ °C];TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W [%];W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated β)
590 B = (QM^2 / (4.6 * 10^-8 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (calculate discharge coefficient)
640 C = 0.73823 + 0.3309 * B - 1.1615 * B^2 + 1.5084 * B^3
650 REM STEP 8 (calculate new β)
660 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
670 REM check if calculated β agrees with previous β within 0.01%
680 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 600
690 REM STEP 9 (calculate d orifice at line temp)
700 DO = B1 * D
710 REM STEP 10 (calculate d orifice at ambient temp)
720 DOM = DO * (1 - 0.55 * (DH / DO)^2) / (1 + AO * (T - TO))
730 REM STEP 11 (calculate the radius)
740 RA = (0.0757141 * B1 - 0.06253143) * DOM / (B1 - 0.6828572)
750 REM the following lines will print the output and restart the program
760 PRINT "Orifice diameter at To";DOM [ mm];DOM
770 PRINT "The radius of the orifice";RA [ mm];RA
780 PRINT "Beta ratio";B1
790 PRINT "Reynolds Number";RED
800 INPUT "A new calculation Y/N";A$
810 IF A$="Y" GOTO 10
820 END

```

APPENDIX A-5

SIZING FORM FOR CONICAL ENTRANCE ORIFICES WITH CORNER TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.1 \leq \beta \leq 0.316$	
Bleed hole size y	mm	$250 \beta \leq Re_D \leq 2 \cdot 10^5 \beta$	
Ratio of specific heats $\kappa = C_p/C_v$			
1. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
2. $(Re_D)_{des} = \frac{1.2732 \cdot 10^6 (q_m)_{des}}{\eta D}$		$(Re_D)_{des} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)_{des}^2}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{des}^2} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $C = 0.734$ for $250 \beta \leq Re_D \leq 5000 \beta$ $C = 0.730$ for $5000 \beta \leq Re_D \leq 2 \cdot 10^5 \beta$		$C =$	
7. $\beta = \left[\frac{28\,470.5 (q_m)_{des} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. If $Re_D \geq 10^6$ then $Z_{Re_D} = Z_0$, otherwise $Z_{Re_D} = (Z_0 - 1) [\log (Re_D)/6]^2 + 1$		$Z_{Re_D} =$	
9. $\beta = \beta (Z_{Re_D})^{-0.5}$		corrected $\beta =$	
10. $d = \beta D$		$d =$ mm	
11. $d_m = d [1 - 0.55 (y/d)^2] [1 + \alpha_{plate} (T - T_0)]^{-1}$		$d_m =$ mm	
Calculated by: Date: Sign.:			

COMPUTER PROGRAM IN BASIC FOR A-5

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM
30 INPUT "Viscosity under operating conditions";N
40 INPUT "Operating temperature";T
50 INPUT "Density under operating conditions";R
60 INPUT "Operating pressure";P
70 INPUT "Internal pipe diameter at To";DM
80 INPUT "Transmitter range";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH
110 INPUT "Linear expansion coeff. pipe";AP
120 INPUT "Linear expansion coeff. orifice";AO
130 INPUT "Ambient temperature";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated  $\beta$ )
590 B = (QM^2 / (4.6 * 10^-8 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (calculate discharge coefficient)
640 IF RED >= 250 * B AND RED <= 5000 * B THEN C = 0.734
650 IF RED > 5000 * B AND RED <= 20000 * B THEN C = 0.730
660 REM STEP 8 (calculate new  $\beta$ )
670 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
680 REM check if calculated  $\beta$  agrees with previous  $\beta$  within 0.01%
690 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 600
700 REM STEP 9 (check on roughness correction factor)
710 PRINT "Beta ratio";B1
720 INPUT "Roughness correction factor Zo";ZO
730 IF RED >= 1000000 THEN ZRED=ZO ELSE ZRED =(ZO-1)*(LOG(RED/1000000))^2 +1
740 REM STEP 10 (calculate corrected  $\beta$ )
750 B1 = B1 / ZRED^0.5
760 REM STEP 11 (calculate d orifice at line temp)
770 DO = B1 * D
780 REM STEP 12 (calculate d orifice at ambient temp)
790 DOM = DO * (1 - 0.55 * (DH / DO)^2) / (1 + AO * (T - TO))
800 REM the following lines will print the output and restart the program
810 PRINT "Orifice diameter at To";DOM
820 PRINT "Beta ratio";B1
830 PRINT "Reynolds Number";RED
840 INPUT "A new calculation Y/N";A$
850 IF A$="Y" GOTO 10
860 END

```

APPENDIX A-6

SIZING FORM FOR VENTURI TUBES (A, B AND C)			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Venturi throat diameter d_m at T_0	mm	Linear expansion coeff. $\alpha_{venturi}$	/°C
Venturi inlet dia. D_m at T_0	mm	Ambient temp. T_0	°C
Transmitter range DP	bar	Limitations:	
Indication X of q_m on scale (0-10)		Type A: $0.3 \leq \beta \leq 0.75$ and $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$	
Ratio of specific heats $\kappa = C_p/C_v$		Type B: $0.4 \leq \beta \leq 0.75$ and $2 \cdot 10^5 \leq Re_D \leq 10^6$	
		Type C: $0.4 \leq \beta \leq 0.70$ and $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$	
1. $D = D_m [1 + \alpha_{venturi} (T - T_0)]$		$D =$ mm	
2. $(Re_D)_{des} = \frac{1.2732 \cdot 10^6 (q_m)_{des}}{\eta D}$		$(Re_D)_{des} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)_{des}^2}{(12.3 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{des}^2} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$ N.B.: If the fluid is a liquid $\epsilon = 1$			
6. Type A: In case of rough cast convergent $C = 0.984$ Type B: In case of machine convergent $C = 0.995$ Type C: In case of rough cast, welded sheet iron convergent $C = 0.985$		$C =$	
7. $\beta = \left[\frac{28\,470.5 (q_m)_{des} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. $d = \beta D$		$d =$ mm	
9. $d = d_m [1 + \alpha_{venturi} (T - T_0)]$		$d_m =$ mm	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR A-6

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Type of Venturi A, B or C";T$
30 IF T$<>"A" OR T$<>"B" OR T$<>"C" THEN GOTO 20
40 INPUT "Approx. normal flow";QM [ kg/s];QM
50 INPUT "Viscosity under operating conditions";N [ m Pa·s];N
60 INPUT "Operating temperature";T [ °C];T
70 INPUT "Density under operating conditions";R [ kg/m3];R
80 INPUT "Operating pressure";P [ bar];P
90 INPUT "Internal pipe diameter at To";DM [ mm];DM
100 INPUT "Transmitter range";DP [ bar];DP
110 INPUT "Indication of normal flow on scale (0-10)";X
120 INPUT "Linear expansion coeff. Venturi";AP [ /°C];AP
130 INPUT "Ambient temperature";TO [ °C];TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W [ %];W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated β)
590 B = (QM^2 / (1.23 * 10^-7 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="L" THEN GOTO 650
630 K = (P-DPN)/P
640 K1 = K^(2/Y)
650 K2 = K^((Y-1)/Y)
660 E=((Y*K1/(Y-1))*((1-B^4)/(1-B^4*K1))*((1-K2)/(1-K)))^0.5
670 REM STEP 7
680 IF T$="A" THEN C=0.984
690 IF T$="B" THEN C=0.995
700 IF T$="C" THEN C=0.985
710 REM STEP 8 (calculate new β)
720 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
730 REM check if calculated β agrees with previous β within 0.01%
740 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 580
750 REM STEP 9 (calculate d orifice at line temp)
760 DO = B1 * D
770 REM STEP 10 (calculate d orifice at ambient temp)
780 DOM = DO / ( 1 + AP * ( T - TO ))
790 REM the following lines will print the output and restart the program
800 PRINT "Orifice diameter at To"; [ mm];DOM
810 PRINT "Beta ratio";B1
820 PRINT "Reynolds Number";RED
830 INPUT "A new calculation Y/N";A$
840 IF A$="Y" GOTO 10
850 END

```

APPENDIX A-7

SIZING FORM FOR RECTANGULAR VENTURI TUBES			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Throat width w at T_0	mm	Linear expansion coeff. α_{venturi}	/°C
Throat height h at T_0	mm	Ambient temp. T_0	°C
Duct width W at T_0	mm	Limitations: $0.44 \leq \sqrt{\frac{wh}{WH}} \leq 0.74$ $2 \cdot 10^3 \leq Re_D \leq 2 \cdot 10^7$	
Duct height H at T_0	mm		
Transmitter range DP	bar		
Indication X of q_m on scale (0-10)			
Ratio of specific heats $\kappa = C_p/C_v$			
1. $D_e = 1.1284 (WH)^{0.5}$		$D_e = \dots\dots\dots$ mm	
2. $D = D_e [1 + \alpha_{\text{venturi}} (T - T_0)]$		$D = \dots\dots\dots$ mm	
3. $(Re_D)_{\text{des}} = \frac{1.2732 \cdot 10^6 (q_m)_{\text{des}}}{\eta D}$		$(Re_D)_{\text{des}} = \dots\dots\dots$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s = \dots\dots\dots$	
5. $\beta = \left[\frac{(q_m)_{\text{des}}^2}{(12.3 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{\text{des}}^2} \right]^{0.25}$		estimated $\beta = \dots\dots\dots$	
6. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon = \dots\dots\dots$	
Where: $K = [p - (DP) (X/10)^2]/p$			
N.B.: If the fluid is a liquid $\epsilon = 1$			
7. $C = 0.975$		$C = 0.975$	
8. $\beta = \left[\frac{28\,470.5 (q_m)_{\text{des}} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta = \dots\dots\dots$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
9. In case of two-plane contraction select w and h $wh = \beta^2 WH$ $w =$ $h =$		$wh = \dots\dots\dots$ mm ² $w = \dots\dots\dots$ mm $h = \dots\dots\dots$ mm	
10. In case of one-plane contraction $w = \beta^2 w$ $h =$		$w = \dots\dots\dots$ mm $h = \dots\dots\dots$ mm	
Calculated by: Date: Sign.:			

COMPUTER PROGRAM IN BASIC FOR A-7

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM [ kg/s];
30 INPUT "Viscosity under operating conditions";N [ m Pa·s];
40 INPUT "Operating temperature";T [ °C];
50 INPUT "Density under operating conditions";R [ kg/m3];
60 INPUT "Operating pressure";P [ bar];
70 INPUT "Pipe width at To";PW [ mm];
80 INPUT "Pipe height at To";PH [ mm];
90 INPUT "Transmitter range";DP [ bar];
100 INPUT "Indication of normal flow on scale (0-10)";X
110 INPUT "Linear expansion coeff. Venturi";AP [ /°C];
120 INPUT "Ambient temperature";TO [ °C];
130 IF FLUID$="L" THEN W=0 :GOTO 500
140 INPUT "Ratio of specific heats Cp/Cv";Y
150 IF FLUID$="G" GOTO 500
160 INPUT "Water content in wet steam";W [ %];
500 REM STEP 1 (calculate D under operating conditions)
510 DM = 1.1284 * ( PH * PW )^0.5
520 REM STEP 2
530 D = DM * ( 1 + AP * ( T - TO ) )
540 REM STEP 3 (calculate ReD)
550 RED = 1273200 * QM / ( N * D )
560 REM STEP 4 (calculate steam correction factor Fs)
570 FS = 1 + 0.0074 * W
580 REM STEP 5 (calculate dp at normal flow indication)
590 DPN = DP * ( X / 10 )^2
600 REM STEP 6 (calculate estimated β)
610 B = (QM^2 / (1.23 * 10^-7 * D^4 * DPN * R + QM^2)) ^0.25
620 REM STEP 7 (calculate epsilon)
630 E = 1
640 IF FLUID$="L" THEN GOTO 690
650 K = ( P - DPN )/P
660 K1 = K^(2/Y)
670 K2 = K^((Y - 1)/Y)
680 E=((Y *K1 / (Y - 1)) * ((1 - B^4) / (1 - B^4 *K1)) * ((1 - K2) / (1 - K)))^0.5
690 REM STEP 8
700 C=0.975
710 REM STEP 9 (calculate new β)
720 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
730 REM check if calculated β agrees with previous β within 0.01%
740 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 620
750 REM STEP 10 (calculate d orifice at line temp)
760 PRINT "For two-plane contraction:"
770 PRINT "Throat width * height"; [ mm];B1^2 * PW * PH
780 REM STEP 11
790 PRINT "For one-plane contraction:"
800 PRINT "Throat width"; [ mm];B1^2 * PW
810 PRINT "Throat height"; [ mm];PH
820 REM the following lines will print the output and restart the program
830 PRINT "Beta ratio";B1
840 PRINT "Reynolds Number";RED
850 INPUT "A new calculation Y/N";A$
860 IF A$="Y" GOTO 10
870 END

```

APPENDIX A-8

SIZING FORM FOR ISA 1932 NOZZLES			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Throat diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{nozzle}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.3 \leq \beta \leq 0.8$	
Ratio of specific heats $\kappa = C_p/C_v$		$70\,000 \leq Re_D \leq 10^7$ for $0.30 \leq \beta \leq 0.44$	
		$20\,000 \leq Re_D \leq 10^7$ for $0.44 < \beta \leq 0.80$	
1. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
2. $(Re_D)_{des} = \frac{1.2732 \cdot 10^6 (q_m)_{des}}{\eta D}$		$(Re_D)_{des} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)_{des}^2}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)_{des}^2} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$ N.B.: If the fluid is a liquid $\epsilon = 1$			
6. $C = 0.99 - 0.2262 \beta^{4.1} +$ $+ [0.000215 - 0.001125 \beta + 0.00249 \beta^{4.7}] \cdot \left[\frac{10^6}{(Re_D)_{des}} \right]^{1.15}$		$C =$	
7. $\beta = \left[\frac{28\,470.5 (q_m)_{des} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho (DP)}} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. $d = \beta D$		$d =$ mm	
9. $d_m = d [(1 + \alpha_{nozzle} (T - T_0))^{-1}]$		$d_m =$ mm	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR A-8

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM
30 INPUT "Viscosity under operating conditions";N
40 INPUT "Operating temperature";T
50 INPUT "Density under operating conditions";R
60 INPUT "Operating pressure";P
70 INPUT "Nozzle pipe diameter at To";DM
80 INPUT "Transmitter range";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Linear expansion coeff. of the pipe";AP
110 INPUT "Linear expansion coeff. of the nozzle";AO
120 INPUT "Ambient temperature";TO
130 IF FLUID$="L" THEN W=0 :GOTO 500
140 INPUT "Ratio of specific heats Cp/Cv";Y
150 IF FLUID$="G" GOTO 500
160 INPUT "Water content in wet steam";W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated beta)
590 B = (QM^2 / (4.6 * 10^-8 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="L" THEN GOTO 670
630 K = (P-DPN)/P
640 K1 = K^(2/Y)
650 K2 = K^((Y-1)/Y)
660 E=((Y*K1/(Y-1))*((1-B^4)/(1-B^4*K1))*((1-K2)/(1-K)))^0.5
670 REM STEP 7 (calculate discharge coefficient)
680 C = 0.99 - 0.2262 * B^4.1 + (0.000215 - 0.001125 * B + 0.00249 * B^4.7) * (1000000 / RED)^1.15
690 B1 = (2847.05 * QM / (D^2 * E * FS * C * (1 - B^4)^-0.5 * (DPN * R)^0.5))^0.5
700 REM check if calculated beta agrees with previous beta within 0.01%
710 IF ABS ((B - B1) / B1) > 0.0001 THEN B=B1 : GOTO 600
720 REM STEP 9 (calculate d nozzle at line temp)
730 DO = B1 * D
740 REM STEP 10 (calculate d nozzle at ambient temp)
750 DOM = DO / ( 1 + AO * ( T - TO ))
760 REM the following lines will print the output and restart the program
770 PRINT "Orifice diameter nozzle at To [ mm]";DOM
780 PRINT "Beta ratio";B1
790 PRINT "Reynolds Number";RED
800 INPUT "A new calculation Y/N";A$
810 IF A$="Y" GOTO 10
820 END

```

APPENDIX A-9

SIZING FORM FOR LONG RADIUS NOZZLES			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Throat diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{nozzle}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.2 \leq \beta \leq 0.80$	
Ratio of specific heats $\kappa = C_p/C_v$		$10^4 \leq Re_D \leq 10^7$	
1. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
2. $(Re_D)_{des} = \frac{1.2732 \cdot 10^6 (q_m)_{des}}{\eta D}$		$(Re_D)_{des} =$	
3. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
4. $\beta = \left[\frac{(q_m)^2_{des}}{(4.6 \cdot 10^{-10} D^4 (DP) X^2 \rho) + (q_m)^2_{des}} \right]^{0.25}$		estimated $\beta =$	
5. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$ N.B.: If the fluid is a liquid $\epsilon = 1$			
6. $C = 0.9965 - 0.00653 \beta^{0.5} \left[\frac{10^6}{(Re_D)_{des}} \right]^{0.5}$		$C =$	
7. $\beta = \left[\frac{28470.5 (q_m)_{des} \sqrt{1 - \beta^4}}{D^2 \epsilon C X F_s \sqrt{\rho} (DP)} \right]^{0.5}$		calculated $\beta =$	
Repeat 5 through 7 until calculated β agrees with previously calculated β to within 0.01%			
8. $d = \beta D$		$d =$ mm	
9. $d_m = d [(1 + \alpha_{nozzle} (T - T_0))^{-1}]$		$d_m =$ mm	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR A-9

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Approx. normal flow";QM [ kg/s];QM
30 INPUT "Viscosity under operating conditions";N [ m Pa·s];N
40 INPUT "Operating temperature";T [ °C];T
50 INPUT "Density under operating conditions";R [ kg/m3];R
60 INPUT "Operating pressure";P [ bar];P
70 INPUT "Nozzle pipe diameter at To";DM [ mm];DM
80 INPUT "Transmitter range";DP [ bar];DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Linear expansion coeff. of the pipe";AP [ /°C];AP
110 INPUT "Linear expansion coeff. of the nozzle";AO [ /°C];AO
120 INPUT "Ambient temperature";TO [ °C];TO
130 IF FLUID$="L" THEN W=0 :GOTO 500
140 INPUT "Ratio of specific heats Cp/Cv";Y
150 IF FLUID$="G" GOTO 500
160 INPUT "Water content in wet steam";W [%];W
500 REM STEP 1 (calculate D under operating conditions)
510 D = DM * ( 1 + AP * ( T - TO ))
520 REM STEP 2 (calculate ReD)
530 RED = 1273200 * QM / ( N * D )
540 REM STEP 3 (calculate steam correction factor Fs)
550 FS = 1 + 0.0074 * W
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * ( X / 10 )^2
580 REM STEP 5 (calculate estimated β)
590 B = (QM^2 / (4.6 * 10^-8 * D^4 * DPN * R + QM^2)) ^0.25
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="L" THEN GOTO 670
630 K = (P-DPN)/P
640 K1 = K^(2/Y)
650 K2 = K^((Y-1)/Y)
660 E=((Y*K1/(Y-1))*((1-B^4)/(1-B^4*K1))*((1-K2)/(1-K)))^0.5
670 REM STEP 7 (calculate discharge coefficient)
680 C = 0.9965 -0.00653 *B^0.5 *(1000000 / RED)^1.15
690 B1 = (2847.05 *QM / (D^2 *E *FS *C *(1 -B^4)^-0.5 *(DPN* R)^0.5))^0.5
700 REM check if calculated β agrees with previous β within 0.01%
710 IF ABS ((B -B1) /B1) > 0.0001 THEN B=B1 : GOTO 600
720 REM STEP 9 (calculate d nozzle at line temp)
730 DO = B1 * D
740 REM STEP 10 (calculate d nozzle at ambient temp)
750 DOM = DO / ( 1 +AO * (T -TO))
760 REM the following lines will print the output and restart the program
770 PRINT "Orifice diameter nozzle at To [ mm]";DOM
780 PRINT "Beta ratio";B1
790 PRINT "Reynolds Number";RED
800 INPUT "A new calculation Y/N";A$
810 IF A$="Y" GOTO 10
820 END

```


Appendix B

Flow factor calculation

- 1 Flow factor calculation form for square edge orifices with flange tappings
- 2 Flow factor calculation form for square edge orifices with corner tappings
- 3 Flow factor calculation form for square edge orifices with radius tappings
- 4 Flow factor calculation form for quarter of circle orifices with flange tappings
- 5 Flow factor calculation form for conical entrance orifices with corner tappings
- 6 Flow factor calculation form for Venturi tubes (A, B and C)
- 7 Flow factor calculation form for rectangular Venturi tubes
- 8 Flow factor calculation form for ISA 1932 nozzles
- 9 Flow factor calculation form for long radius nozzles

Note:

For the computer program in Basic as given in the following sheets, the accuracy of the calculation depends on the type of computer used, and the type of variable. The listings are written with single-position variables, double-position will increase the accuracy.

APPENDIX B-1

FLOW FACTOR CALCULATION FORM FOR SQUARE EDGE ORIFICES WITH FLANGE TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.2 \leq \beta \leq 0.75$	
Bleed hole size y	mm	$1260 \beta^2 D \leq Re_D \leq 10^8$	
Ratio of specific heats $\kappa = C_p/C_v$			
1. $d = d_m [1 + 0.55 (y/d_m)^2] [1 + \alpha_{plate} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $q_m = 2.107 \cdot 10^{-5} \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 \sqrt{DP} \rho$		estimated $q_m =$ kg/s	
7. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
8. $C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)} \right]^{0.75} +$ $+ \left[\frac{2.286}{D} \right] \beta^4 \cdot (1 - \beta^4)^{-1} - \left[\frac{0.85598}{D} \right] \beta^3$		$C =$	
Note: If $D < 58.615$ mm use 0.0390 as coefficient of $\beta^4 (1 - \beta^4)^{-1}$			
9. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP} \rho$		calculated $q_m =$ kg/s	
Repeat 7 through 9 until calculated q_m agrees with previously calculated q_m to within 0.01%			
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR B-1

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions [ m Pa·s]:";N
30 INPUT "Operating temperature [ °C]:";T
40 INPUT "Density under operating conditions [ kg/m3]:";R
50 INPUT "Operating pressure [ bar]:";P
60 INPUT "Internal pipe diameter at To [ mm]:";DM
70 INPUT "Orifice diameter at To [ mm]:";DOM
80 INPUT "Transmitter range [ bar]:";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size [ mm]:";DH
110 INPUT "Linear expansion coeff. pipe [ /°C]:";AP
120 INPUT "Linear expansion coeff. orifice [ /°C]:";AO
130 INPUT "Ambient temperature [ °C]:";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam [ %]:";W
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + 0.55 * (DH / DOM)^2) * (1 + AO * (T - TO))
520 REM STEP 2 (calculate D under operating conditions)
530 D = DM * (1 + AP * (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DO / D
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * (X / 10)^2
580 REM STEP 5 (calculate steam correction factor Fs)
590 FS = 1 + 0.0074 * W
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7
640 QM = 2.107 * 10^-4 * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
650 REM STEP 8 (calculate ReD)
660 RED = 1273200 * QM / (N * D)
670 REM STEP 9 (calculate discharge coefficient)
680 C = 0.5959 + 0.0312 * B^2.1 - 0.184 * B^8 + 0.0029 * B^2.5 *
    * (1000000 / RED)^0.75 - 0.85598 * B^3 / D
690 IF D < 58.615 THEN C = C + 0.039 * B^4 / (1 - B^4) : GOTO 710
700 C = C + 2.286 * B^4 / (D * (1 - B^4))
710 REM STEP 10 (calculate new QM)
720 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
730 REM check if calculated QM agrees with previous QM within 0.01%
740 IF ABS ((QM - QM1) / QM1) > 0.0001 THEN QM=QM1 : GOTO 650
750 REM the following lines will print the output and restart the program
760 PRINT "Normal flow at scale [ kg/s]:";QM1
770 PRINT "Flow factor [ kg/s]:";QM1/X
780 PRINT "Beta ratio";B
790 PRINT "Reynolds Number";RED
800 INPUT "A new calculation Y/N";A$
810 IF A$="Y" GOTO 10
820 END

```

APPENDIX B-2

FLOW FACTOR CALCULATION FORM FOR SQUARE EDGE ORIFICES WITH CORNER TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.23 \leq \beta \leq 0.80$	
Bleed hole size y	mm	$5000 \leq Re_D \leq 10^8$ for $0.23 \leq \beta \leq 0.45$	
Ratio of specific heats $\kappa = C_p/C_v$		$10\,000 \leq Re_D \leq 10^8$ for $0.45 < \beta \leq 0.77$	
		$20\,000 \leq Re_D \leq 10^8$ for $0.77 < \beta \leq 0.80$	
1. $d = d_m [1 + 0.55 (y/d_m)^2] [1 + \alpha_{plate} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $q_m = 2.107 \times 10^{-5} \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 \sqrt{DP} \rho$		estimated $q_m =$ kg/s	
7. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
8. $C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)} \right]^{0.75}$		$C =$	
9. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP} \rho$		calculated $q_m =$ kg/s	
Repeat 7 through 9 until calculated q_m agrees with previously calculated q_m to within 0.01%			
10. If $Re_D \geq 10^6$ then $Z_{Re_D} = Z_0$, otherwise $Z_{Re_D} = (Z_0 - 1) [\log (Re_D)/6]^2 + 1$		$Z_{Re_D} =$	
11. $q_m = q_m Z_{Re_D}$		corrected $q_m =$ kg/s	
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR B-2

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions [ m Pa·s]";N
30 INPUT "Operating temperature [ °C]";T
40 INPUT "Density under operating conditions [ kg/m3]";R
50 INPUT "Operating pressure [ bar]";P
60 INPUT "Internal pipe diameter at To [ mm]";DM
70 INPUT "Orifice diameter at To [ mm]";DOM
80 INPUT "Transmitter range [ bar]";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size [ mm]";DH
110 INPUT "Linear expansion coeff. pipe [ /°C]";AP
120 INPUT "Linear expansion coeff. orifice [ /°C]";AO
130 INPUT "Ambient temperature [ °C]";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam [ %]";W
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + 0.55 * (DH / DOM)^2) * (1 + AO * (T - TO))
520 REM STEP 2 (calculate D under operating conditions)
530 D = DM * (1 + AP * (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DO / D
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * (X / 10)^2
580 REM STEP 5 (calculate steam correction factor Fs)
590 FS = 1 + 0.0074 * W
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7
640 QM = 2.107 * 10^-4 * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
650 REM STEP 8 (calculate ReD)
660 RED = 1273200 * QM / (N * D)
670 REM STEP 9 (calculate discharge coefficient)
680 C = 0.5959 + 0.0312 * B^2.1 - 0.184 * B^8 + 0.0029 * B^2.5 * (1000000 / RED)^0.75
690 REM STEP 10 (calculate new QM)
700 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
710 REM check if calculated QM agrees with previous QM within 0.01%
720 IF ABS ((QM - QM1) / QM1) > 0.0001 THEN QM=QM1 : GOTO 650
730 REM STEP 11
740 PRINT "Beta ratio";B
750 INPUT "Roughness correction factor Zo";ZO
760 IF RED >= 1000000 THEN ZRED=ZO ELSE ZRED = (ZO-1)*(LOG(RED/1000000))^2 + 1
770 QM1 = QM1 * ZRED
780 REM the following lines will print the output and restart the program
790 PRINT "Normal flow at scale [ kg/s]";QM1
800 PRINT "Flow factor [ kg/s]";QM1/X
810 PRINT "Beta ratio";B
820 PRINT "Reynolds Number";RED
830 INPUT "A new calculation Y/N";A$
840 IF A$="Y" GOTO 10
850 END

```

APPENDIX B-3

FLOW FACTOR CALCULATION FORM FOR SQUARE EDGE ORIFICES WITH RADIUS TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.2 \leq \beta \leq 0.75$	
Bleed hole size y	mm	$1260 \beta^2 D \leq Re_D \leq 10^8$	
Ratio of specific heats $\kappa = C_p/C_v$			
1. $d = d_m [1 + 0.55 (y/d_m)^2] [1 + \alpha_{plate} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $q_m = 2.107 \cdot 10^{-5} \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 \sqrt{DP \rho}$		estimated $q_m =$ kg/s	
7. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
8. $C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^3 + 0.0029 \beta^{2.5} \left[\frac{10^6}{(Re_D)} \right]^{0.75} +$ $+ 0.039 \beta^4 (1 - \beta^4)^{-1} - 0.015839 \beta^3$		$C =$	
9. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP \rho}$		calculated $q_m =$ kg/s	
Repeat 7 through 9 until calculated q_m agrees with previously calculated q_m to within 0.01%			
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign.:			

COMPUTER PROGRAM IN BASIC FOR B-3

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions";N
   [ m Pa·s];N
30 INPUT "Operating temperature";T
   [ °C];T
40 INPUT "Density under operating conditions";R
   [ kg/m3];R
50 INPUT "Operating pressure";P
   [ bar];P
60 INPUT "Internal pipe diameter at To";DM
   [ mm];DM
70 INPUT "Orifice diameter at To";DOM
   [ mm];DOM
80 INPUT "Transmitter range";DP
   [ bar];DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH
   [ mm];DH
110 INPUT "Linear expansion coeff. pipe";AP
   [ / °C];AP
120 INPUT "Linear expansion coeff. orifice";AO
   [ / °C];AO
130 INPUT "Ambient temperature";TO
   [ °C];TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
   [ %];W
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + 0.55 * (DH / DOM)^2) * (1 + AO * (T - TO))
520 REM STEP 2 (calculate D under operating conditions)
530 D = DM * (1 + AP * (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DO / D
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * (X / 10)^2
580 REM STEP 5 (calculate steam correction factor Fs)
590 FS = 1 + 0.0074 * W
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7
640 QM = 2.107 * 10^-4 * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
650 REM STEP 8 (calculate ReD)
660 RED = 1273200 * QM / (N * D)
670 REM STEP 9 (calculate discharge coefficient)
680 C = 0.5959 + 0.0312 * B^2.1 - 0.184 * B^8 + 0.0029 * B^2.5 *
   (1000000 / RED)^0.75 + 0.039 * B^4 / (1 - B^4) - 0.015839 * B^3
690 REM STEP 10 (calculate new QM)
700 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
710 REM check if calculated QM agrees with previous QM within 0.01%
720 IF ABS ((QM - QM1) / QM1) > 0.0001 THEN QM=QM1 : GOTO 650
730 REM the following lines will print the output and restart the program
740 PRINT "Normal flow at scale";Q1
   [ kg/s];Q1
750 PRINT "Flow factor";Q1/X
   [ kg/s];Q1/X
760 PRINT "Beta ratio";B
770 PRINT "Reynolds Number";RED
780 INPUT "A new calculation Y/N";A$
790 IF A$="Y" GOTO 10
800 END

```

APPENDIX B-4

FLOW FACTOR CALCULATION FORM FOR QUARTER OF CIRCLE ORIFICES WITH FLANGE TAPPINGS

PLANT: TAG No.:
SERVICE:

DATA TO BE SUPPLIED BY OPERATIONS

Approx. norm. quantity q_m	 kg/s	Density ρ under operating cond.	 kg/m ³
Viscosity η under operating cond.	 mPa·s	Operating pressure p	 bar
Operating temp. T	 °C	Water content in wet steam	 % wt

Orifice diameter d_m at T_0	 mm	Linear expansion coeff. α_{pipe}	 /°C
Internal pipe dia. D_m at T_0	 mm	Linear expansion coeff. α_{plate}	 /°C
Transmitter range DP	 bar	Ambient temp. T_0	 °C
Indication X of q_m on scale (0-10)		Limitations:	$0.245 \leq \beta \leq 0.6$
Bleed hole size y	 mm		$1000 \beta + 9.4 \cdot 10^5 (\beta - 0.24)^8 \leq Re_D \leq 10^5 \beta$
Ratio of specific heats $\kappa = C_p/C_v$			

1. $d = d_m [1 + 0.55 (y/d_m)^2] [1 + \alpha_{plate} (T - T_0)]$ $d = \dots\dots\dots$ mm

2. $D = D_m [1 + \alpha_{\text{pipe}} (T - T_0)]$ $D = \dots \text{ mm}$

3. $\beta = d/D$ $\beta =$

4. $F_s = 1 + 0.0074 W_t$ $F_s = \dots\dots\dots$
For gas and liquid $F_s = 1$

5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ $\epsilon = \dots\dots\dots$
 N.B.: If the fluid is a liquid $\epsilon = 1$

6. $C = 0.73823 + 0.3309 \beta - 1.1615 \beta^2 + 1.5084 \beta^3$ $C = \dots\dots\dots$

7. $q_m = 3.512407 \cdot 10^{-5} \text{ C} \frac{1}{\sqrt{1 - \beta^4}} \epsilon \times d^2 F_s \sqrt{DP \rho}$ calculated $q_m = \dots\dots\dots \text{ kg/s}$

8. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\pi D}$ $Re_D = \dots$

X =

Flow factor $q_m/X = \dots\dots\dots$ kg/s

Calculated by: Date: Sign:

COMPUTER PROGRAM IN BASIC FOR B-4

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions [ m Pa·s]";N
30 INPUT "Operating temperature [ °C]";T
40 INPUT "Density under operating conditions [ kg/m3]";R
50 INPUT "Operating pressure [ bar]";P
60 INPUT "Internal pipe diameter at To [ mm]";DM
70 INPUT "Orifice diameter at To [ mm]";DOM
80 INPUT "Transmitter range [ bar]";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size [ mm]";DH
110 INPUT "Linear expansion coeff. pipe [ /°C]";AP
120 INPUT "Linear expansion coeff. orifice [ /°C]";AO
130 INPUT "Ambient temperature [ °C]";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam [ %]";W
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + 0.55 * (DH / DOM)^2) * (1 + AO * (T - TO))
520 REM STEP 2 (calculate D under operating conditions)
530 D = DM * (1 + AP * (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DO / D
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * (X / 10)^2
580 REM STEP 5 (calculate steam correction factor Fs)
590 FS = 1 + 0.0074 * W
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (calculate discharge coefficient)
640 C = 0.73823 + 0.3309 * B - 1.1615 * B^2 + 1.5084 * B^3
650 REM STEP 8 (calculate QM)
660 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
670 REM STEP 9 (calculate ReD)
680 RED = 1273200 * QM1 / (N * D)
690 REM the following lines will print the output and restart the program
700 PRINT "Normal flow at scale [ kg/s]";QM1
710 PRINT "Flow factor [ kg/s]";QM1/X
720 PRINT "Beta ratio";B
730 PRINT "Reynolds Number";RED
740 INPUT "A new calculation Y/N";A$
750 IF A$="Y" GOTO 10
760 END

```

APPENDIX B-5

FLOW FACTOR CALCULATION FORM FOR CONICAL ENTRANCE ORIFICES WITH CORNER TAPPINGS			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Orifice diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{plate}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.1 \leq \beta \leq 0.316$	
Bleed hole size y	mm	$250 \beta \leq Re_D \leq 2 \cdot 10^5 \beta$	
Ratio of specific heats $\kappa = C_p/C_v$			
1. $d = d_m [1 + 0.55 (y/d_m)^2] [1 + \alpha_{plate} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = 1 - [0.41 + 0.35 \beta^4] \cdot [(DP)/p] \cdot [X/10]^2 \cdot \kappa^{-1}$ N.B.: If the fluid is a liquid $\epsilon = 1$		$\epsilon =$	
6. $C = 0.734$ for $250 \beta \leq Re_D \leq 5000 \beta$ $C = 0.730$ for $5000 \beta \leq Re_D \leq 2 \cdot 10^5 \beta$ Note: assume $Re_D < 5000 \beta$		$C =$	
7. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP \rho}$ calculated $q_m =$ kg/s			
8. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
9. Has the correct C factor been used, if not, recalculate q_m with the correct factor			
10. If $Re_D \geq 10^6$ then $Z_{Re_D} = Z_0$, otherwise $Z_{Re_D} = (Z_0 - 1) [\log (Re_D)/6]^2 + 1$		$Z_{Re_D} =$	
11. $q_m = q_m Z_{Re_D}$		corrected $q_m =$ kg/s	
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR B-5

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions";N
   [ m Pa·s];
30 INPUT "Operating temperature";T
   [ °C];
40 INPUT "Density under operating conditions";R
   [ kg/m3];
50 INPUT "Operating pressure";P
   [ bar];
60 INPUT "Internal pipe diameter at To";DM
   [ mm];
70 INPUT "Orifice diameter at To";DOM
   [ mm];
80 INPUT "Transmitter range";DP
   [ bar];
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Bleed hole size";DH
   [ mm];
110 INPUT "Linear expansion coeff. pipe";AP
   [ /°C];
120 INPUT "Linear expansion coeff. orifice";AO
   [ /°C];
130 INPUT "Ambient temperature";TO
   [ °C];
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
   [ %];
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + 0.55 * (DH / DOM)^2) * (1 + AO * (T - TO))
520 REM STEP 2 (calculate D under operating conditions)
530 D = DM * (1 + AP * (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DO / D
560 REM STEP 4 (calculate dp at normal flow indication)
570 DPN = DP * (X / 10)^2
580 REM STEP 5 (calculate steam correction factor Fs)
590 FS = 1 + 0.0074 * W
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="G" OR FLUID$="S" THEN E = 1 - (0.41 + 0.35 * B^4) * (DPN/P)/Y
630 REM STEP 7 (select discharge coefficient)
640 C = 0.730
650 REM STEP 8 (calculate QM)
660 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
670 REM STEP 9 (calculate ReD)
680 RED = 1273200 * QM1 / (N * D)
690 IF RED * B > 5000 THEN GOTO 720
700 C = 0.734
710 GOTO 660
720 REM STEP 10 (enter roughness correction factor)
730 PRINT "Beta ratio";B
740 INPUT "Roughness correction factor Zo";ZO
750 IF RED >= 1000000 THEN ZRED=ZO ELSE ZRED = (ZO-1)*(LOG(RED/1000000))^2 + 1
760 QM1 = QM1 * ZRED
770 REM the following lines will print the output and restart the program
780 PRINT "Normal flow at scale";[ kg/s];QM1
790 PRINT "Flow factor";[ kg/s];QM1/X
800 PRINT "Beta ratio";B
810 PRINT "Reynolds Number";RED
820 INPUT "A new calculation Y/N";A$
830 IF A$="Y" GOTO 10
840 END

```

APPENDIX B-6

FLOW FACTOR CALCULATION FORM FOR VENTURI TUBES (A, B AND C)			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Venturi throat diameter d_m at T_0	mm	Linear expansion coeff. $\alpha_{Venturi}$	/°C
Venturi inlet dia. D_m at T_0	mm	Ambient temp. T_0	°C
Transmitter range DP	bar	Limitations:	
Indication X of q_m on scale (0-10)		Type A: $0.3 \leq \beta \leq 0.75$ and $2 \cdot 10^4 \leq Re_D \leq 2 \cdot 10^6$	
Ratio of specific heats $\kappa = C_p/C_v$		Type B: $0.4 \leq \beta \leq 0.75$ and $2 \cdot 10^4 \leq Re_D \leq 10^6$	
		Type C: $0.4 \leq \beta \leq 0.70$ and $2 \cdot 10^4 \leq Re_D \leq 2 \cdot 10^6$	
1. $d = d_m [1 + \alpha_{Venturi} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{Venturi} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$			
N.B.: If the fluid is a liquid $\epsilon = 1$			
6. Type A: In case of rough cast convergent		$C =$	
$C = 0.984$			
Type B: In case of machined convergent			
$C = 0.995$			
Type C: In case of rough cast, welded sheet iron convergent			
$C = 0.985$			
7. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP \rho}$		calculated $q_m =$ kg/s	
8. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR B-6

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Type of Venturi A, B or C";T$
30 IF T$<>"A" OR T$<>"B" OR T$<>"C" THEN GOTO 20
40 INPUT "Viscosity under operating conditions";N
50 INPUT "Operating temperature";T
60 INPUT "Density under operating conditions";R
70 INPUT "Operating pressure";P
80 INPUT "Internal pipe diameter at To";DM
90 INPUT "Internal throat diameter at To";DOM
100 INPUT "Transmitter range";DP
110 INPUT "Indication of normal flow on scale (0-10)";X
120 INPUT "Linear expansion coeff. Venturi";AP
130 INPUT "Ambient temperature";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam";W
500 REM STEP 1 (calculate  $\beta$  ratio)
510 B = DOM / DM
520 REM STEP 2 (calculate steam correction factor Fs)
530 FS = 1 + 0.0074 * W
540 REM STEP 3 (calculate dp at normal flow indication)
550 DPN = DP * (X / 10)^2
560 REM STEP 4 (calculate epsilon)
570 E = 1
580 IF FLUID$="L" THEN GOTO 650
590 K = (P - DPN) / P
600 K1 = K^(2/Y)
610 K2 = K^((Y - 1)/Y)
620 E=((Y * K1 / (Y - 1))*((1 - B^4)/(1 - B^4 * K1))*((1 - K2)/(1 - K)))^0.5
630 REM STEP 5 (calculate QM)
640 IF T$="A" THEN C=0.984
650 IF T$="B" THEN C=0.995
660 IF T$="C" THEN C=0.985
670 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
680 REM STEP 6 (calculate ReD)
690 RED = 1273200 * QM1 / (N * D)
700 REM the following lines will print the output and restart the program
710 PRINT "Normal flow at scale";Q1:Q1=QM1
720 PRINT "Flow factor";Q1/X
730 PRINT "Beta ratio";B
740 PRINT "Reynolds Number";RED
750 INPUT "A new calculation Y/N";A$
760 IF A$="Y" GOTO 10
770 END

```

APPENDIX B-7

FLOW FACTOR CALCULATION FORM FOR RECTANGULAR VENTURI TUBES			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Throat width w at T_0	mm	Linear expansion coeff. α_{Venturi}	/°C
Throat height h at T_0	mm	Ambient temp. T_0	°C
Duct width W at T_0	mm	Limitations: $0.44 \leq \sqrt{\frac{wh}{WH}} \leq 0.74$ $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^7$	
Duct height W at T_0	mm		
Transmitter range DP	bar		
Indication X of q_m on scale (0-10)			
Ratio of specific heats $\kappa = C_p/C_v$			
1. $\beta = (wh/WH)^{0.5}$		$\beta =$	
2. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
3. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$ N.B.: If the fluid is a liquid $\epsilon = 1$			
4. $C = 0.975$		$C = 0.975$	
5. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP \rho}$		calculated $q_m =$ kg/s	
6. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
		$X =$	
		Flow factor $q_m/X =$ kg/s	

Calculated by: Date: Sign.:

COMPUTER PROGRAM IN BASIC FOR B-7

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions [ m Pa·s]";N
30 INPUT "Operating temperature [ °C]";T
40 INPUT "Density under operating conditions [ kg/m3]";R
50 INPUT "Operating pressure [ bar]";P
60 INPUT "Throat width at To [ mm]";TW
70 INPUT "Throat height at To [ mm]";TH
80 INPUT "Internal pipe width at To [ mm]";PW
90 INPUT "Internal pipe height at To [ mm]";PH
100 INPUT "Transmitter range [ bar]";DP
110 INPUT "Indication of normal flow on scale (0-10)";X
120 INPUT "Linear expansion coeff. Venturi [ /°C]";AP
130 INPUT "Ambient temperature [ °C]";TO
140 IF FLUID$="L" THEN W=0 :GOTO 500
150 INPUT "Ratio of specific heats Cp/Cv";Y
160 IF FLUID$="G" GOTO 500
170 INPUT "Water content in wet steam [ %]";W
500 REM STEP 1 (calculate β ratio)
510 B = (TH * TW / (PH * PW))^0.5
520 REM STEP 2 (calculate steam correction factor Fs)
530 FS = 1 + 0.0074 * W
540 REM STEP 3 (calculate dp at normal flow indication)
550 DPN = DP * (X / 10)^2
560 REM STEP 4 (calculate epsilon)
570 E = 1
580 IF FLUID$="L" THEN GOTO 650
590 K = (P - DPN)/P
600 K1 = K^(2/Y)
610 K2 = K^((Y-1)/Y)
620 E=((Y*K1/(Y-1))*((1-B^4)/(1-B^4*K1))*((1-K2)/(1-K)))^0.5
630 REM STEP 5 (calculate QM)
640 C = 0.984
650 QM1 = 3.512407 * 10^-4 * C * FS * (1-B^4)^-0.5 * E * DO^2*(DPN*R)^0.5
660 REM STEP 6 (calculate ReD)
670 RED = 1273200 * QM1 / (N * D)
680 REM the following lines will print the output and restart the program
690 PRINT "Normal flow at scale [ kg/s]";QM1
700 PRINT "Flow factor [ kg/s]";QM1/X
710 PRINT "Beta ratio";B
720 PRINT "Reynolds Number";RED
730 INPUT "A new calculation Y/N";A$
740 IF A$="Y" GOTO 10
750 END

```

APPENDIX B-8

FLOW FACTOR CALCULATION FORM FOR ISA 1932 NOZZLES			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Throat diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{nozzle}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.3 \leq \beta \leq 0.8$	
Ratio of specific heats $\kappa = C_p/C_v$		$70\,000 \leq Re_D \leq 10^7$ for $0.30 \leq \beta \leq 0.44$	
		$20\,000 \leq Re_D \leq 10^7$ for $0.44 < \beta \leq 0.80$	
1. $d = d_m [1 + \alpha_{nozzle} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = \left[\left(\frac{\kappa (K)^\kappa}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^\kappa} \right) \left(\frac{1 - (K)^{\frac{\kappa-1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$			
N.B.: If the fluid is a liquid $\epsilon = 1$			
6. $q_m = 2.107 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 \sqrt{DP} \rho$		estimated $q_m =$ kg/s	
7. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
8. $C = 0.99 - 0.2262 \beta^{4.1} +$ $+ [0.000215 - 0.001125 \beta + 0.00249 \beta^{4.7}] \cdot \left[\frac{10^6}{(Re_D)} \right]^{1.15}$		$C =$	
9. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP} \rho$		calculated $q_m =$ kg/s	
Repeat 7 through 9 until calculated q_m agrees with previously calculated q_m to within 0.01%			
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR B-8

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions [ m Pa·s]";N
30 INPUT "Operating temperature [ °C]";T
40 INPUT "Density under operating conditions [ kg/m3]";R
50 INPUT "Operating pressure [ bar]";P
60 INPUT "Pipe diameter at To [ mm]";DM
70 INPUT "Nozzle throat diameter at To [ mm]";DOM
80 INPUT "Transmitter range [ bar]";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Linear expansion coeff. of the pipe [ / °C]";AP
110 INPUT "Linear expansion coeff. of nozzle [ / °C]";AO
120 INPUT "Ambient temperature [ °C]";TO
130 IF FLUID$="L" THEN W=0 :GOTO 500
140 INPUT "Ratio of specific heats Cp/Cv";Y
150 IF FLUID$="G" GOTO 500
160 INPUT "Water content in wet steam [ %]";W
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + AO (T - TO))
520 REM STEP 2 (calculate D at line conditions)
530 D = DM * (1 + AP (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DO / D
560 REM STEP 4 (calculate steam correction factor Fs)
570 FS = 1 + 0.0074 * W
580 REM STEP 5 (calculate dp at normal flow indication)
590 DPN = DP * (X / 10)^2
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="L" THEN GOTO 650
630 K = (P - DPN)/P
640 K1 = K^(2/Y)
650 K2 = K^((Y-1)/Y)
660 E=((Y * K1 / (Y - 1))*((1 - B^4)/(1 - B^4 * K1))*((1 - K2)/(1 - K)))^0.5
670 REM STEP 7
680 QM = 2.107 * 10^-4 * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
690 REM STEP 8 (calculate ReD)
700 RED = 1273200 * QM / (N * D)
710 REM STEP 9 (calculate discharge coefficient)
720 C = 0.99 + 0.2262 * B^4.1 (0.000215 - 0.001125 * B + 0.00249 * B^4.7) * (1000000 / RED)^1.15
730 REM STEP 10 (calculate new QM)
740 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
750 REM check if calculated QM agrees with previous QM within 0.01%
760 IF ABS ((QM - QM1) / QM1) > 0.0001 THEN QM=QM1 : GOTO 690
770 REM the following lines will print the output and restart the program
780 PRINT "Normal flow at scale [ kg/s]";QM1
790 PRINT "Flow factor [ kg/s]";QM1/X
800 PRINT "Beta ratio";B
810 PRINT "Reynolds Number";RED
820 INPUT "A new calculation Y/N";A$
830 IF A$="Y" GOTO 10
840 END

```

APPENDIX B-9

FLOW FACTOR CALCULATION FORM FOR LONG RADIUS NOZZLES			
PLANT:		TAG No.:	
SERVICE:			
DATA TO BE SUPPLIED BY OPERATIONS			
Approx. norm. quantity q_m	kg/s	Density ρ under operating cond.	kg/m ³
Viscosity η under operating cond.	mPa·s	Operating pressure p	bar
Operating temp. T	°C	Water content in wet steam	% wt
Throat diameter d_m at T_0	mm	Linear expansion coeff. α_{pipe}	/°C
Internal pipe dia. D_m at T_0	mm	Linear expansion coeff. α_{nozzle}	/°C
Transmitter range DP	bar	Ambient temp. T_0	°C
Indication X of q_m on scale (0-10)		Limitations: $0.2 \leq \beta \leq 0.80$	
Ratio of specific heats $\kappa = C_p/C_v$		$10^4 \leq Re_D \leq 10^7$	
1. $d = d_m [1 + \alpha_{nozzle} (T - T_0)]$		$d =$ mm	
2. $D = D_m [1 + \alpha_{pipe} (T - T_0)]$		$D =$ mm	
3. $\beta = d/D$		$\beta =$	
4. $F_s = 1 + 0.0074 W_t$ For gas and liquid $F_s = 1$		$F_s =$	
5. $\epsilon = \left[\left(\frac{\kappa (K)^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 (K)^{\frac{2}{\kappa}}} \right) \left(\frac{1 - (K)^{\frac{\kappa - 1}{\kappa}}}{1 - K} \right) \right]^{0.5}$		$\epsilon =$	
Where: $K = [p - (DP) (X/10)^2]/p$			
N.B.: If the fluid is a liquid $\epsilon = 1$			
6. $q_m = 2.107 \cdot 10^{-5} \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 \sqrt{DP} \rho$		estimated $q_m =$ kg/s	
7. $Re_D = \frac{1.2732 \cdot 10^6 q_m}{\eta D}$		$Re_D =$	
8. $C = 0.9965 - 0.00653 \beta^{0.5} \left[\frac{10^6}{(Re_D)} \right]^{0.5}$		$C =$	
9. $q_m = 3.512407 \cdot 10^{-5} C \frac{1}{\sqrt{1 - \beta^4}} \epsilon X d^2 F_s \sqrt{DP} \rho$		calculated $q_m =$ kg/s	
Repeat 7 through 9 until calculated q_m agrees with previously calculated q_m to within 0.01%			
		$X =$	
		Flow factor $q_m/X =$ kg/s	
Calculated by: Date: Sign:			

COMPUTER PROGRAM IN BASIC FOR B-9

```

10 INPUT "Service Liquid (L), Gas (G) or Steam (S)";FLUID$
20 INPUT "Viscosity under operating conditions [ m Pa·s]";N
30 INPUT "Operating temperature [ °C]";T
40 INPUT "Density under operating conditions [ kg/m3]";R
50 INPUT "Operating pressure [ bar]";P
60 INPUT "Pipe diameter at To [ mm]";DM
70 INPUT "Nozzle throat diameter at To [ mm]";DOM
80 INPUT "Transmitter range [ bar]";DP
90 INPUT "Indication of normal flow on scale (0-10)";X
100 INPUT "Linear expansion coeff. of pipe [ / °C]";AP
110 INPUT "Linear expansion coeff. of nozzle [ / °C]";AO
120 INPUT "Ambient temperature [ °C]";TO
130 IF FLUID$="L" THEN W=0 :GOTO 500
140 INPUT "Ratio of specific heats Cp/Cv";Y
150 IF FLUID$="G" GOTO 500
160 INPUT "Water content in wet steam [ %]";W
500 REM STEP 1 (calculate d orifice at line conditions)
510 DO = DOM * (1 + AO (T - TO))
520 REM STEP 2 (calculate D at line conditions)
530 D = DM * (1 + AP (T - TO))
540 REM STEP 3 (calculate β ratio)
550 B = DOM / DM
560 REM STEP 4 (calculate steam correction factor Fs)
570 FS = 1 + 0.0074 * W
580 REM STEP 5 (calculate dp at normal flow indication)
590 DPN = DP * (X / 10) ^2
600 REM STEP 6 (calculate epsilon)
610 E = 1
620 IF FLUID$="L" THEN GOTO 650
630 K = (P - DPN) / P
640 K1 = K^(2/Y)
650 K2 = K^((Y - 1)/Y)
660 E=((Y * K1 / (Y - 1))*((1 - B^4)/(1 - B^4 * K1))*((1 - K2)/(1 - K)))^0.5
670 REM STEP 7
680 QM = 2.107 * 10^-4 * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
690 REM STEP 8 (calculate ReD)
700 RED = 1273200 * QM / (N * D)
710 REM STEP 9 (calculate discharge coefficient)
720 C = 0.9965 + 0.00653 * B^0.5 * (1000000 / RED)^0.5
730 REM STEP 10 (calculate new QM)
740 QM1 = 3.512407 * 10^-4 * C * FS * (1 - B^4)^-0.5 * E * DO^2 * (DPN * R)^0.5
750 REM check if calculated QM agrees with previous QM within 0.01%
760 IF ABS ((QM - QM1) / QM1) > 0.0001 THEN QM=QM1 : GOTO 690
770 REM the following lines will print the output and restart the program
780 PRINT "Normal flow at scale [ kg/s]";QM1
790 PRINT "Flow factor [ kg/s]";QM1/X
800 PRINT "Beta ratio";B
810 PRINT "Reynolds Number";RED
820 INPUT "A new calculation Y/N";A$
830 IF A$="Y" GOTO 10
840 END

```

Appendix C

Computer flow calculation program

- 1 Application
- 2 Requirements for a computer program
- 3 Available programs
- 4 Commercial availability

Appendix C Computer flow calculation program

1 Application

If computer facilities are available, their use for flow calculations is recommended because the computer will give uniform, reliable and accurate results which are strictly in accordance with the standards; this will generally result in better material balances of the plant, and in a reduction of the time required by skilled personnel.

2 Requirements for a computer program

The program shall at least perform at choice:

- 1 For design calculations: the selection of the type of primary element, meter range and throat diameter within the permitted limits and the accurate calculation of the flow factor.
- 2 For existing installations: accurate flow factor calculations with a check against limits giving messages in case limits are violated.

3 Available programs

A number of computer programs for flow calculations are commercially available. As far as is known, these programs are not in all respects in accordance with this handbook or do not include a selection feature. Therefore a special program completely in accordance with this handbook has been developed in the Fortran 77 language.

The program incorporates the following operations:

1. Selection of the primary element, throat diameter and meter range.
2. Checking and reporting invalidity or incompleteness of input data and limitations of β , r/D , roughness and Re_D .
3. Calculation of the exact flow factor.
4. Calculation of some related data, i.e. β , Re_D at scale reading, viscosity and density of steam, flow coefficient, expansion factor and the expected error of measurement assuming the following standard deviations:

$$\Sigma_d = \pm 0.05\%$$

$$\Sigma_D = \pm 0.50\% \text{ if internal } D \text{ is not given}$$

$$\Sigma_D = \pm 0.10\% \text{ if internal } D \text{ is given}$$

$$\Sigma_{dp} = \pm 1.00\%$$

$$\Sigma\rho \text{ liquid} = \pm 1.50\%$$

$$\Sigma\rho \text{ steam} = \pm 3.00\%$$

$$\Sigma\rho \text{ gas} = \pm 4.00\%$$

5. A data base system to store all the input values and the calculated results.
6. A full on-line screen option with data entry panels and tutorial panels (this version runs under CMS).

4 Commercial availability

For further details of commercial availability contact SIPM The Hague, MFEE/4 Division.