



STANDARDS
for
STEAM JET VACUUM SYSTEMS

FIFTH EDITION

HEAT EXCHANGE INSTITUTE, INC.

STANDARDS for STEAM JET VACUUM SYSTEMS

FIFTH EDITION

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2.2 Operating Principles

2.2.1 The operating principle of a steam jet ejector stage is that the pressure energy in the motive steam is converted into velocity energy in the nozzle, and, this high velocity jet of steam entrains the vapor or gas being pumped. The resulting mixture, at the resulting velocity, enters the diffuser where this velocity energy is converted to pressure energy so that the pressure of the mixture at the ejector discharge is substantially higher than the pressure in the suction chamber.

2.2.2 An ejector stage has operating limitations on the compression attainable and will operate efficiently only up to a limited ratio of compression. The ratio of compression is the absolute discharge pressure divided by the absolute suction pressure.

For greater ratios of compression than can be attained in a single ejector stage, two or more stages can be arranged to operate in series. This assembly constitutes a multi-stage ejector.

2.2.3 An ejector stage is inherently a constant capacity device. The capacity is a function of the physical proportions of the diffuser.

To obtain variation in capacity, two or more ejectors, either single or multi-stage, can be arranged to operate in parallel, each series constituting an element of a multiple element ejector. This arrangement permits the operation of the number of elements needed for the required capacity, as each element is capable of completely compressing a portion of the total capacity.

2.3 Description of Types

2.3.1 Terminology

A typical steam jet ejector system consists of one, or more, steam jet ejector stage assemblies with associated condensers arranged to condense vapors discharged from the previous stage assemblies. In noncondensing system designs, condensers are not used. For specific nomenclature of steam jet ejector assemblies refer to Paragraph 2.1.

The first stage of a multi-stage ejector is the stage into which the vapor or gas being compressed first enters; the second stage that which it enters second; the third stage that which it enters third; etc.

Figure 2 shows the industry wide system developed to establish a standard technology for ejector systems. Each ejector stage and condenser has a distinct letter or letters which is a function of its position in the system. Each stage has a single letter designation. The last stage has the letter Z assigned to it. The remaining stages are assigned letters in reverse order, i.e., the stage directly preceding a Z stage would be a Y stage. This method is continued for all remaining stages in the system. Intercondensers are assigned the two letters of the stages immediately preceding and following the condenser, i.e. for a condenser between a Y and Z stage, the letter designation would be YZ. An aftercondenser is assigned a letter combination ZA. A precondenser is assigned a first letter of P followed by the letter designation of the stage following it. For example, if a precondenser is used ahead of a two stage system, the designation would be PY.

2.3.2 System Types

Some of the various types of ejector systems commonly used are illustrated in Figures 3 to 10 inclusive.

2.3.2.1 Single Stage, Single Element Ejectors

These consist of one basic assembly (Figure 3) which is designed to operate at a suction pressure below atmospheric pressure and to discharge at atmospheric pressure or higher.

2.3.2.2 Single Stage, Multiple Element Ejectors

These consist of two or more basic assemblies, each designed to operate at a suction pressure below atmospheric pressure and to discharge at atmospheric pressure or higher. In these combinations, each basic assembly is termed an element. The complete unit is termed a single stage, twin element ejector, (Figure 4); single stage, triple element ejector; etc., depending on the number of elements provided.

2.3.2.3 Multi-Stage, Single Element Ejectors

These consist of two or more basic assemblies arranged in series, (Figures 5, 6, 8, 9, and 10). The first and any intermediate assembly of the series is designed to operate at suction and discharge pressures substantially below atmospheric pressure. The final assembly of the series is designed to discharge at atmospheric pressure or higher.

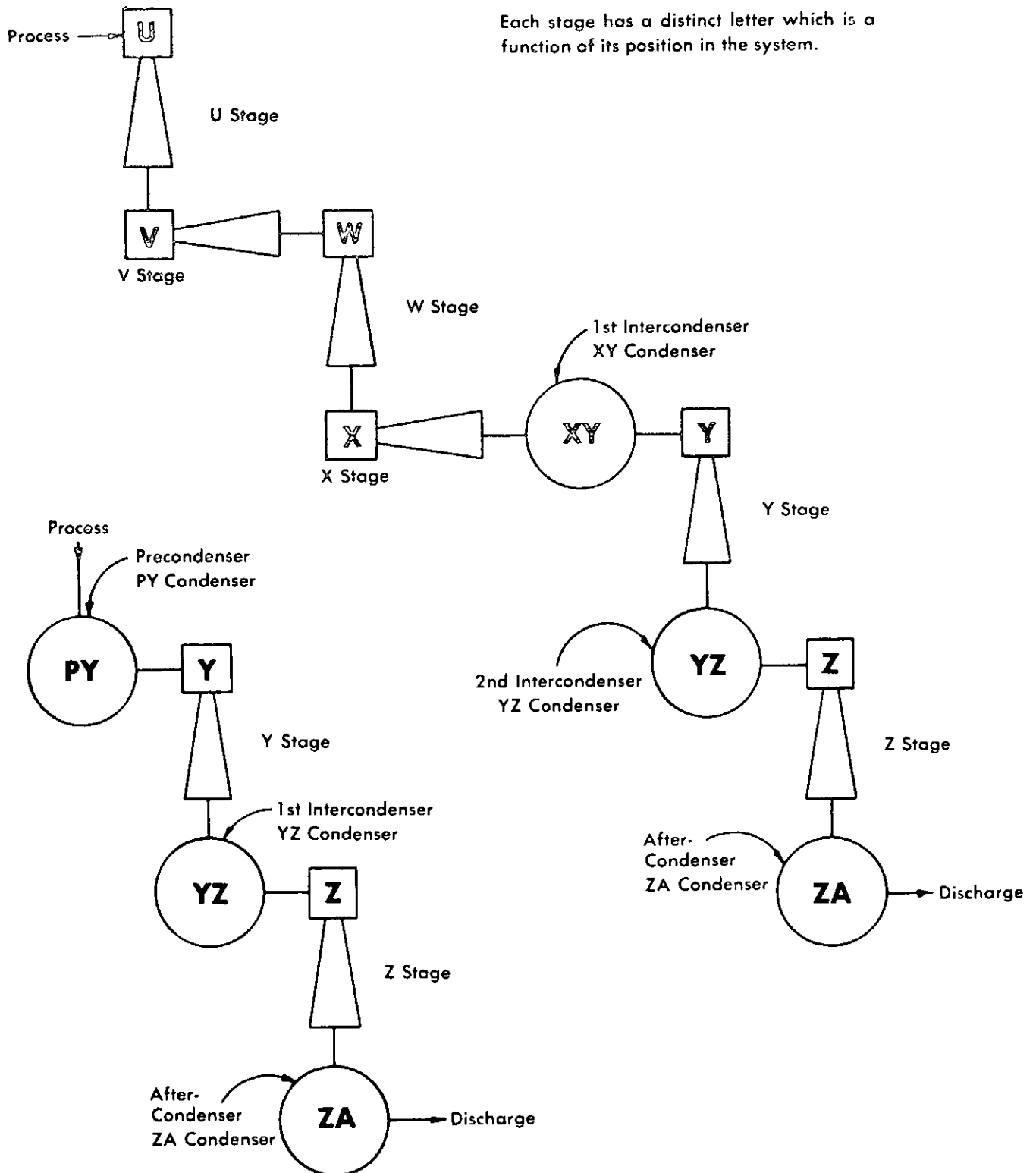


Figure 2
DESIGNATIONS FOR EJECTOR ASSEMBLIES

2.4 Definitions of Terms

Definitions of the terms used in this Standard are given in the following paragraphs:

Discharge Pressure. Discharge pressure is the absolute static pressure prevailing at the discharge of the ejector expressed in pounds per square inch, inches or millimeters of mercury.

Breaking Pressure. Breaking pressure is that pressure of either the motive steam or the discharge, which causes the ejector to become unstable.

Recovery Pressure. Recovery pressure (Pick-Up Pressure) is that pressure of either the motive steam or the discharge, at which the ejector recovers to a condition of stable operation.

Absolute Temperature. Absolute temperature is the temperature above absolute zero. It is equal to the degrees Fahrenheit plus 460. The unit is degree Rankin.

Suction Temperature. Suction temperature is the temperature of the gas at the suction of the ejector. The unit is degrees Fahrenheit.

Stable Operation. Stable operation is the operation of the ejector without violent fluctuation of the suction pressure.

Design Load. Design load is the specified mass flow rate of components to be handled by the ejector. The unit is pounds per hour.

Test Load. Test load is the mass flow rate of air and/or water vapor to meter into the ejector for test purposes. The unit is pounds per hour.

Capacity. Capacity is the weight rate of flow of the gas that can be handled by the ejector. The unit is pounds per hour.

Design Point. The required combination of design absolute suction pressure and equivalent air or equivalent steam flow in pounds per hour.

Dry Air. Atmospheric air at normal room temperature is considered dry air. The very small weight of water vapor in it is considered insignificant and is ignored. For example, the weight of water vapor in atmospheric air at 50 percent relative humidity and 60°F temperature is less than 0.0055 lb per lb of air.

Equivalent Air. Equivalent air is a calculated weight rate of air that is equivalent to the weight rate of gas handled by the ejector at the suction conditions. The unit is pounds per hour.

Equivalent Steam. Equivalent steam is a calculated rate of steam that is equivalent to the weight rate of gas handled by the ejector at the suction conditions. The unit is pounds per hour.

Molecular Weight. Molecular weight is the sum of the atomic weights of all the atoms in a molecule.

Mole. Mole is a mass numerically equal to the molecular weight.

Mole Fraction. Mole fraction of a component in a homogeneous mixture is defined as the number of moles of that component divided by the sum of the number of moles of all components.

Total Steam Consumption. Total steam consumption is the total weight rate of flow passing through the nozzles of all ejector stages at specified conditions of steam pressure and temperature. The unit is pounds per hour.

Total Water Consumption. Total water consumption is the total rate of flow passing through the ejector condensers at specified inlet temperature. The unit is gallons per minute.

Critical Flow. Critical flow is the flow through a nozzle when the downstream absolute pressure is below critical pressure, i.e., the downstream absolute pressure must be less than approximately 50 percent of the upstream absolute pressure.

Subcritical Flow. Subcritical flow is the flow through a nozzle when the downstream absolute pressure is above critical pressure, i.e., there is a relatively low pressure drop across the nozzle.

Design Steam Pressure. The pressure to be supplied to the ejector at the steam chest connection.

2.5 Notation

2.5.1 Symbols

The following symbols are used in this Standard:

C	Nozzle coefficient	p_1	Initial pressure in system, inches of mercury absolute
C_{pa}	Specific heat of air at constant pressure (0.24 approximately)	p_2	Final pressure in system, inches of mercury absolute
C_{ps}	Specific heat of steam at constant pressure corresponding to downstream absolute (0.45 approximately)	R_D	Reynolds number
D	Inside diameter of pipe, feet	S_a	Allowable stress, psi
D_n	Diameter of nozzle throat, inches	T	Time, minutes
D_1	Inlet diameter, inches	T_1	Upstream temperature, °R
D_2	Discharge diameter, inches	t	Temperature, °F
d	Inside diameter pipe, inches	t_a	Ambient air temperature, °F
F	Pressure drop, inches of water per 100 feet of pipe	tk	Thickness, inches
f	Friction factor, dimensionless	t_m	Temperature of mixture at ejector suction, °F
g	Acceleration due to gravity, feet per second	t_s	Temperature of steam on downstream side of nozzle, °F
k	Ratio of specific heats	V	Volume, cubic feet
L	Length of pipe, feet	V_1	Upstream specific volume, cubic feet per pound
l	Leakage rate, pounds per hour	v	Average velocity, feet per second
M_n	Molecular weight of noncondensable gas	W_a	Air flow rate, pounds per hour
M_v	Molecular weight of vapor	W_s	Steam flow rate, pounds per hour
P_d	Internal design pressure, psi	W_1	Weight of air in system at initial pressure, pounds
P_n	Partial pressure of noncondensable gas, inches of mercury absolute	W_2	Weight of air in system at final pressure, pounds
P_v	Partial pressure of water vapor, inches of mercury absolute	w	Flow rate, pounds per hour
P_1	Upstream static pressure, pounds per square inch absolute	w_n	Flow rate of noncondensable gas, pounds per hour
P_2	Downstream static pressure, pounds per square inch absolute	w_v	Flow rate of vapor of saturation, pounds per hour
		β	Ratio of nozzle diameter to pipe diameter
		μ	Absolute viscosity of air, pounds per foot-second
		ρ	Average density, pounds per cubic foot

4.0 CONSTRUCTION STANDARDS

4.1 General Information

4.1.1 Purpose

This section defines general rules for the design, manufacture and pressure testing of ejector components, including stage assemblies, and surface condensers used in ejector service.

These guidelines are presented to provide standards for construction and are not to be used as the sole basis for design. The specific design of components is the responsibility of the manufacturer in complying with the customer's specification.

In those instances where complete details and procedures are not specified, the manufacturer shall utilize design and construction procedures which have been demonstrated as being adequate for the service intended and conform to accepted engineering practice.

The condensers covered by the Standard may also be required to conform to the ASME Boiler and Pressure Vessel Code; Section VIII, Division 1 (hereafter referred to as the Code).

Where reference is made to the Code and other codes or standards, the applicable document shall be that existing at the time of publication of this HEI Standard (Fifth Edition, Standards for Steam Jet Vacuum Systems).

4.1.2 Materials of Construction

Tables 1 and 2 list typical materials of construction. For allowable stress values, refer to the Code except where noted by double asterisk. The table does not cover all possible materials of construction. Other materials which are equally suitable may be used.

When conditions dictate, non-metallic materials, such as graphite and ceramic alumina, may be used as agreed upon between purchaser and manufacturer.

TABLE 1
TYPICAL MATERIALS OF CONSTRUCTION

Component	Form ¹	Material ¹	Specification ^{1,2}	Grade/UNS No ¹
Diffuser, Steam Chest, Suction Chamber	Plate ^{3,4}	Carbon Steel	ASTM A 36 ASTM A283 ASTM A 285 ASTM A515 ASTM A516	
		Stainless Steel	ASTM A240	S30400, S30403 S31600, S31603
	Bar	Carbon Steel	ASTM A36 ASTM A675	
		Stainless Steel	**ASTM A276 ⁴ ASTM A216	S30400, S30403, S31600, S31603, S32100, S34700
	Castings	Carbon Steel	**ASTM A27 ⁴ ASTM A216	
		Alloy & Stainless Steel	ASTM A217	
		Stainless Steel	**ASTM A743 **ASTM A744	
		Stainless & Duplex Stainless Steel	ASTM A351	
		Cast Iron ⁴	*ASTM A48 ASTM A278 ASTM A395	
		Cast Bronze	ASTM B62 ASTM B584	
	Pipe		Refer to piping section	
Fasteners	Bolts	Steel	ASTM A193 ASTM A325	
	Nuts	Steel	ASTM A194 ASTM A563	
Nozzle & Nozzle Extension	Bar	Stainless Steel	**ASTM A276 ASTM A479	S30400, S31600, S32100, S34700
			**ASTM A582	S30300, S41600
		Nickel-Copper	ASTM B164	N04405
	Plate		ASTM A240	S30400, S31600
	Pipe		Refer to piping section	

TABLE 1 TYPICAL MATERIALS OF CONSTRUCTION *(continued)*

Component	Form ¹	Material ¹	Specification ^{1,2}	Grade/UNS No ¹
Shell & Waterboxes	Plate	Carbon Steel	ASTM A36 ASTM A283 ASTM A285 ASTM A515 ASTM A516	
		Stainless Steel	ASTM A240	S30400, S30403, S31600, S31603, S31803 (duplex)
		70/30 Copper Nickel	ASTM B171	C71500
		90/10 Copper Nickel	ADTM B171	C70600
	Pipe		Refer to piping section	
	Bar	Carbon Steel	ASTM A36 ASTM A675	
		Stainless Steel	**ASTM A276 ASTM A479	S30400, S30403, S31600, S31603, S31803 (duplex)
	Structural Shapes	Carbon Steel	ASTM A36	
	Pipe (Structural Applications)	Carbon Steel	ASTM A53 ASTM A106	
		Stainless Steel	ASTM A312	S30400, S30403, S31600, S31603
			ASTM A790	S31803 (duplex)
	Forgings	Carbon Steel	ASTM A266	
	Castings	Cast Iron	**ASTM A48 ASTM A278	
Piping & Pipe Flanges, Fittings, etc. ³ For use with Ejector Components, Steam & Vapor Piping and Shell & Waterbox Connections	Pipe	Steel	ASTM A53 ASTM A106 ASTM A335	
		Stainless Steel	ASTM A312 ASTM A376	
			ASTM A790	S31803 (duplex)
	Forged, Flanges, Fittings, etc.	Carbon Steel	ASTM A105 ASTM A181	
		Alloy Steel	ASTM A182	K11572, K21590
		Stainless Steel	ASTM A182	S30400, S30403, S31600, S31603, S32100, S34700, S31803 (duplex)
	Wrought Flanges, Fittings, etc.	Carbon & Alloy Steel	ASTM A234	
		Stainless Steel	ASTM A403	S30400, S30403, S31600, S31603
	Plate	Carbon Steel	ASTM A815 ASTM A285	S31803 (duplex)
		Stainless Steel	ASTM A240	S31603, S31803 (duplex)

TABLE 1 TYPICAL MATERIALS OF CONSTRUCTION (continued)

Component	Form ¹	Material ¹	Specification ^{1,2}	Grade/UNS No ¹
Tube Sheets	Plate	Muntz Metal	ASTM B171	C36500
		Aluminum Bronze	ASTM B171	C61400
		Naval Brass	ASTM B171	C46400
		70/30 Copper Nickel	ASTM B171	C71500
		90/10 Copper Nickel	ASTM B 171	C70600
		Silicon Bronze (Copper Silicon Alloy)	ASTM B96	C65500
		Titanium	ASTM B265	
		Stainless Steel	ASTM A240	S30400, S30403, S31600, S31603, S31803 (duplex)
		Carbon Steel	ASTM A283 ASTM A285 ASTM A515 ASTM A516	
Tubes		Reference Table 2		

NOTES:

- Selection of materials is the responsibility of Purchaser. The Manufacturer assumes no responsibility for deterioration of any part or parts of the equipment due to erosion or corrosion, or any other causes. Service conditions such as pressure, temperature, steam velocity, moisture, etc. should be considered for application of particular material and grade.
- Allowable stress values should be taken from Section VIII, Division 1 of the ASME Pressure Vessel Code, except where noted for non-ASME Code material:
 - * $.1 \times S_1$
 - ** Allowable stress values used should conform to accepted engineering practice.
- Plate and welded fittings are not recommended for use in high pressure and/or high temperature applications such as the steam chest or steam piping systems.
 - If used for this application, the rolling direction of plate should be parallel to the pressure boundary (e.g. Flat covers, stamped pipe caps, etc.).
- Shall not be used for steam chest. Plate may be used for steam chest covers.

TABLE 2
MATERIALS FOR CONDENSER TUBES^(b)

Material Category	Material	Typical ASTM Specification Alloy Designations	Physical Properties See Notes Below			
			Density lbs./cu in	Thermal Conductivity BTU-Ft/hr • Ft ² -°F	Coefficient of Thermal Expansion in/in, °F. (See Note C)	Modules of Elasticity p.s.i.
COPPER BRASS ALLOYS	Admiralty	B111 B543 UNS C44300	0.308	(a 1) 64 at 68°F	11.2 x 10 ⁻⁶	16.0 x 10 ⁶
	Admiralty	B111 B543 UNS C44400	0.308	(a 1) 64 at 68°F	11.2 x 10 ⁻⁶	16.0 x 10 ⁶
	Admiralty	B111 B543 UNS C44500	0.308	(a 1) 64 at 68°F	11.2 x 10 ⁻⁶	16.0 x 10 ⁶
	Alum. Brass	B111 B543 UNS C68700	0.301	(a 1) 58 at 68°F	10.3 x 10 ⁻⁶	16.0 x 10 ⁶
	Alum. Bronze	B111 B543 UNS C60800	(a 1) 0.295	(a 1) 46 at 68°F	9.0 x 10 ⁻⁶	17.5 x 10 ⁶
	Copper Nickel 70-30	B111 B543 UNS C71500	0.323	(a 1) 17 at 68°F	9.1 x 10 ⁻⁶	22.0 x 10 ⁶
	Copper Nickel 90-10	B111 B543 UNS C70600	0.323	(a 1) 26 at 68°F	9.5 x 10 ⁻⁶	18.0 x 10 ⁶
	Arsenical Copper	B111 B543 UNS C14200	(a 1) 0.323	(a 1) 112 at 68°F	9.8 x 10 ⁻⁶	17.0 x 10 ⁶
	Copper Iron 194	B543 UNS C19400	(a 1) 0.317	(a 1) 150 at 68°F	9.0 x 10 ⁻⁶	17.5 x 10 ⁶
STAINLESS STEELS	Stainless Steel	A249 A213 A269 UNS S30400	0.29	7.7 at 70°F	9.45 x 10 ⁻⁶	28.3 x 10 ⁶
	Stainless Steel	A249 A213 A269 UNS S31600	0.29	7.7 at 70°F	9.45 x 10 ⁻⁶	28.3 x 10 ⁶
	Stainless Steel	A268 UNS S43035	(a 4) 0.28	(a 2) 12.3 at 68°F	(a 4) 5.6 x 10 ⁻⁶	(a 4) 29.0 x 10 ⁶
	Stainless Steel	B676 UNS N08367	(a 5) 0.29	(a 2) 7.9 at 68°F	(a 5) 8.5 x 10 ⁻⁶	(a 5) 27.0 x 10 ⁶
	Stainless Steel	A268 UNS S44735	(a 6) 0.28	(a 2) 9.8 at 68°F	(a 6) 5.4 x 10 ⁻⁶	(a 6) 31.0 x 10 ⁶
	Stainless Steel	A268 UNS S446600	(a 7) 0.28	(a 2) 9.8 at 70°F	(a 7) 5.4 x 10 ⁻⁶	(a 7) 31.0 x 10 ⁶
TITANIUM	Titanium	B338 Grades 1 & 2	0.163	12.5 at 70°F	4.9 x 10 ⁻⁶	14.9 x 10 ⁶
CARBON STEEL	Carbon Steel	A179 A214	(a 3) 0.283	(a 3) 27.0 at 70°F	7.34 x 10 ⁻⁶	29.5 x 10 ⁶

TABLE 2 MATERIALS FOR CONDENSER TUBES^(b) (continued)**NOTES:**

- (a) The origin of the above typical physical properties is the A.S.M.E. Boiler & Pressure Vessel Code Section II, Part D, 1992 except where otherwise indicated.
1. Copper Development Association-Standards Handbook Part Two Alloy Data, 1985.
 2. Allegheny Ludlum Communication to HEI (I. Franson to L. Culling) May 12, 1994.
 3. Structural Alloys Handbook-Mechanical Prop. Data Center, 1976.
 4. Allegheny Ludlum Technical Data Blue Sheet, B-139-Ed5-5M689-L/J, 1989.
 5. Allegheny Ludlum Technical Data Blue Sheet, B-155/Ed3/5M/590/GF, 1990.
 6. Allegheny Ludlum Technical Data Blue Sheet, B-151/Ed3/5M590/GF, 1990.
 7. Trent Tube Alloy and Application Data, Trent Sea - Cure Stainless Steel Tubing, 1989.
- (b) Selections of material is the responsibility of the Purchaser. The Manufacturer assumes no responsibility for deterioration of any part or parts of the equipment due to erosion or corrosion or any other causes.
- (c) Copper Base Alloys 68-572°F, Stainless and Titanium 70-550°F, Carbon Steel-Mean 150°F.

4.1.3 Welding

4.1.3.1 For applicable joint efficiencies to be used with formulas in the Standard, refer to Table UW-12 in the Code.

4.1.3.2 For fillet welds, the stress shall not exceed 0.55 times allowable (S_a) stress of base material based upon minimum leg length ($0.55 S_a = 0.8 S_a \times \text{Sine of } 45^\circ\text{F}$).

4.1.3.3 For designs not specifically covered in this section, all welds should be of sufficient size and configuration to transfer the loads in the adjoining plates at an allowable stress level that is no greater than that of the base material.

4.1.3.4 Types of Welds and Joints

4.1.3.4.1 Pressure boundary welds may be either full penetration or properly designed fillet welds. For one sided full penetration welds, a backing strip, consumable insert or gas backing shall be used. Where fillet welds are utilized, the weld configuration must be such as to be adequate to support whatever loads are present at the joint.

For structural joints other than pressure boundary, the minimum leg distance for fillet welds shall be 5/16" or the thickness of the thinner member of the joint, whichever is less.

Non-pressure boundary and non-structural welds shall be designed in accordance with good engineering practice.

4.1.3.4.2 All butt-type field welds used for assembly of the pressure boundary will be full penetration welds. When the weld is made without a backing, it must be welded from both sides unless otherwise specified.

4.1.3.5 Inspection Standard for Welds

This section establishes minimum standards for visual inspection of ejector components. The visual acceptance criterion were developed using recognized codes and standards such as ASME codes, ANSI standards, AWWA, and AWS as a guide. More stringent requirements may be specified by the purchaser and would be governing.

Non-destructive examination, where not required by the Code, is not performed except by special arrangement between the manufacturer and the purchaser.

The welding shall be performed using welders and written weld procedures which have been qualified in a manner comparable to that defined in Section IX of the ASME Unfired Pressure Vessel Code.

Welds shall be examined in the "as welded" condition preceded only by normal cleaning.

4.1.3.5.1 Weld Inspection Methods and Equipment

Personnel performing weld inspections shall be visually qualified in accordance with Society of Nondestructive Testing (SNT) requirements.

Inspection shall be performed with the naked eye or corrective lenses as required to obtain the visual acuity required by SNT. Magnifying glasses, microscopes and other optical devices shall not be used.

Any required measurements of welds shall be made using instruments such as scales, rules, calipers, gauges (height and depth), fillet gauges, and dial-type equipment. Micromasuring or vernier-type equipment is not required.

Accuracy of measurement equipment shall be to 1/64". All measuring equipment shall be maintained and calibrated in accordance with the manufacturer's approved quality control manuals and procedures.

4.1.3.5.2 Weld Categories

The following categories are established considering the service requirements of specific types of welds. These criteria apply to shop welds and to field welds in the apparatus except for pipe welds made to connection stubs.

Category I includes pressure boundary welds.

Category II includes structural welds.

Category III includes all other welds.

4.1.3.5.3 Acceptance Levels

Acceptance levels for various types of welds in each of Categories I, II III are tabulated in Table 3. Refer to Figure 11 for nomenclature.

4.1.4 Interface Configurations

4.1.4.1 Flanges (Note: Refers only to bolting geometry of interface between customer's piping and manufacturer's connection.)

4.1.4.1.1 ANSI B-16.5 Pipe Flanges and Flanged Fittings (Including rating for class 150, 300, 400, 600, 900, 1500 and 2500).

4.1.4.1.2 ANSI B-16.1 Cast Iron Pipe Flanges and Flange Fittings Class 25, 125, 250, and 500.

4.1.4.1.3 Other mutually agreed upon flange design.

4.1.4.2 Weld Ends To suit required installation.

4.1.4.3 Threaded Connections In accordance with ANSI Standard B-2.1 Pipe Threads (Except Dry Seal).

4.1.5 Quality Assurance

The manufacturer shall have an organized and operational Quality Assurance Program. This program shall be outlined in a Quality Assurance Manual which shall be available to the purchaser and his representatives upon request. The system shall provide for control of quality in both the manufacturer's plant and that of any subcontractor fabricating ejector components. Quality Assurance for work performed in the field by other than the manufacturer shall be the responsibility of the purchaser and/or his agent.

The Quality Assurance Program shall provide for compliance with, but not limited to, the manufacturer's and the Heat Exchange Institute Standards, which shall provide as a minimum:

- (1) Base material control
(e.g., plate, weld wire, etc.).
- (2) Controlled distribution of materials.
- (3) Control of purchasing requirements.
- (4) Written weld procedures which have been qualified in a manner comparable to that defined in Section IX of the ASME Unfired Pressure Vessel Code.
- (5) Qualification of welders and control of welder assignments to assure that the personnel doing welding are qualified.
- (6) Audit system for control of procedures.
- (7) Detail drawings that contain definition of size and applicable weld procedures.

TABLE 3
WELD ACCEPTANCE CRITERIA*

SUBJECT	REFERENCE	ACCEPTANCE CRITERIA		
		CATEGORY I	CATEGORY II	CATEGORY III
Fillet Weld Fit-Up	S Sketch 1	$x \leq \frac{S}{4}$ (1/8" Maximum) See Notes 4 and 5.	For $T < 3" \times \leq 3/16"$ For $T \geq 3" \times \leq 3/16"$ See Notes 4 and 5.	
Fillet Weld Size Minimum	S Sketch 1	$S_{min} = S - 0"$ See Note 5.	$S_{min} = S - 1/16"$ For .1 L_w See Note 5.	$S_{min} = S - 1/16"$ For .25 L_w See Note 5.
Fillet Weld Size Maximum	S Sketch 1	$S_{max} = S + T$ or $S + 3/8"$ (Whichever is greater) See Note 5.		
Fillet Weld Concavity	(-) C Sketch 1	Concavity shall not encroach upon minimum required weld throat.	$(-)C \leq 1/16"$ for .1 L_w (Not to exceed 3" in any foot.)	$(-)C \leq 1/16"$ for .25 L_w (Not to exceed 6" in any foot.)
Fillet Weld Convexity	C Sketch 1	$C \leq \frac{S}{8} + 1/32"$	$C \leq \frac{S}{8} + 1/16"$	
Weld Overlap	Ø Sketch 2	None Allowed	Ø ≤ 3/32" Depth for a .1 L_w Length of 0 not to exceed 6" in any 60" length of weld. The fusion line must be visible.	
Butt Weld Fit-Up Misalignment	T Sketch 3	$M = \frac{T}{4}$ (1/4" Maximum)		$M = \frac{T}{4}$ or 1/8" (Whichever is greater)
Taper Required for Butt Weld Misalignment	M Sketch 3	3 to 1, Width of weld to M (Both Sides)	3 to 2, Width of weld to M, both sides only when M exceeds $\frac{T}{8}$	Not Required
Butt Weld Root Opening With Backing (<u>Strip</u> , <u>Gas</u> , <u>Consumable Inset</u>)	G Sketch 5	G_{min} = as qualified The weld geometry should be such as to permit complete joint penetration where required.		

*See Notes

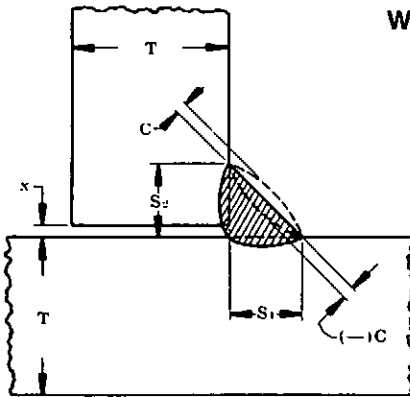
TABLE 3
WELD ACCEPTANCE CRITERIA*

SUBJECT	REFERENCE	ACCEPTANCE CRITERIA		
		CATEGORY I	CATEGORY II	CATEGORY III
Butt Weld Root Opening Without Backing	G Sketch 5	None Allowed	G_{min} = as qualified Oversize gaps shall be welded with a technique which will close the gap without excessive bridging of the open root. The weld geometry should be such as to permit complete joint penetration where required.	
Butt Weld Size	B Sketch 4	$B \geq T$ See Note 5.		$B = T - \frac{T}{4}$ ($\frac{T}{4}$ not to exceed 1/8") See Note 5.
Butt Weld Capout Pass Excluding Weld Metal Used For Tapering and Blending	W Sketch 4	W_{min} = Equal to Width of Weld Geometry $W_{max} \leq 2-1/2 \times$ thickness of the thicker of the members being joined. Note: Capout may consist of multiple passes.		
Butt Weld Reinforcement on Both Sides	R Sketch 4	When $T \leq 1/2"$ $R = 1/8"$ Max. $T > 1/2"$ or $\leq 1"$, $R = 3/16"$ Max. $T > 1"$ or $\leq 2"$, $R = 1/4"$ Max. $T > 2"$, $R = 5/16"$ Max. Where T is the thinner of the members being joined.		
Undercut	U Sketch 2	1/32" Continuous	1/32" undercut is permitted for full length weld; up to 1/16" for .25 L _w .	
Visible Porosity (Defined as a Hole 1/32" in Diameter or Greater)		No visible pore 1/32" is allowed.	The sum of the diameters shall not exceed 3/8" in any linear in. or 3/4" in any 12" length of weld. The maximum single pore diameter is 1/8". Linear porosity must be separated by a minimum of one pore diameter.	
Visible Cracks		None Allowed		
Incomplete Fusion		None Allowed		

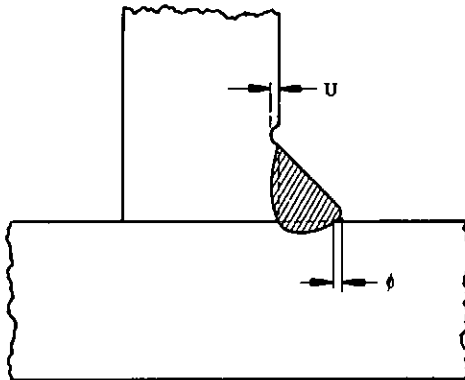
NOTES:

1. Highly localized concavity or weld reinforcement such as caused by weld restarts or where welds join or cross another weld are not to be considered unacceptable under these criteria.
2. Weld ripples transverse to the direction of electrode travel are permitted providing that the crest-to-trough height is not greater than 3/22" and providing that the weld throat dimension is within acceptable range. Valleys between successive weld beads shall not exceed 1/8" providing that minimum weld size is maintained.
3. On weldments made by more than one welder and when combinations of stringer and weave techniques are used, the quality of the weld shall be judged by the visual acceptance criteria defined.
4. If fit-up root gap of fillet welds in any category exceeds 1/16", the fillet weld size shall be locally increased (in the area where fit-up is beyond this criteria) by an amount equal to the size of the separation.
5. Fit-ups and weld sizes not within these criteria shall be resolved by the manufacturer and/or as provided in the contract documents.

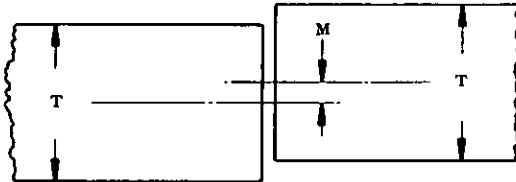
WELDING NOMENCLATURE



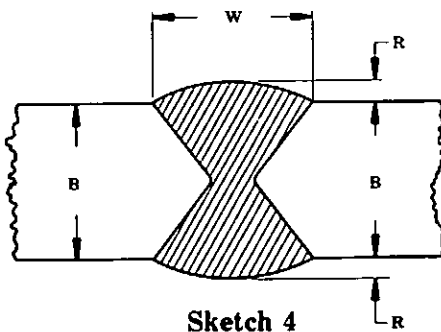
Sketch 1



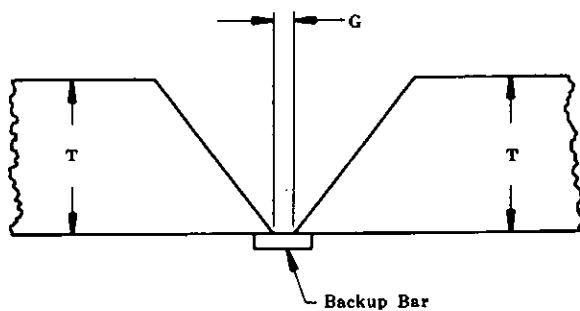
Sketch 2



Sketch 3



Sketch 4



Sketch 5

- S — Min. Specified Weld Leg
- S₁ — Weld Leg Size
- S₂ — Weld Leg Size
- x — Weld Gap (Excluding Local gouges)
- T — Material Thickness of the Thinnest Member
- C — Convexity
- (-)C — Concavity
- L_w — Length of Weld Described by the Weld Symbol
- Ø — Overlap
- U — Undercut

M — Misalignment

B — Size of Butt Weld

R — Reinforcement

L_w — Length of Weld Described by the Weld Symbol

W — Width of Cap Pass

G — Root Gap

Figure 11

4.1.6 Preparation for Shipment

4.1.6.1 Cleaning Exterior Surfaces

Unmachined surfaces are to be cleaned with a suitable solvent to remove oil and dirt. Where required, weld splatter may be removed by wire brushing, grinding or other suitable means.

4.1.6.2 Painting Exterior Surfaces

(a) Carbon Steel – One coat of manufacturer's standard primer, unless other coatings are required by the Specifications.

(b) Other Materials – Painting will not be required for corrosion resistant materials, unless required in the Specifications.

4.1.6.3 Protection of Machined Flanged Surfaces

(a) Apply protective coating.

(b) Openings to be closed with suitable covers or tape.

4.1.6.4 Protection of Weld End Connections

Ends are to be covered with suitable waterproof paper and/or tape sealed.

4.1.6.5 Internal Surfaces

No painting of internal surfaces shall be permitted. An acceptable protective coating may be applied to internal surfaces where specified by the purchaser.

4.1.7 Pressure Relief Devices

Pressure relief devices are necessary on ejector systems where the potential exists for the pressure to exceed the design pressure of any of the system components.

4.1.7.1 External Jackets

Ejectors may have external jackets used for heating and cooling of the ejector and the gases passing through the ejector. A relief device should be used to protect from the possibility of pressurizing the jacket beyond the design value.

4.1.7.2 Protection of Atmospheric and Subatmospheric Spaces

Ejectors shall be protected against excessive pressure in the normally atmospheric and subatmospheric spaces.

4.1.7.2.1 Ejector Units Without Interstage Isolating Valves

These units are to be provided with relief devices set to relieve at 15 PSIG, or higher, (depending on the system design pressure), if the internal pressure can exceed the above value under any service condition. To provide for venting from the after-condenser, a vent of adequate size must be provided at the air outlet connection. When an air meter and/or a valve is installed in the discharge line, an

adequate relief device must be provided at the point of highest expected pressure.

4.1.7.2.2 Ejector Units With Interstage Isolating Valves

A. Unit types with isolating valves at the suction and discharge of both primary and secondary elements are to be provided with relief devices on all elements set to relieve at 15 PSIG, or higher, (depending on unit design), and sized for maximum steam flow under the following conditions:

1. Operating motive steam pressure at ejector nozzle 25% above design, and

2. Steam nozzle throat area 10% in excess of design.

B. Unit types which do not include isolating valves at discharge of secondary stages, are to be provided with relief devices on primary elements only and a vent of adequate size must be provided at the air outlet connection similar to that described in Paragraph 4.1.7.2.1.

C. If the system includes a motive steam line pressure reducing unit, a relief device should be installed between the pressure reducing station and the ejector inlet header selected to relieve at 25% above the ejector design steam pressure and sized for maximum steam flow through the pressure reducing station. To permit reasonable sizing of a relief device, full size by-pass lines should not be used with the pressure reducing station.

4.1.7.2.3 Inter/After Condenser Protection

When the shell side design pressure is less than the tube side design pressure, a relief device may be needed to protect the shell from overpressure in the case of a tube failure. A connection on the shell should be provided for this relief device.

4.1.7.2.4 Systems with Coolant Inlet and Outlet Valves The coolant side of the condensers should be protected against overpressure when the coolant inlet and outlet valves are closed. A connection for installation of a relief valve should be provided between the coolant inlet and outlet valves.

4.2 Ejector System Components

4.2.1 Scope

This section includes materials, structural design, interface configurations, manufacturing and hydrostatic testing of steam jet ejector stage assemblies. This section may also be applied to ejectors using motive fluids other than steam.

4.2.2 Structural Design of Ejector Components

4.2.2.1 General Considerations

The design criteria for ejector components is a function of several variables. The minimum thicknesses required are not only stress dependent, they

are also dependent upon minimum thickness required for fabrication, welding and/or casting.

For applications where explosive mixtures are present, the components may be designed for higher pressures. For those applications, the design stress and pressure shall be mutually agreed upon.

4.2.2.2 External Loading - Forces and Moments

In most cases, the ejector is an integral part of a system (e.g., ejectors combined with condensing units). Therefore, it is not possible to design the ejector for specific external loads without reviewing the total system.

In general, external loads, due to thermal movement and mechanical loading, shall be minimized by the purchaser. It should be understood by the purchaser that the ejectors are not intended to serve as anchor points for the system. For example, external forces and moments which cause misalignment of ejector nozzles and diffusers can have a detrimental effect on ejector performance. In cases where this is not possible, the forces and moments at the ejector interfaces shall be specified by the purchaser, reviewed and mutually resolved.

4.2.2.3 Thickness of Suction Chambers and Diffusers

Suction chambers and diffusers consist of conical and cylindrical sections either alone or in combination. The following formulae are used to determine the thickness required for internal pressure.

(a) Conical Section:

$$tk = \frac{PD}{2 \cos \alpha (SE - 0.6P)}$$

For $\alpha \leq 30^\circ$

(b) Cylindrical Section:

$$tk = \frac{PR}{SE - 0.6P} \quad \text{or} \quad tk = \frac{PR}{2SE + 0.4P}$$

Whichever is greater

Where:

tk = Required thickness exclusive of corrosion allowance (in.)

P = Internal design pressure (psi)

D = Maximum inside diameter of cone, measured perpendicular to the longitudinal axis of cone (in.)

S = Allowable stress (psi). Refer to Code

E = Weld joint efficiency. For allowable joint efficiency refer to Code

R = Inside radius of cylinder (in.), before corrosion allowance is added

α = Half the included (apex) angle of conical element (degrees)

4.2.2.4 Design Considerations

4.2.2.4.1 The suction chamber and diffuser pressure shall be 15 PSIG (internal) and full vacuum unless otherwise specified.

4.2.2.4.2 The thickness of the suction chamber and diffuser should be reviewed for external pressure using the Code.

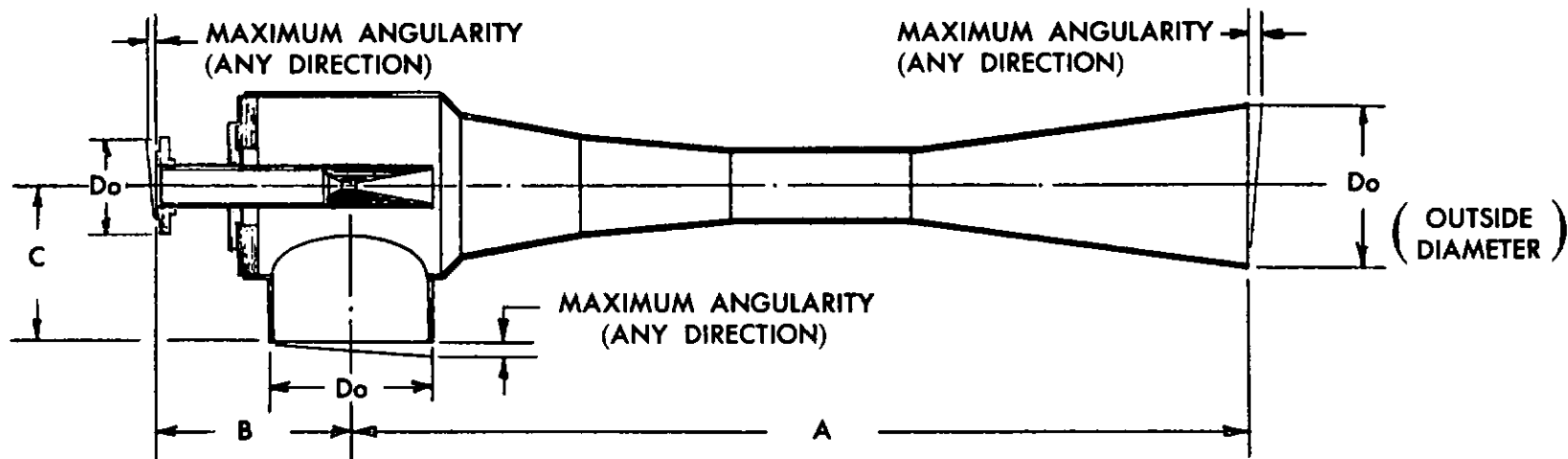
4.2.2.4.3 Flat plates and flanges (other than interfaces) shall be designed utilizing design and construction procedures which have been demonstrated as being adequate for the service intended and conform to accepted engineering practices.

4.2.2.4.4 The use of cast iron and other materials may require special design consideration; for example, the wall thickness of a casting may be dictated by foundry practice rather than structural design. However, in no case shall the thickness be less than that required by stress analysis.

4.2.2.4.5 As an alternate to the analytical methods previously described, the design of ejector components can be confirmed by pressure test and/or successful operation of duplicate designs.

4.2.2.4.6 Ejectors should have protective devices in the system, if a pressure higher than the design pressure is possible. These protective devices shall be supplied by the customer unless otherwise specified. Refer to Section 4.1.7.

LENGTH TOLERANCE			MAXIMUM ANGULARITY
20 FT.	< A, B, C	; $\pm 3/8"$	24" < Do ; $5/16"$
10 FT.	< A, B, C $\leq$ 20 FT.	; $\pm 1/4"$	10" < Do $\leq$ 24"; $1/4"$
5 FT.	< A, B, C $\leq$ 10 FT.	; $\pm 3/16"$	5" < Do $\leq$ 10"; $1/8"$
	A, B, C $\leq$ 5 FT.	; $\pm 1/8"$	Do $\leq$ 5"; $1/16"$



THE SAME TOLERANCES APPLY TO FLANGED CONNECTIONS AS ARE SHOWN FOR BUTT WELDED CONNECTIONS

Figure 12
END CONNECTION TOLERANCES FOR EJECTORS

4.2.2.5 Material Limitations

4.2.2.5.1 All motive steam piping shall be designed in accordance with ANSI Pressure Piping Code B31.1.

4.2.2.5.2 Materials for steam nozzles and steam chests shall be selected for the pressure and temperature range over which the unit will operate. Refer to Table 1 for typical materials.

4.2.3 Tolerances for Interfacing

Figure 12 shows tolerance for interfacing between ejector and adjacent piping.

4.2.4 Hydrostatic Testing

4.2.4.1 Steam piping shall be hydrostatically tested in accordance with ANSI pressure Piping Code B-31.1

(Note: All piping up to the steam nozzle throat shall be tested.)

4.2.4.2 Steam chests shall be tested at the same pressure used for testing steam piping.

4.2.4.3 Diffusers and suction chambers shall be hydrostatically tested at 1.3 times the internal design pressure unless otherwise dictated by the Code.

4.2.4.4 The temperature of the water used to field hydrotest the ejector components shall not be below 60°F, unless all materials of construction have a sufficiently low Nil Ductility Transition Temperature. If the customer anticipates a field test temperature lower than 60°F, he shall specify the materials of construction.

4.2.5 Corrosion Allowance

On ejector stage assemblies where the use of corrosion allowance is indicated, the additional material shall be added to the outside surface.

4.3 Surface Type Condensers for Ejector Service

4.3.1 Scope

This section includes nomenclature, structural design, tolerances for interfacing and hydrostatic testing for steam jet ejector surface condensers.

4.3.2 Nomenclature

In order to establish standard terminology for surface type condensers used on ejector service, refer to Figure 13.

4.3.3 Structural Design

4.3.3.1 Cylindrical Shell and Water Box Thickness

The thickness calculated by the following procedures are exclusive of any corrosion allowance requirements. If corrosion allowance is required, it shall be added to the calculated thickness.

A. Shells

1. Shells operating under vacuum should be designed for minimum external pressure of 15 PSIG in accordance with the Code, Paragraph UG-28. Where stiffening rings are required, they shall be designed in accordance with the Code, Paragraph UG-29.

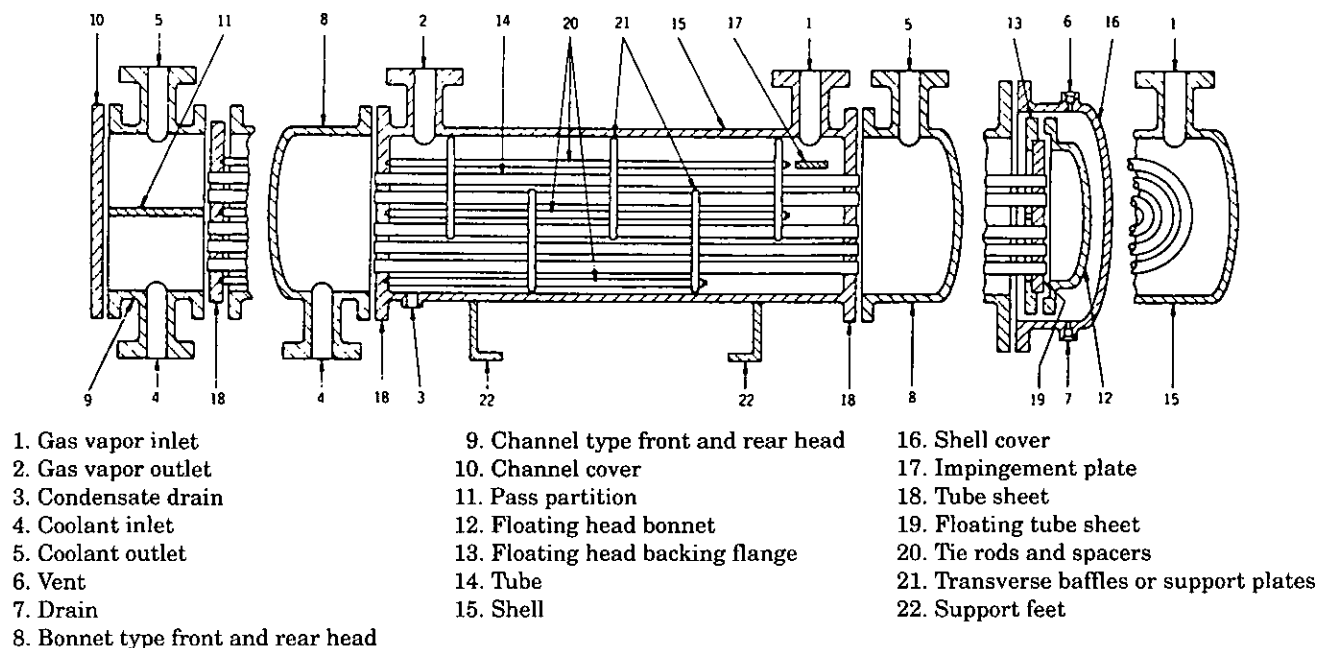


Figure 13
NOMENCLATURE

2. Shells should be designed for the specified internal pressure in accordance with the Code, Paragraph UG-27.

B. Water Boxes

Water boxes should be designed for the specified internal pressure in accordance with the Code, Paragraph UG-27.

Where a single component serves as both shell and water box, the larger calculated thickness (from A or B above) shall be used.

4.3.3.2 Flat Plate and/or Covers

4.3.3.2.1 Unstayed Flat Heads and Covers

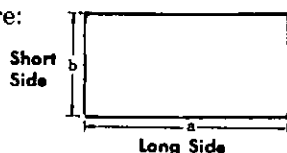
Unstayed flat heads and cover plates shall be designed in accordance with the Code, Paragraph UG-34.

4.3.3.2.2 Rectangular Flat Plate Without Ribs

The thickness of rectangular welded end flat plates shall be determined from the following formula:

$$tk = \frac{b}{2} \sqrt{2Z \frac{P}{S_a}}$$

Where:



$$Z = 3.4 - \frac{2.4b}{9} \leq 2.5$$

P = Pressure (psi)

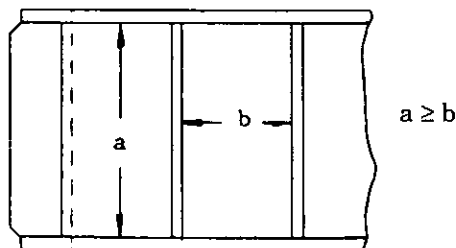
S_a = Allowable Stress (psi)

tk = Plate thickness (in.)

4.3.3.2.3 Rectangular Flat Panel Sections

Flat panel widths or plate thickness shall be determined in accordance with the following formula:

4.3.3.2.3.1 Rib Supported Panels



$$\frac{tk}{b} \geq \sqrt{\frac{KS_a}{P_d}}$$

P_d = Internal design pressure (psi)

S_a = Allowable stress (psi)

$\frac{a}{b}$	1.0	1.2	1.4	1.5	1.6	1.8	2.0	3.0	4.0
k	.205	.256	.290	.302	.312	.325	.332	.334	.334

Note: These factors apply to Channels only and assume the maximum fiber stress to be equal to 1.5 S_a.

4.3.3.2.4 Braced and Stayed Surfaces

For braced and stayed flat plates, refer to the Code, Paragraphs UG-47, UG-48, UG-49, UG-50 and UG-53.

4.3.3.3 Dished Heads

The thickness calculated by the following procedures are exclusive of any corrosion allowance requirements. If corrosion allowance is required, it shall be added to the calculated thickness.

A. Dished heads operating under internal pressure shall be designed in accordance with the Code, Paragraphs UG-32, UG-37, UG-38, Part UHT, UW-13 and all applicable appendices.

B. Dished heads operating under external pressure shall be designed in accordance with the Code, Paragraphs UCS-33, UG-33, UG-37, UG-38, UHA-31, Part UHT, UW-13 and all applicable appendices.

4.3.3.4 Nozzles and Nozzle Openings

Nozzle projection shall be in accordance with the manufacturer's normal practice, unless otherwise specified by the purchaser. The bolt holes in flanged nozzles should straddle centerlines.

4.3.3.4.1 Nozzles shall be constructed in accordance with the applicable paragraphs of the Code.

4.3.3.4.2 Nozzle openings shall be in accordance with Paragraph UG-36 and other applicable paragraphs of the Code.

4.3.3.4.3 Nozzle Loads

In general, external loads due to thermal movement and mechanical loading shall be minimized by the purchaser. It should be understood by the purchaser that ejector equipment is not intended to serve as an anchor point for the system. The purchaser may furnish the manufacturer with external forces and moments on the nozzle and the manufacturer will advise if the existing design will permit acceptance of these conditions.

4.3.3.5 Tubesheet

More factors influence the design of a tubesheet than most other heat exchanger parts. These factors include, but are not limited to, the following:

1. tube diameter
2. tube thickness
3. tube pitch
4. tube field layout
5. tube length
6. number of tubes
7. outer tube limit radius
8. shell and channel cylinder thickness
9. method of attachment of tubesheet to shell and channel
10. shell and tube side design pressures and metal temperatures
11. shell and tube side material properties
12. method of attachment of tube to tubesheet
13. gasket type

Specific application of the above parameters can be determined from applicable procedures such as those described in other HEI Standards, TEMA, or other documents.

4.3.3.6 Tubes

The useful life of a tube is normally affected by the conditions of service, such as fluid chemistry, operating temperatures and fluid velocities, as well as the effects of short and long term shutdowns. These factors should be taken into consideration by the purchaser when making a tube material selection.

4.3.3.6.1 Internal Pressure

The required wall thickness for tubes under internal pressure shall be determined in accordance with the Code, Paragraph UG-27. For U-tubes, see Paragraph 4.3.3.6.6.

4.3.3.6.2 External Pressure

The required wall thickness for tubes under external pressure shall be determined in accordance with the Code, Paragraph UG-28.

4.3.3.6.3 Tube Gages

Average wall or minimum wall tubes are equally acceptable providing that, in the case of average wall tubes, the calculated thickness for pressure takes into consideration the tolerance in wall thickness.

4.3.3.6.4 Unsupported Tube Length

Unsupported tube length shall be limited to those values given in Table 4. Actual values will be determined by specific flow conditions.

Table 4

MAXIMUM UNSUPPORTED STRAIGHT TUBE LENGTH - INCHES

Tube OD Inches	Aluminum Brass/Bronze Admiralty Copper-Nickel Titanium	Stainless Steel Nickel-Copper Carbon Steel
5/8	46	52
3/4	52	60
7/8	58	67
1	64	74

4.3.3.6.5 Tube Impingement

The condenser shall be designed to avoid direct impingement of incoming shell-side vapors on the tubes. If necessary, an impingement protection device shall be placed in front of each vapor inlet nozzle. A flow area not less than the nozzle area shall be provided between the nozzle and the impingement protection device.

4.3.3.6.6 U-tubes

The minimum radius of U-bends should be 1-1/2 times the tube diameter. The following formula should be used to determine the required thickness of the tube wall before bending:

$$t_k = \frac{P \times d}{2S_a + (0.8P)} \left(1 + \frac{d}{4R} \right)$$

Where:

t_k = Tube wall thickness before bending (in.)

d = Outside diameter of tubes (in.)

P = Design pressure (psi)

R = Radius of bend at centerline of tube (in.)

S_a = Allowable design stress at the saturation temperature corresponding to the shell design pressure (psi).

4.3.3.6.7 Stress Relieving U-bends

Cold work in forming U-bends may induce susceptibility to stress corrosion cracking in certain materials and environments. The purchaser should specify if stress relief of the U-bends is required.

4.3.3.7 Baffles and Support Plates

4.3.3.7.1 Minimum Spacing

Segmental baffles normally should not be spaced closer than 1/5 of the shell I.D. or 2 inches, whichever is greater.

4.3.3.7.2 Maximum Spacing

Tube support plates shall be so spaced that the unsupported tube length does not exceed the value indicated in Table 4.

4.3.3.7.3 Thickness

The recommended minimum thickness of carbon steel support plates and baffles shall be as shown in Table 5.

Table 5**SUPPORT PLATE AND BAFFLE THICKNESS**

Shell Diameter (in.)	Support or Baffle Plate (in.)
20 or less	1/4
20-48	3/8
greater than 48	1/2

4.3.3.7.4 Tube Holes

Baffle holes and tube support holes shall be nominally drilled 1/64" greater than outside diameter of tubes. All burrs shall be removed to prevent damage to the tubes.

4.3.3.7.5 Longitudinal Baffles

Longitudinal carbon steel baffles shall have a minimum total metal thickness of 1/4". Longitudinal alloy baffles shall have a minimum total metal thickness of 1/8".

4.3.3.7.6 Support of U-bends

Any U-bend tubes where the diameter of the bend plus twice the length from the tangent point to the last support plate exceed the values given in Table 4 shall have provisions in the U-bend area for support of such tubes.

4.3.3.8 Tie Rods and Spacers

Tie rods and spacers shall be provided, where necessary to retain baffles and tube support plates securely in position.

4.3.3.9 Gaskets

The choice of a suitable gasket material depends on the flange joint design; therefore, the selection shall be in accordance with the standards of the manufacturer.

4.3.3.10 Bolting**4.3.3.10.1 Stud and Stud Bolts**

For carbon and low alloy steel materials, refer to the Code, Table UCS-23. Threads to be in accordance with ANSI B1.1. Sizes 1 inch and smaller shall be threaded in accordance with the National Coarse thread series, and 1-1/8 inch and larger in diameter with the 8 pitch-thread series.

4.3.3.10.2 Nuts

For carbon and low alloy steel materials, refer to the Code, Table UCS-23.

4.3.3.11 Corrosion Allowance

The manufacturer is seldom in a position to determine the proper corrosion allowance. The user, on the basis of past experience, the existing conditions and the fluids involved, should specify the corrosion allowance. Values given below present nominal allowances.

Carbon Steel or Cast Iron Pressure Parts – 1/32 inch on each wetted surface unless a greater allowance is specified by the purchaser.

In those cases where a lined material is used, no corrosion allowance will be applied to the base material unless specified by the purchaser.

The corrosion allowance on a fillet weld, if required, shall be added to the calculated throat depth.

No corrosion allowance will be furnished on tubes unless specified by the purchaser.

Non-pressure parts do not require corrosion allowance unless specified by the purchaser.

Stainless steel and non-ferrous alloys shall have no corrosion allowance unless specified by the purchaser.

4.3.4 Tolerances for Interfacing

Figure 14 shows tolerances for inter-facing between the ejector or condenser and adjacent piping.

4.3.5 Hydrostatic Testing

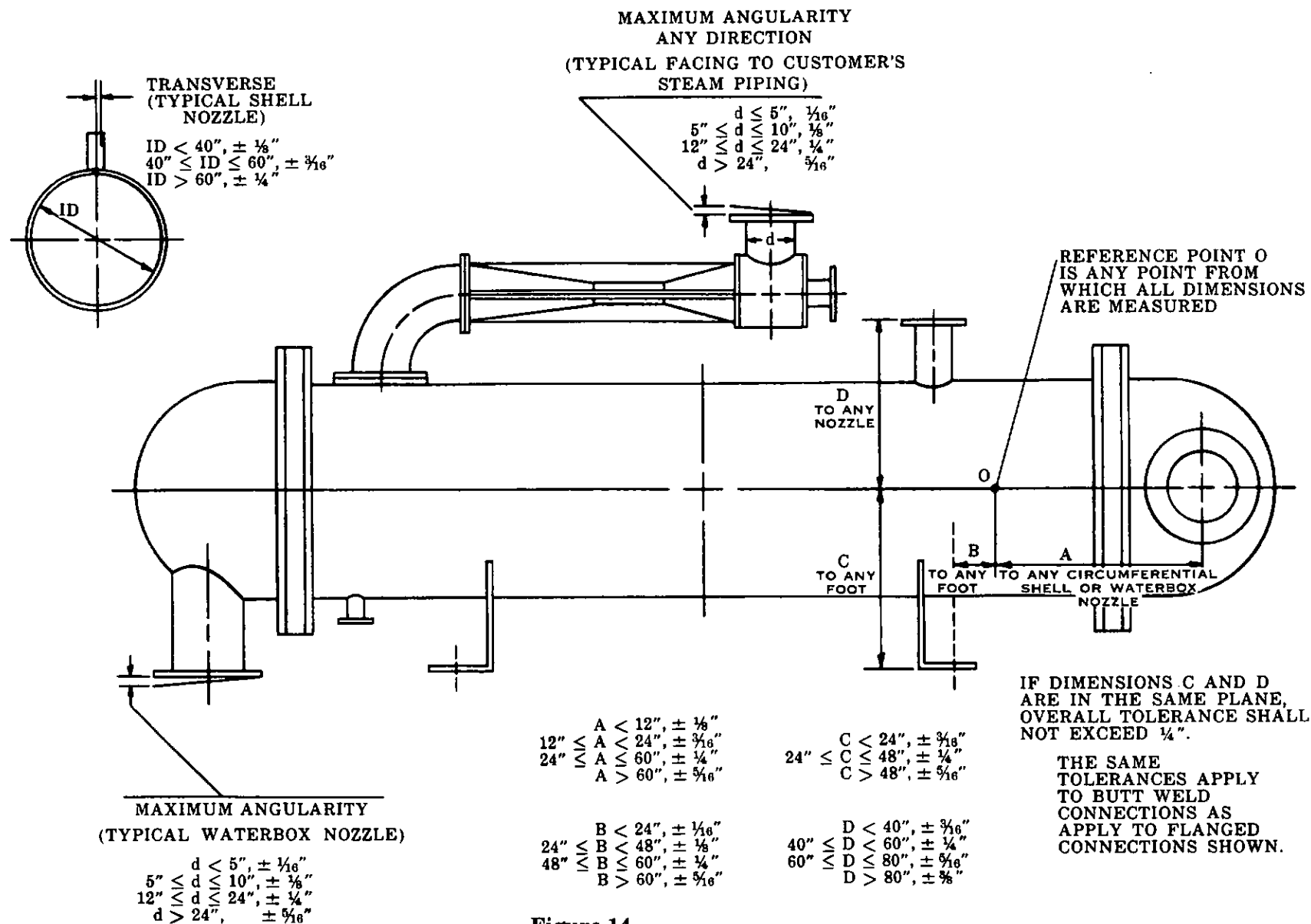
4.3.5.1 The vapor side designed for vacuum shall be hydrostatically tested to a minimum internal pressure of 20 PSIG.

4.3.5.2 The coolant and/or vapor side designed for positive pressure shall be hydrostatically tested at 1.3 times the design pressure unless otherwise dictated by the Code.

4.3.5.3 Where combined condensers are used, each compartment shall be tested separately.

4.3.5.4 The duration of the test shall be established by the manufacturer.

4.3.5.5 The temperature of the water used to hydrotest the condensers shall not be below 60°F, unless all the materials of construction have a sufficiently low Nil Ductility Transition Temperature. If the customer anticipates field test temperature lower than 60°F, he shall specify the materials of construction.



d = Nominal Pipe Size

TOLERANCES FOR INTERFACING

5.0 PERFORMANCE TEST STANDARDS

5.1 Purpose of Tests

5.1.1 Uniform Methods

These test standards provide methods of factory testing steam jet ejectors which will permit evaluation of test results regardless of the source of ejector manufacture. The methods given in these standards are the results of a great many years of accumulated experience within the industry. They are sufficiently reliable and accurate to provide both the purchaser and the manufacturer with assurance that all steam jet ejectors tested in accordance with them will meet the performance determined by the test and that these ejectors have been tested under conditions that will tend to obviate any possible difficulties after the ejectors have been installed in the purchaser's plant.

5.1.2 Alternate Methods

These test standards permit alternate methods of testing. For example, while single-stage and multi-stage noncondensing ejectors shall be tested as a complete unit, multi-stage condensing ejectors may, at the manufacturer's option, be either stage tested or tested as a complete unit. If stage tested, the manufacturer shall provide the test equipment required for such tests. The Heat Exchange Institute has satisfied itself concerning the accuracy of these alternate testing methods.

5.1.3 Unnecessary Testing

These standards are not intended to encourage unnecessary testing. In some instances, the manufacturer's method of design, manufacture and inspection are such that tests on similar units may be eliminated without prejudice to the purchaser.

5.1.4 Witness Tests

It is recommended that all routine witness acceptance tests on steam jet ejectors be conducted in accordance with the Heat Exchange Institute Standards.

5.1.5 Field Tests

These Standards cover applicable procedures for factory testing but may also be used for field testing provided the requirements of Paragraph 5.9.3 "Field Tests" are observed.

5.2 Scope of Tests

5.2.1 Test Items

To test a steam jet ejector adequately, it is necessary to establish the correct values for the items listed below, when the ejector is operating at the design point and at specified steam and water conditions:

- (a) load components
- (b) suction temperature

- (c) suction pressure
- (d) discharge pressure
- (e) total steam consumption
- (f) total water consumption, if the ejector has condensers

5.2.2 Test Gases

Since the manufacturer cannot be expected to maintain facilities for testing steam jet ejectors using all of the numerous entrained gas mixtures and at all of the many entrained gas temperatures for which ejectors are used, it shall suffice in all cases to test ejectors with dry air at normal room temperature, or with steam at any temperature convenient for the manufacturer, or with a mixture of dry air at normal room temperature and steam at any convenient temperature. (This applies to both shop tests and field tests.)

5.3 Equivalent Loading

Individual steam jet ejectors shall be tested to meet the "70°F Air Equivalent", as calculated in the following paragraphs: (For equivalent loading of ejector stages in multi-stage ejector systems refer to Section 5.10.3).

5.3.1 Air

When the specified air temperature is greater than 70°F, the 70°F air equivalent is determined by using the temperature entrainment ratio data for air shown in the "Temperature Entrainment Ratio Curve", Figure 15*. For example, the 70°F air equivalent of 100 lbs per hour of 800°F air is $\frac{100}{82.55\%}$ (from Figure 15) = 121.1 lbs per hour.

5.3.2 Steam

When the specified gas to be handled is steam, the 70°F steam equivalent is first determined by using

*This temperature entrainment ratio curve is the result of extensive research work sponsored by the Heat Exchange Institute. It is based on the results of 97 carefully run tests comprising a total of 659 individual test points. The results of the first 72 tests were reported in "Effect of Temperature of Entrained Fluid on the Performance of Steam Jet Ejectors", W.C. Holton and E.J. Schulz, *ASME Transactions*, Volume 73, No. 7, October 1951, pages 911-913. Subsequent tests resulted in a minor change in the results reported in this paper, and the final results are shown in Figure 15. These tests were run at absolute pressures ranging from 3 mm Hg to 10 in. Hg. As the results were independent of the absolute pressure, it is believed they are sufficiently accurate for all commercial work at absolute pressures both lower and higher than the test absolute pressures.

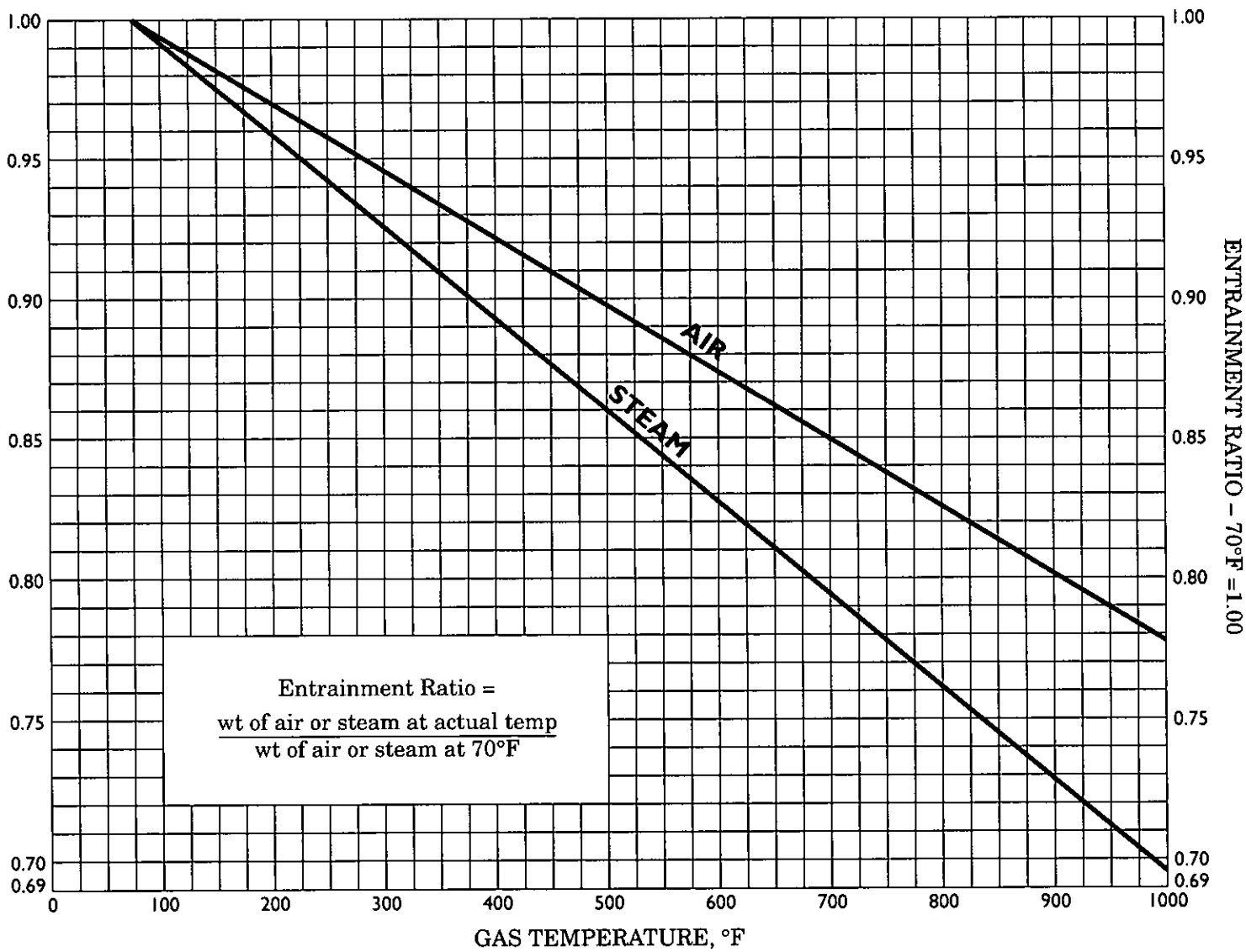


Figure 15

the temperature entrainment ratio data for steam shown in Figure 15; and the 70°F air equivalent is then determined by using the "Molecular Weight Entrainment Ratio Curve" Figure 16**. For example, the 70°F steam equivalent of 1000 lbs per hour of 450 °F steam is $\frac{1000}{87.5\%}$ (from Figure 15) = 1143 lbs per hour (70°F steam equivalent). The 70°F air equivalent of this 70°F steam equivalent is $\frac{1143}{81\%}$ (from Figure 16) = 1411 lbs per hour.

5.3.3 Mixtures of Air and Steam

When the specified gas is a mixture of air and steam, the 70°F air equivalent of each is determined separately and then added together. For example, for 660 lbs per hour mixture consisting of 200 lbs per hour air and 460 lbs per hour steam at 400°F the 70°F air equivalent of the air component is $\frac{200}{92.1\%}$ (from Figure 15) = 217 lbs per hour. The 70°F air equivalent of the steam component is $\frac{460}{89.2\%}$ (from Figure 15) = 516 lbs per hour and $\frac{516}{81\%}$ (from Figure 16) = 637 lbs per hour. The 70°F air equivalent of the mixture is therefore, 217 + 637 = 854 lbs per hour.

The curve "Entrainment Ratio Curves for Air - Steam Mixtures", Figure 17, may be used to simplify the above calculations. For example, the percent air in the mixture is $\frac{200}{660} = 30.3\%$ air. From Figure 17, for 30.3% air and 400°F the 70°F air equivalent is $\frac{660}{77.3\%} = 854$ lbs per hour.

5.3.4 Mixtures of Gases Not Including Steam

When the specified gas is a mixture of gases not including steam, the 70°F air equivalent is determined by first calculating the average molecular weight of the mixture; then the air equivalent is determined by using Figure 16; and, finally, the 70°F air equivalent is determined by using the air curve from Figure 15.

For example, the average molecular weight of a mixture of gases is calculated as follows:

** This molecular weight entrainment ratio curve is the result of extensive research work sponsored by the Heat Exchange Institute. It is based on the results of 35 carefully run tests comprising a total of 279 individual test points and involving 13 pure gases and 12 mixtures of gases as reported in "Effect of Molecular Weight of Entrained Fluid on the Performance of Steam Jet Ejectors". W. C. Holton, ASME Transactions, Volume 73, No. 7, October, 1951, pages 905-910.

The molecular weight entrainment ratio correction will vary with the ratio of entrained fluid to motive fluid and the pressure range over which an ejector operates. Figure 16 represents average correction values found by test and should give reasonable accuracy at suction pressures above 10mm HgA.

(1) When the gas flow is specified in pounds per hour, divide the weight flow of each gas by its molecular weight to determine the pounds moles per hour of each gas. The average molecular weight is the total weight flow of the mixture divided by the sum of the pounds moles per hour. For example, the mixture consists of 6 lbs per hour CO₂ 24 lbs per hour of N₂ 62 lbs per hour of Ar, and 108 lbs per hour of He, or total of 200 lbs per hour.

$$6 \div 44 = 0.136 \text{ lb moles per hr of CO}_2$$

$$24 \div 28 = 0.857 \text{ lb moles per hr of N}_2$$

$$62 \div 40 = 1.550 \text{ lb moles per hr of Ar}$$

$$\frac{108}{200} \div 4 = \frac{27.000}{29.543} \text{ lb moles per hr of He}$$

The average molecular weight of the gas is $\frac{200}{29.543} = 6.77$.

(2) If the specified analysis of the 200 lbs per hour of mixture is by weight, divide the percentage of each gas by the molecular weight of that gas. The reciprocal of the sum of the results is the average molecular weight. For example, analysis of the gas by weight percent:

$$\text{CO}_2 = 3\%; \text{N}_2 = 12\%; \text{Ar} = 31\%; \text{and, He} = 54\%.$$

$$\text{CO}_2 \ 0.03 \div 44 = 0.000682$$

$$\text{N}_2 \ 0.12 \div 28 = 0.004286$$

$$\text{Ar} \ 0.31 \div 40 = 0.007750$$

$$\text{He} \ 0.54 \div 4 = \frac{0.135000}{0.147718}$$

The average molecular weight of the gas is $\frac{1}{0.1477} = 6.77$.

(3) If the specified analysis of the mixture is by volume, multiply the percentage of each gas by the molecular weight of that gas. The sum of the results is the average molecular weight. For example, analysis of the gas by volume percent:

$$\text{CO}_2 = 0.5\%; \text{N}_2 = 2.9\%; \text{Ar} = 5.2\%; \text{and, He} = 91.4\%.$$

Molecular weights of these gases are:

$$\text{CO}_2 = 44; \text{N}_2 = 28; \text{Ar} = 40; \text{and, He} = 4.$$

$$\text{CO}_2 \ 0.005 \times 44 = 0.22$$

$$\text{N}_2 \ 0.029 \times 28 = 0.81$$

$$\text{Ar} \ 0.052 \times 40 = 2.08$$

$$\text{He} \ 0.914 \times 4 = \frac{3.66}{6.77}$$

The average molecular weight of the gas is 6.77.

ENTRAINMENT RATIO
Based on all gases being handled at 70°F to 80°F temperature and above 10 mm HgA suction pressure

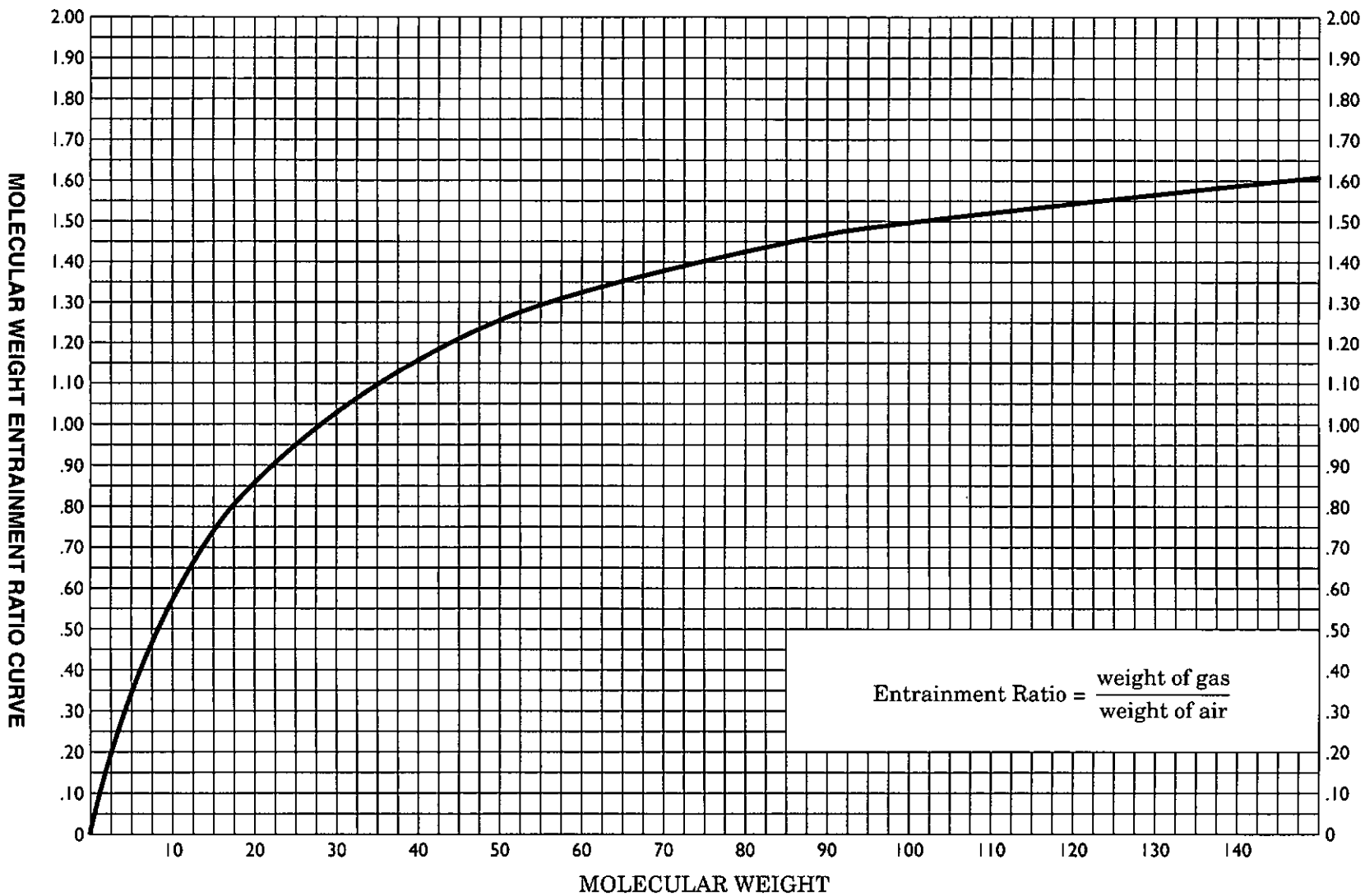
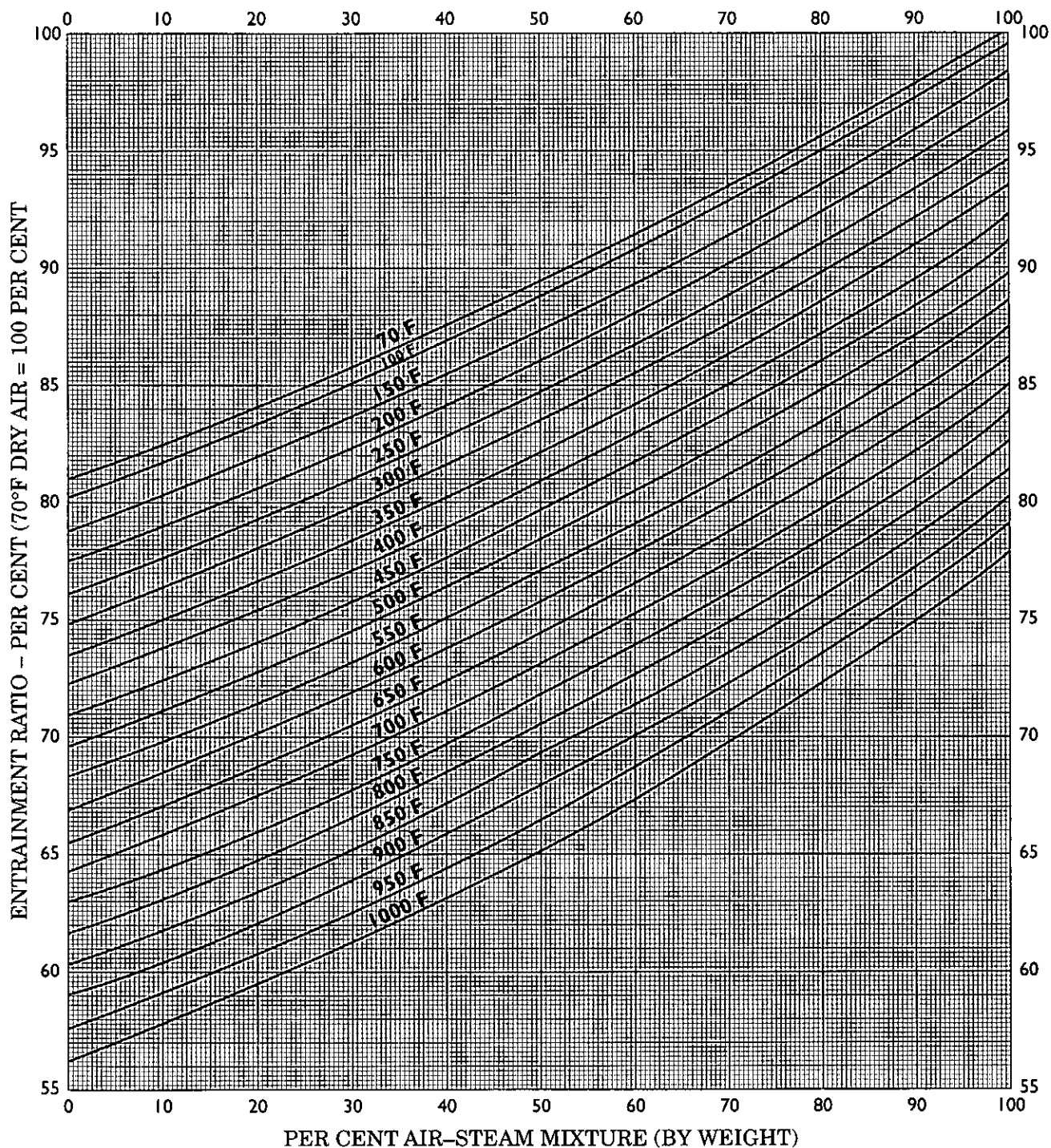


Figure 16



ENTRAINMENT RATIO CURVES FOR AIR-STREAM MIXTURES

Figure 17

The air equivalent of the 200 lbs per hour of mixture is $\frac{200}{46\%}$ (from Figure 16) = 435 lbs per hour.

If the temperature of the 200 lbs per hour of mixture is 400 degrees, the 70°F air equivalent is $\frac{435}{92.1\%}$ (from Figure 15) = 472 lbs per hour.

5.3.5 Mixtures of Gases Including Steam

When the specified mixtures of gases include steam, the 70°F air equivalent of the steam component is calculated as indicated in paragraph 5.3.2 above; and, the 70°F air equivalent of the other gases is calculated as indicated in paragraph 5.3.4 above; and, the two 70°F air equivalents are added.

The ejector may be tested with dry air at normal room temperature or with steam at any convenient temperature or with a mixture of dry air at normal room temperature and steam at any convenient temperature, at the manufacturer's option. The 70°F air equivalents of the test capacities established are then calculated by the methods outlined in paragraphs 5.3.1, 5.3.2, or 5.3.3 above.

5.4 Test Loads

5.4.1 Number of Test Points

Before readings are taken, the ejector shall be run until steady state conditions are reached so that no systemic changes occur in the instrument readings during the test.

The relation of the test load at the design point to the design capacity shall be determined as follows:

(a) By establishing not less than three load values spaced to bracket the design capacity within plus or minus 20%.

(b) Making all necessary corrections to test load values to convert them to 70°F air equivalent values.

(c) Plotting these 70°F air equivalent values versus suction pressure and discharge pressure and drawing a curve through them similar to that shown in Figure 18.

5.4.2 Dry Air Tests

The device employed to measure the flow rate of air handled by the ejector will vary between equipment manufacturers, but the approved flow measurement devices are listed and shall reference the appropriate standard for calibration. Orifice method; HEI, ASME and Square Edge Orifices can be employed. Flow meter method; rotary piston or turbine type of flow meter can be employed.

HEI flow nozzles per Figure 19 provide the basis for all calculations in this standard. At the manufacturer's option either critical flow or subcritical flow, or both, may be used. See paragraph 2.4 for a definition of critical and subcritical flow.

5.4.2.1 Critical Flow

With critical flow, the air flow rate through these HEI type flow nozzles shall be calculated by using the following equation:*

$$W_a = \frac{1503 C D_n^2 P_1}{\sqrt{T_1}} \quad (1)$$

where:

W_a = Air flow rate, pounds per hour

C = Nozzle coefficient

D_n = Diameter of nozzle throat, in.

P_1 = Upstream static pressure, pounds per square inch absolute

T_1 = Upstream temperature, °F absolute

* For gases which follow perfect gas laws, the basic equation for critical flow through a nozzle is:

$$w = 1890 C D_n^2 Z' \sqrt{\frac{P_1}{V_1}} \quad (2)$$

where:

w = Flow rate, pounds per hour

C = Nozzle coefficient

D_n = Diameter of nozzle throat, inches

P_1 = Upstream static pressure, pounds per square inch absolute

T_1 = Upstream temperature, °R

V_1 = Upstream specific volume, cubic feet per pound

$$Z' = \frac{\left(\frac{2}{k+1}\right)^{\frac{1}{k-1}} \left(\frac{k}{k+1}\right)^{\frac{1}{2}}}{\left[1 - \beta^4 \left(\frac{2}{k+1}\right)^{\frac{2}{k-1}}\right]^{\frac{1}{2}}}$$

where:

k = Ratio of specific heats

β = Ratio of nozzle diameter to pipe diameter

For dry air $V_1 = \frac{T_1}{2.699 P_1}$ and $k = 1.400$.

With the critical flow testing arrangement recommended, β approaches zero so the Z' is equal to 0.484 and equation (2) reduces to equation (1).

The nozzle coefficients to use in equation (1) shall be taken from Figure 20*. The Reynolds number needed to determine the nozzle coefficient from Figure 20 shall be calculated for the prevailing test conditions by the following equation:

$$R_D = \frac{W_a}{236\mu D_n} \quad (3)$$

where:

R_D = Reynolds number

W_a = Air flow rate, pounds per hour

μ = Absolute viscosity of air,
pounds per foot-second

D_n = Diameter of nozzle throat, inches

The value for viscosity to use in the above equation is obtained from Figure 21.

The flow values given in the tables, Figures 22 and 23, were calculated by using equation (2) and the proper nozzle coefficient for critical flow from Figure 20. Interpolation can be used to obtain intermediate values for a flow nozzle.

5.4.2.2 Subcritical Flow

With subcritical flow the air flow rate through these nozzles shall be calculated by using the following equation:

$$W_a = 1890 C D_n^2 Y' \sqrt{\frac{P_1 - P_2}{V_1}} \quad (4)$$

where:

W_a = Air flow rate, pounds per hour

C = Nozzle coefficient

D_n = Diameter of nozzle throat, inches

P_1 = Upstream static pressure, pounds per square inch absolute

P_2 = Downstream static pressure, pounds per square inch absolute

V_1 = Upstream specific volume, cubic feet per pound

$$Y' = \left[\left(\frac{k}{k-1} \right) \gamma^{\frac{2}{k}} \left(\frac{1 - (\gamma)^{\frac{k-1}{k}}}{1 - \gamma} \right) \right]^{\frac{1}{2}} \left[\frac{1}{1 - \beta^4 \gamma^{\frac{2}{k}}} \right]^{\frac{1}{2}}$$

where:

k = Ratio of specific heats

$\gamma = \frac{P_2}{P_1}$ = Ratio of expansion through the nozzle

β = Ratio of nozzle diameter to pipe diameter

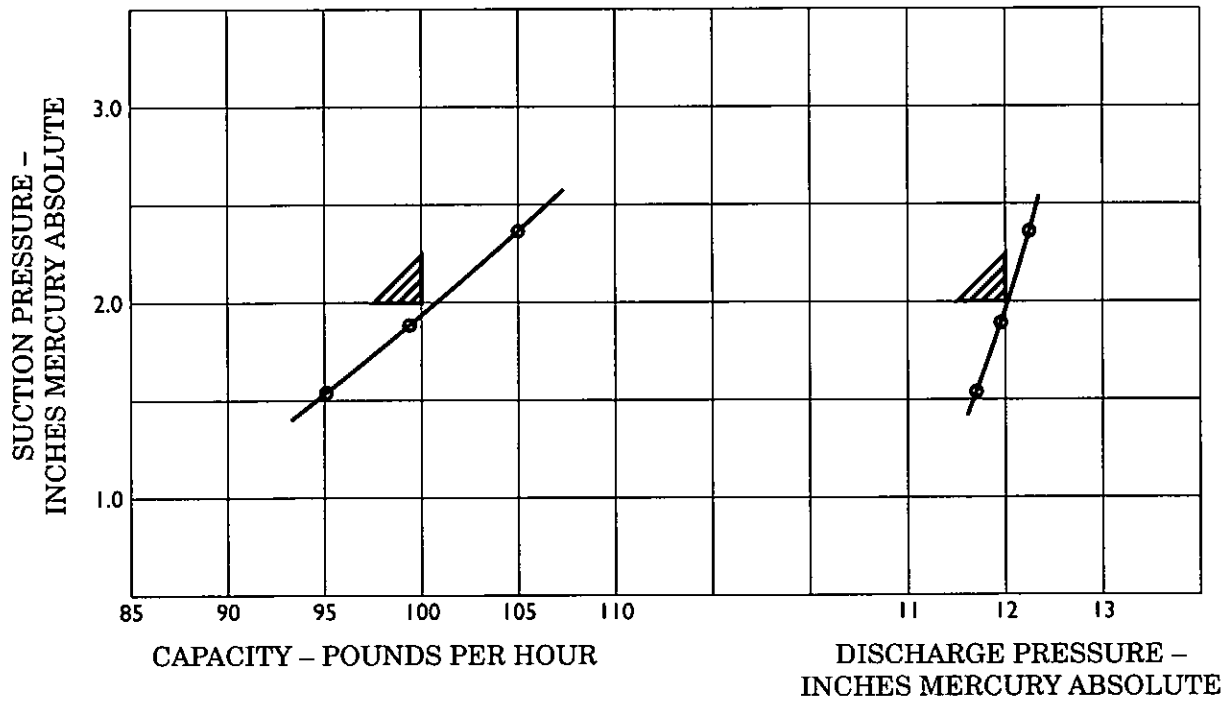
For dry air $k = 1.400$ and for the subcritical flow testing arrangement recommended, β approaches zero. The value of Y' for various ratios of P_2 to P_1 is as follows:

$\frac{P_2}{P_1}$	Y'	$\frac{P_2}{P_1}$	Y'	$\frac{P_2}{P_1}$	Y'
1.00	1.000	0.90	0.9449	0.80	0.8864
0.99	0.9946	0.89	0.9392	0.79	0.8804
0.98	0.9892	0.88	0.9335	0.78	0.8743
0.97	0.9838	0.87	0.9278	0.77	0.8682
0.96	0.9783	0.86	0.9220	0.76	0.8620
0.95	0.9728	0.85	0.9162	0.75	0.8558
0.94	0.9673	0.84	0.9103	0.74	0.8495
0.93	0.9618	0.83	0.9044	0.73	0.8432
0.92	0.9562	0.82	0.8984	0.72	0.8369
0.91	0.9506	0.81	0.8924	0.71	0.8305

The nozzle coefficients to use in equation (4) shall be taken from Figure 20. The Reynolds number needed to determine the nozzle coefficient from Figure 20 shall be calculated for the prevailing test conditions by using equation (3).

To simplify the determination of the air flow rates, Figures 24 and 25 show plots of calculated air flow rates versus pressure drop in inches of water (Figure 24) and versus pressure drop in inches of mercury (Figure 25) for a C of 1.00, a k of 1.400 and a B of 0. Flow values taken from these curves should be corrected by using the proper nozzle coefficient taken from Figure 26* and by making any temperature correction that is necessary by using the proper temperature correction factor taken from Figure 27.

*These nozzle coefficients are the result of some extensive recalibration work on the Heat Exchange Standard Flow Nozzles sponsored by the Heat Exchange Institute and reported in "Small Nozzles at Low Values of the Diameter Ratio", H.S. Bean, R.M. Johnson and T.R. Blakeslee, *ASME Transactions*, Volume 76, No. 6, August 1954, pages 863 - 871.



PLOT OF TEST RESULTS

Figure 18

Nozzle Geometry

Proportions of ASME Long Radius Flow Nozzle used for HEI Standards

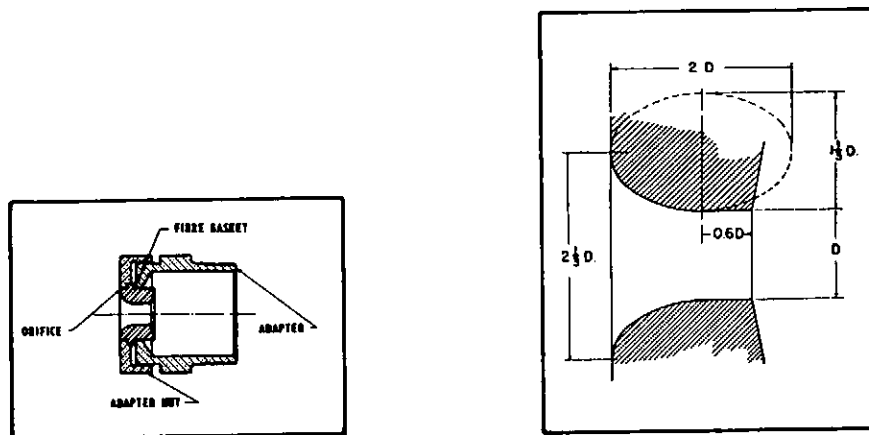


Figure 19

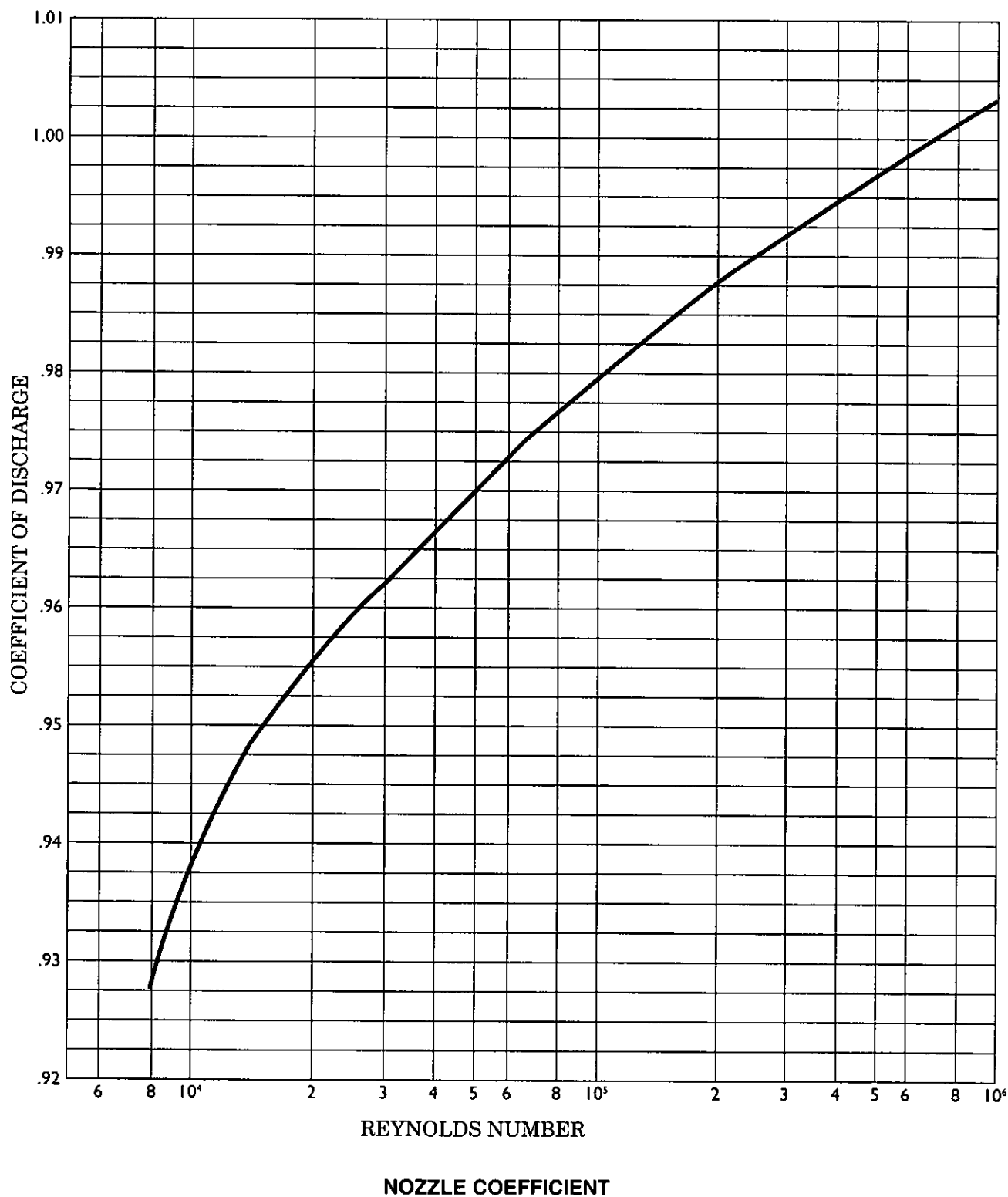


Figure 20

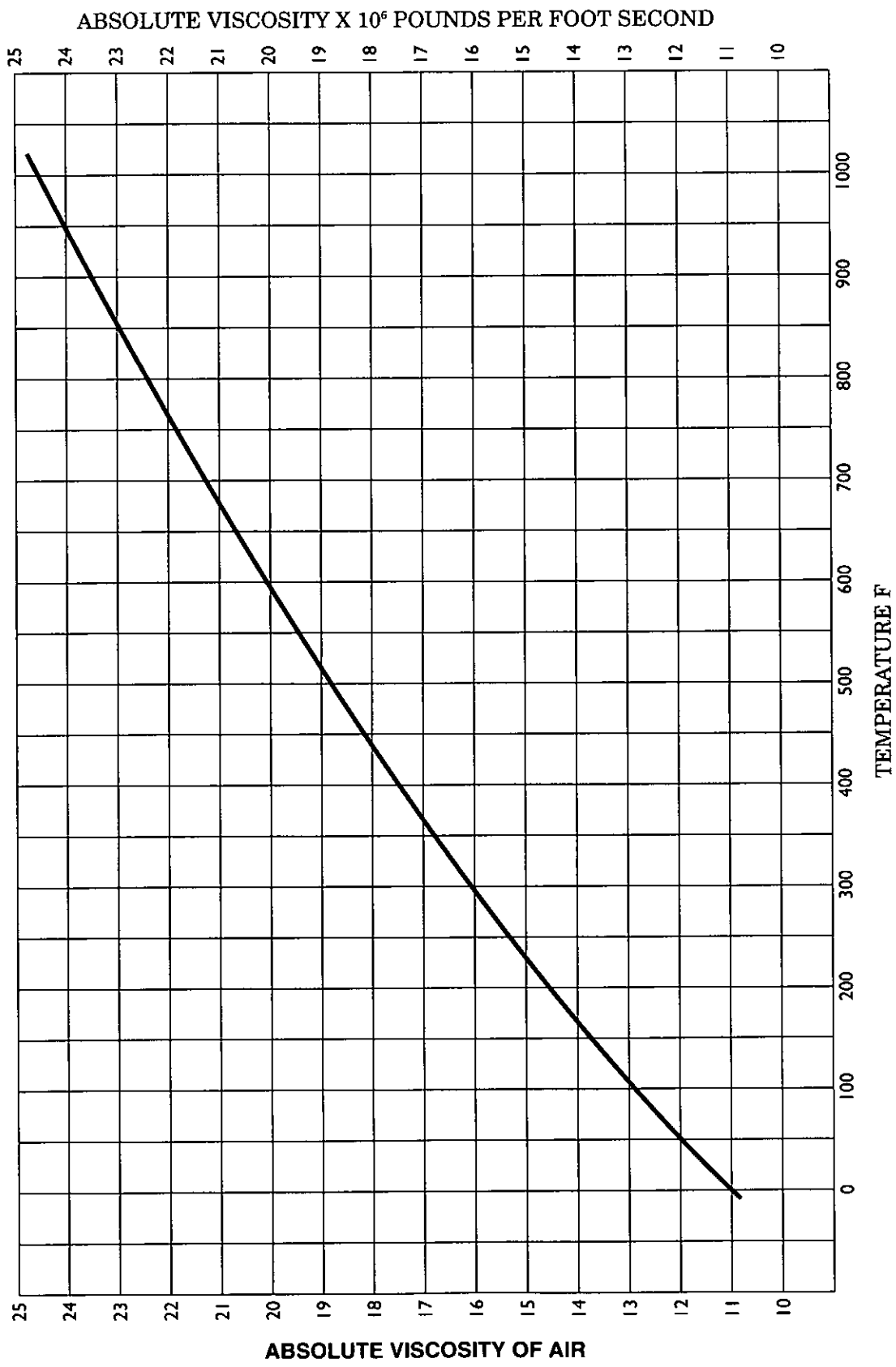


Figure 21

NOZZLE CAPACITIES FOR CRITICAL FLOW OF AIR

In pounds per hour based on dry air

BAROMETRIC PRESSURE 28.8 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.58	3.54	3.50	3.47	3.43	3.40
2	.094	8.00	7.93	7.85	7.78	7.70	7.63
3	.125	14.3	14.1	14.0	13.8	13.7	13.6
4	.188	32.4	32.1	31.8	31.5	31.2	30.9
5	.250	57.6	57.0	56.4	55.9	55.3	54.8
6	.313	90.4	89.5	88.6	87.8	86.9	86.1
7	.375	130.	129.	128.	127.	125.	124.
8	.500	232.	230.	228.	226.	223.	221.
9	.750	524.	519.	514.	509.	504.	500.
10	1.000	936.	926.	917.	908.	900.	892.

BAROMETRIC PRESSURE 29.4 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.65	3.61	3.58	3.54	3.51	3.47
2	.094	8.18	8.09	8.01	7.93	7.87	7.79
3	.125	14.6	14.4	14.3	14.1	14.0	13.9
4	.188	33.1	32.8	32.4	32.1	31.8	31.5
5	.250	58.8	58.2	57.6	57.0	56.5	56.0
6	.313	92.3	91.4	90.5	89.6	88.8	88.0
7	.375	133.	132.	131.	129.	128.	127.
8	.500	237.	235.	232.	230.	228.	226.
9	.750	536.	530.	525.	520.	515.	510.
10	1.000	955.	946.	937.	928.	919.	910.

BAROMETRIC PRESSURE 29.0 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.60	3.56	3.53	3.49	3.47	3.43
2	.094	8.06	7.98	7.90	7.83	7.76	7.68
3	.125	14.4	14.2	14.1	13.9	13.8	13.7
4	.188	32.6	32.3	32.0	31.7	31.4	31.1
5	.250	58.0	57.4	56.8	56.3	55.7	55.2
6	.313	91.1	90.2	89.4	88.4	87.6	86.8
7	.375	131.	130.	129.	128.	126.	125.
8	.500	234.	232.	229.	227.	225.	223.
9	.750	529.	523.	518.	513.	508.	503.
10	1.000	942.	933.	924.	915.	906.	898.

BAROMETRIC PRESSURE 29.6 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.68	3.64	3.60	3.57	3.53	3.50
2	.094	8.23	8.15	8.07	7.99	7.92	7.85
3	.125	14.6	14.5	14.4	14.2	14.1	14.0
4	.188	33.3	33.0	32.7	32.3	32.0	31.7
5	.250	59.1	58.6	58.0	57.4	56.9	56.4
6	.313	93.0	92.0	91.1	90.2	89.4	88.6
7	.375	134.	133.	131.	130.	129.	128.
8	.500	239.	236.	234.	232.	230.	228.
9	.750	540.	534.	529.	523.	518.	514.
10	1.000	961.	953.	943.	934.	925.	916.

BAROMETRIC PRESSURE 29.2 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.63	3.59	3.55	3.52	3.48	3.45
2	.094	8.12	8.04	7.96	7.89	7.81	7.74
3	.125	14.5	14.3	14.2	14.0	13.9	13.8
4	.188	32.9	32.5	32.2	31.9	31.6	31.3
5	.250	58.4	57.8	57.2	56.6	56.1	55.6
6	.313	91.7	90.8	89.9	89.0	88.2	87.4
7	.375	132.	131.	130.	128.	127.	126.
8	.500	235.	233.	231.	229.	227.	224.
9	.750	532.	526.	522.	516.	511.	507.
10	1.000	949.	940.	930.	921.	912.	904.

BAROMETRIC PRESSURE 29.8 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.70	3.66	3.63	3.59	3.56	3.52
2	.094	8.29	8.21	8.12	8.04	7.97	7.90
3	.125	14.8	14.6	14.5	14.3	14.2	14.1
4	.188	33.6	33.2	32.9	32.6	32.3	32.0
5	.250	59.5	59.0	58.4	57.8	57.3	56.8
6	.313	93.6	92.7	91.8	90.9	90.0	89.2
7	.375	135.	134.	132.	131.	130.	129.
8	.500	240.	238.	236.	233.	231.	229.
9	.750	543.	538.	533.	527.	522.	517.
10	1.000	968.	959.	950.	940.	931.	923.

Figure 22

NOZZLE CAPACITIES FOR CRITICAL FLOW OF AIR (CONTINUED)

In pounds per hour based on dry air

BAROMETRIC PRESSURE 30.0 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.73	3.69	3.65	3.62	3.58	3.55
2	.094	8.35	8.26	8.18	8.10	8.02	7.95
3	.125	14.9	14.7	14.6	14.4	14.3	14.2
4	.188	33.8	33.5	33.1	32.8	32.5	32.2
5	.250	59.9	59.4	58.8	58.2	57.7	57.1
6	.313	94.2	93.3	92.4	91.5	90.6	89.8
7	.375	136.	135.	133.	132.	131.	130.
8	.500	242.	240.	237.	235.	233.	231.
9	.750	547.	542.	535.	531.	526.	521.
10	1.000	975.	965.	956.	947.	938.	929.

BAROMETRIC PRESSURE 30.6 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.80	3.77	3.73	3.69	3.66	3.62
2	.094	8.52	8.43	8.35	8.27	8.19	8.11
3	.125	15.2	15.0	14.9	14.7	14.6	14.5
4	.188	34.5	34.1	33.8	33.5	33.1	32.8
5	.250	61.1	60.6	60.0	59.4	58.9	58.3
6	.313	96.1	95.2	94.2	93.3	92.4	91.6
7	.375	139.	137.	136.	135.	133.	132.
8	.500	247.	244.	242.	240.	237.	235.
9	.750	558.	553.	547.	542.	537.	532.
10	1.000	994.	984.	976.	966.	957.	948.

BAROMETRIC PRESSURE 30.2 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.75	3.72	3.68	3.64	3.61	3.57
2	.094	8.41	8.32	8.24	8.15	8.08	8.01
3	.125	15.0	14.8	14.7	14.5	14.4	14.3
4	.188	34.0	33.7	33.3	33.0	32.7	32.4
5	.250	60.3	59.7	59.2	58.6	58.1	57.4
6	.313	94.9	93.9	93.0	92.1	91.3	90.4
7	.375	137.	135.	134.	133.	132.	130.
8	.500	244.	241.	239.	237.	234.	232.
9	.750	551.	545.	540.	535.	529.	524.
10	1.000	981.	971.	963.	953.	944.	935.

BAROMETRIC PRESSURE 30.8 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.83	3.79	3.75	3.72	3.68	3.64
2	.094	8.58	8.49	8.40	8.32	8.24	8.16
3	.125	15.3	15.1	15.0	14.8	14.7	14.5
4	.188	34.7	34.4	34.0	33.7	33.4	33.1
5	.250	61.5	60.9	60.3	59.8	59.2	58.7
6	.313	96.8	95.8	94.9	93.9	93.1	92.2
7	.375	140.	138.	137.	136.	134.	133.
8	.500	249.	246.	244.	241.	239.	237.
9	.750	562.	556.	551.	546.	541.	536.
10	1.000	1001.	991.	981.	973.	963.	954.

BAROMETRIC PRESSURE 30.4 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.78	3.74	3.70	3.67	3.63	3.60
2	.094	8.46	8.38	8.29	8.21	8.13	8.05
3	.125	15.1	14.9	14.8	14.6	14.5	14.4
4	.188	34.1	33.9	33.6	33.2	32.9	32.6
5	.250	60.7	60.2	59.6	59.0	58.5	57.9
6	.313	95.5	94.5	93.6	92.7	91.8	91.0
7	.375	138.	136.	135.	134.	132.	131.
8	.500	245.	243.	240.	238.	236.	234.
9	.750	554.	549.	544.	539.	533.	530.
10	1.000	988.	978.	969.	960.	951.	942.

BAROMETRIC PRESSURE 31.0 In. Hg

H.E.I. No.	Nozzle Diam.	Air Temperature F					
		50	60	70	80	90	100
1	.063	3.86	3.82	3.78	3.74	3.70	3.67
2	.094	8.63	8.55	8.46	8.38	8.30	8.22
3	.125	15.4	15.2	15.1	14.9	14.8	14.6
4	.188	34.9	34.6	34.2	33.9	33.6	33.3
5	.250	61.9	61.3	60.8	60.2	59.6	59.1
6	.313	97.4	96.4	95.5	94.6	93.7	92.8
7	.375	140.	139.	138.	136.	135.	134.
8	.500	250.	248.	245.	243.	241.	238.
9	.750	566.	560.	554.	549.	544.	539.
10	1.000	1008.	998.	988.	979.	970.	961.

Figure 23

The following illustrates the use of Figures 24, 26 and 27:

Nozzle throat diameter	0.125 in.
Barometric pressure	29.0 in. Hg
Differential pressure across nozzle	10.0 in. Hg
Ambient air temperature	90°F

Flow rate (from Figure 24) = 1143 lbs per hr of 70°F air per square inch of nozzle throat area with a nozzle coefficient of unity.

Nozzle throat area = 0.01227 square inches

Temperature correction (from Figure 27) = 0.982

Nozzle coefficient (from Figure 26) = 0.966

Actual flow rate = $1143 \times 0.01227 \times 0.982 \times 0.966 = 13.3$ lbs per hr of 90°F air.

5.4.3 Steam Tests

The quantity of steam handled by the steam jet ejector shall be measured by means of the Heat Exchange Institute Standard Flow Nozzles as shown in Figure 19. Critical flow shall be used.

The steam flow rate through these flow nozzles shall be calculated by using the following equation*:

$$W_s = 892.4 C D_n^2 \sqrt{\frac{P_1}{V_1}} \quad (5)$$

where:

W_s = Steam flow rate, pounds per hour

C = Nozzle coefficient

D_n = Diameter of nozzle throat, inches

P_1 = Upstream static pressure, pounds per square inch absolute

V_1 = Upstream specific volume, cubic feet per pound

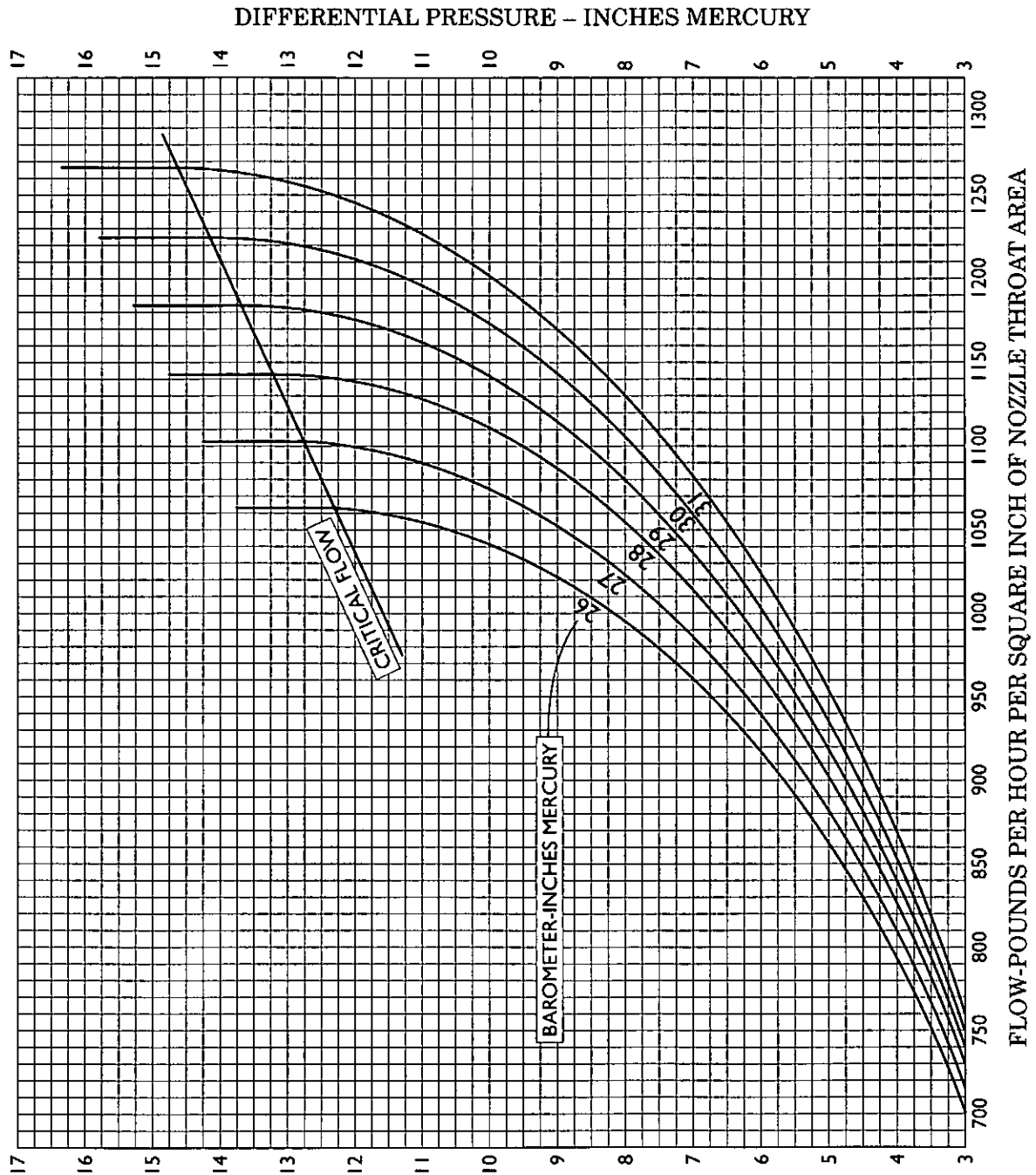
Using the above equation, the curves, Figures 28, 29, 30 and 31, have been plotted for the steam flow rate (W_s) on the basis of one square inch of nozzle throat area and a flow coefficient of 1.00 for pressures from 0 to 620 psig and from saturation temperature to 1000°F total temperature. Flow values taken from these curves shall be corrected by using the proper nozzle coefficient from Figure 20. The Reynolds number needed to determine the nozzle coefficient from Figure 20 shall be calculated for the prevailing test conditions by using equation (3) in Paragraph 5.4.2 with the value for viscosity in equation (3) obtained from Figure 32.**

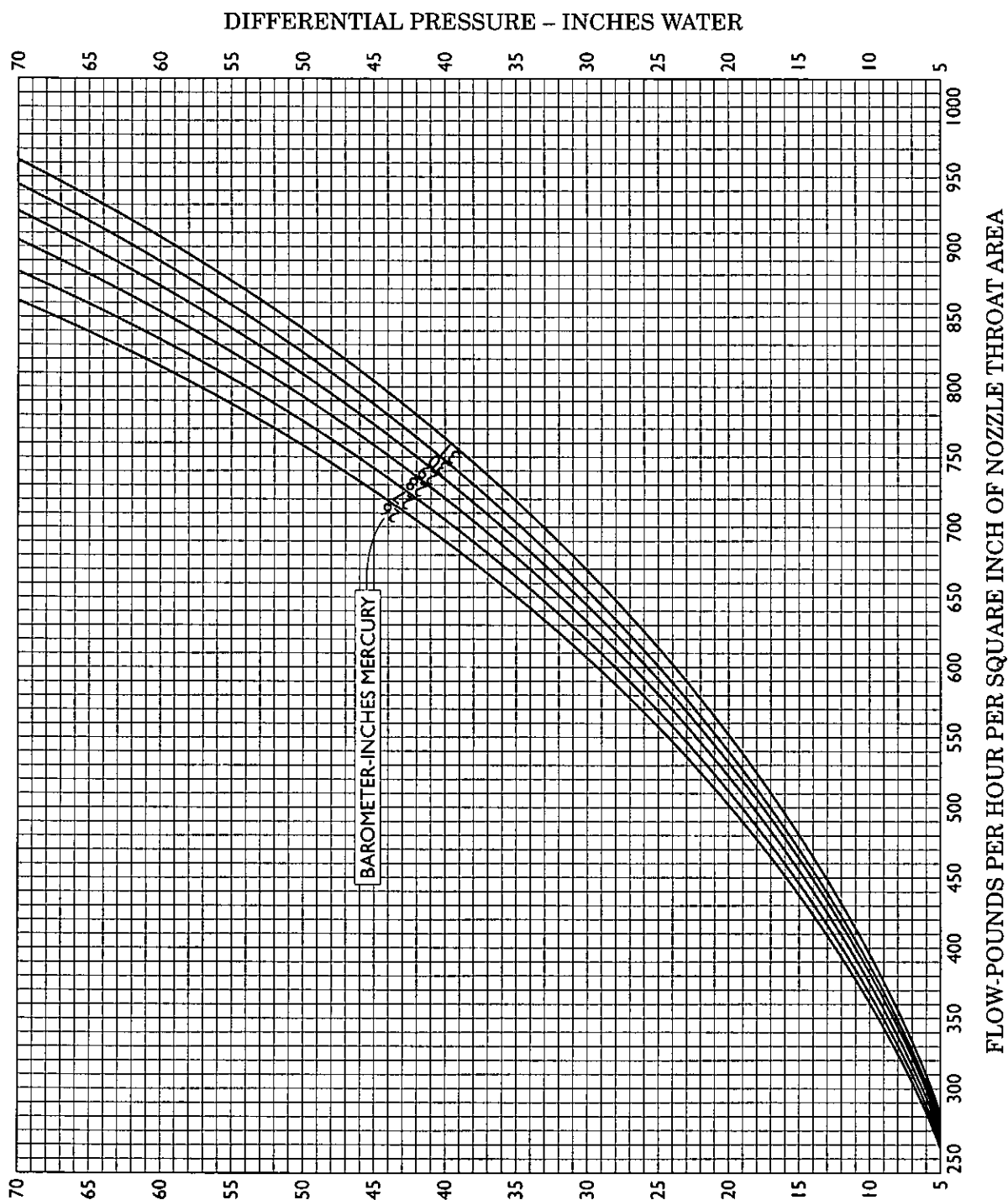
5.4.4 Air and Steam Mixture Tests

The quantity of a mixture of air and steam or water vapor handled by the steam jet ejector shall be determined by measuring the air flow rate, as outlined in Paragraph 5.4.2, and measuring the steam flow rate, as outlined in Paragraph 5.4.3. The air and steam handled shall be mixed in a mixing chamber as shown in Figure 36 before being entrained by the ejector.

* The average value of k for steam is 1.300 and for the critical flow testing arrangement recommend, β is never greater than 0.25 and in practically all cases is 0.20 or less. Using 1.3000 for k and 0.20 as an average for β , Z' becomes 0.4722 and substituting this value for Z' in basic flow equation (2) reduces it to equation (5).

**Steam viscosity taken from "The Viscosity, Thermo Conductivity and Prandtl Number for Air, O_2 , N_2 , NO , H_2 , CO , CO_2 , H_2O , He and Ar " by Joseph Hilsenrath and Y. S. Touloukian, *ASME Transactions*, Volume 76, No. 6, August 1954, pages 967-985.





SUBCRITICAL FLOW - DRY AIR AT 70°F - UNITY NOZZLE COEFFICIENT

Figure 25

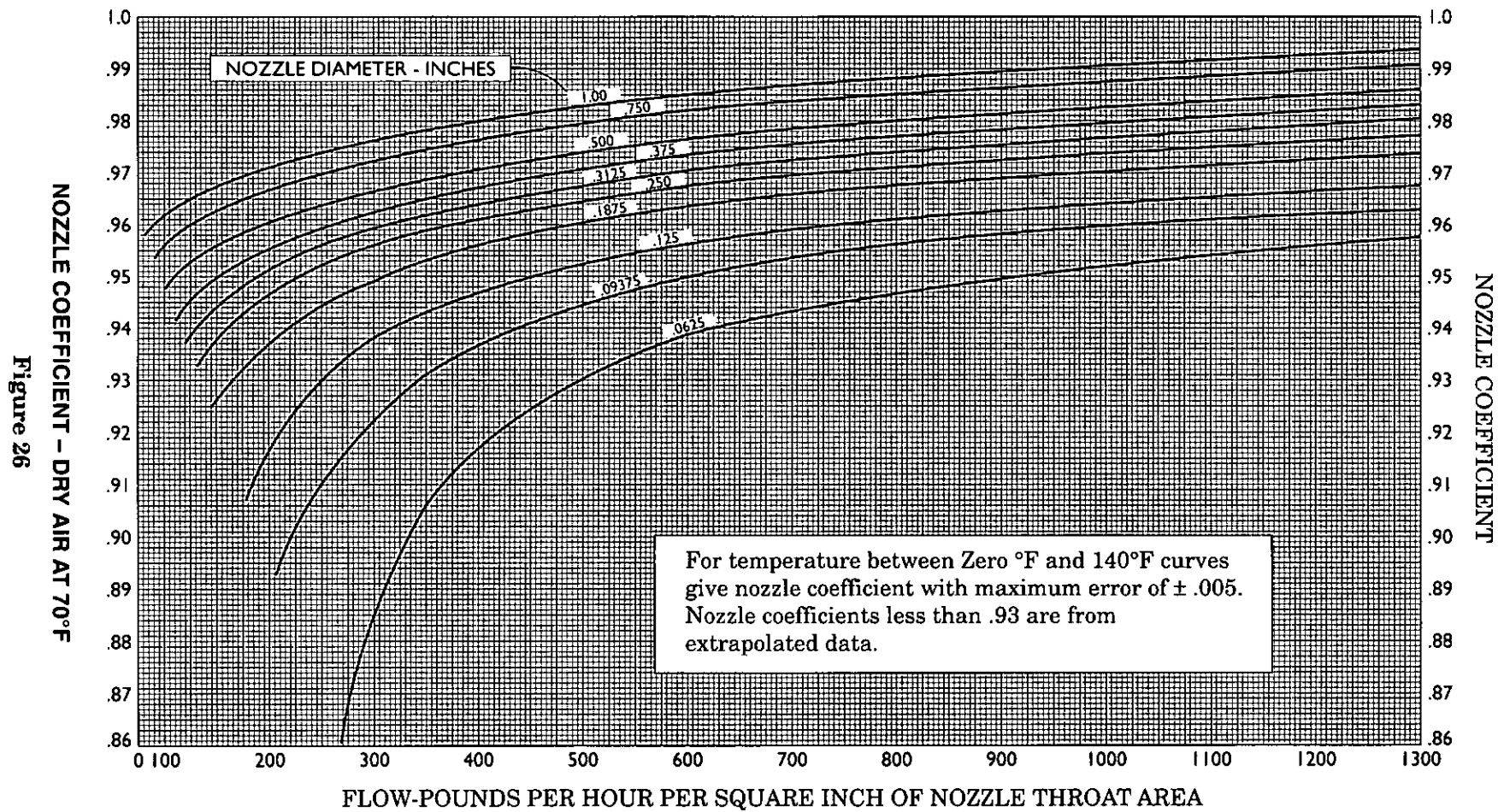
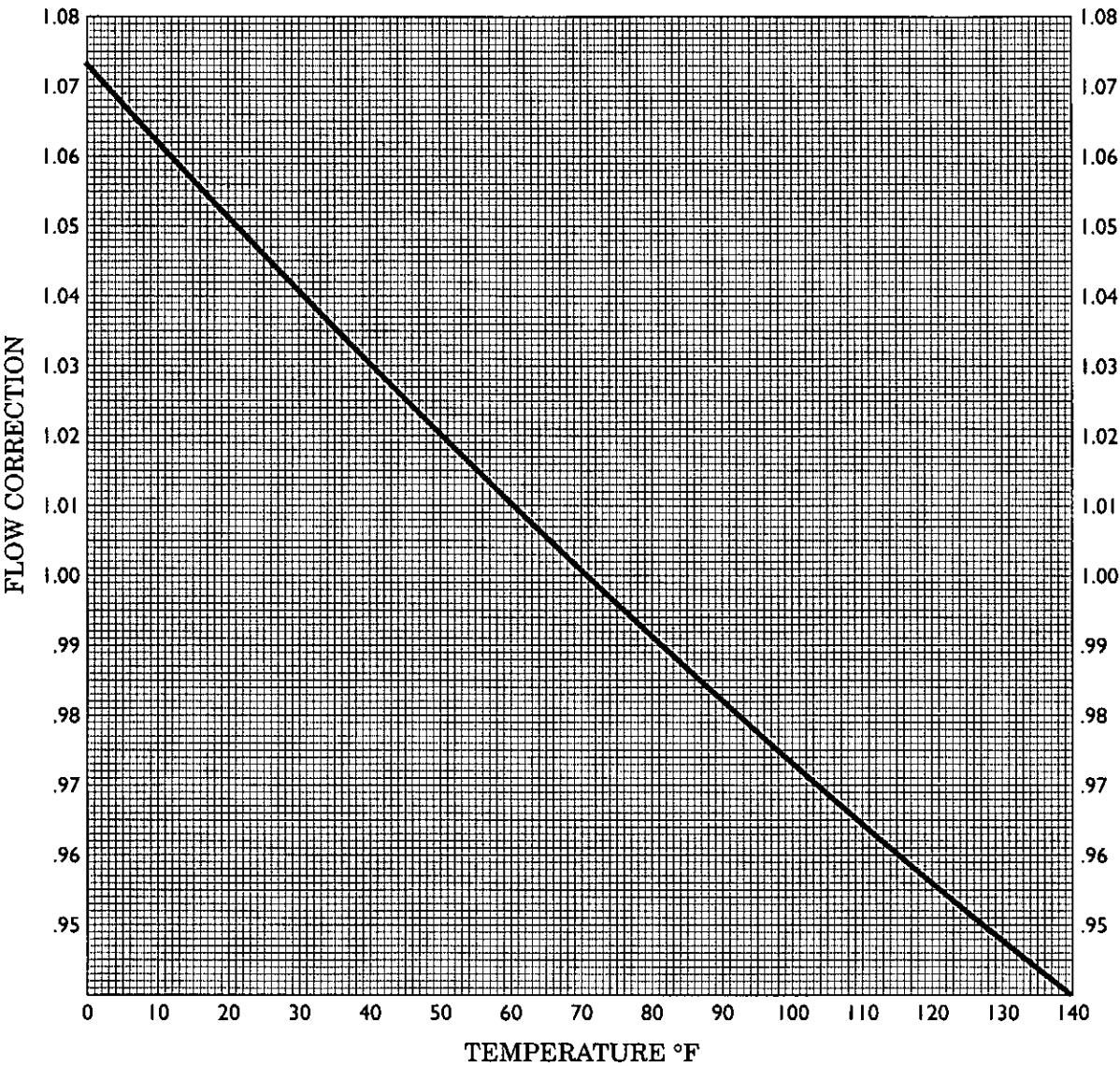
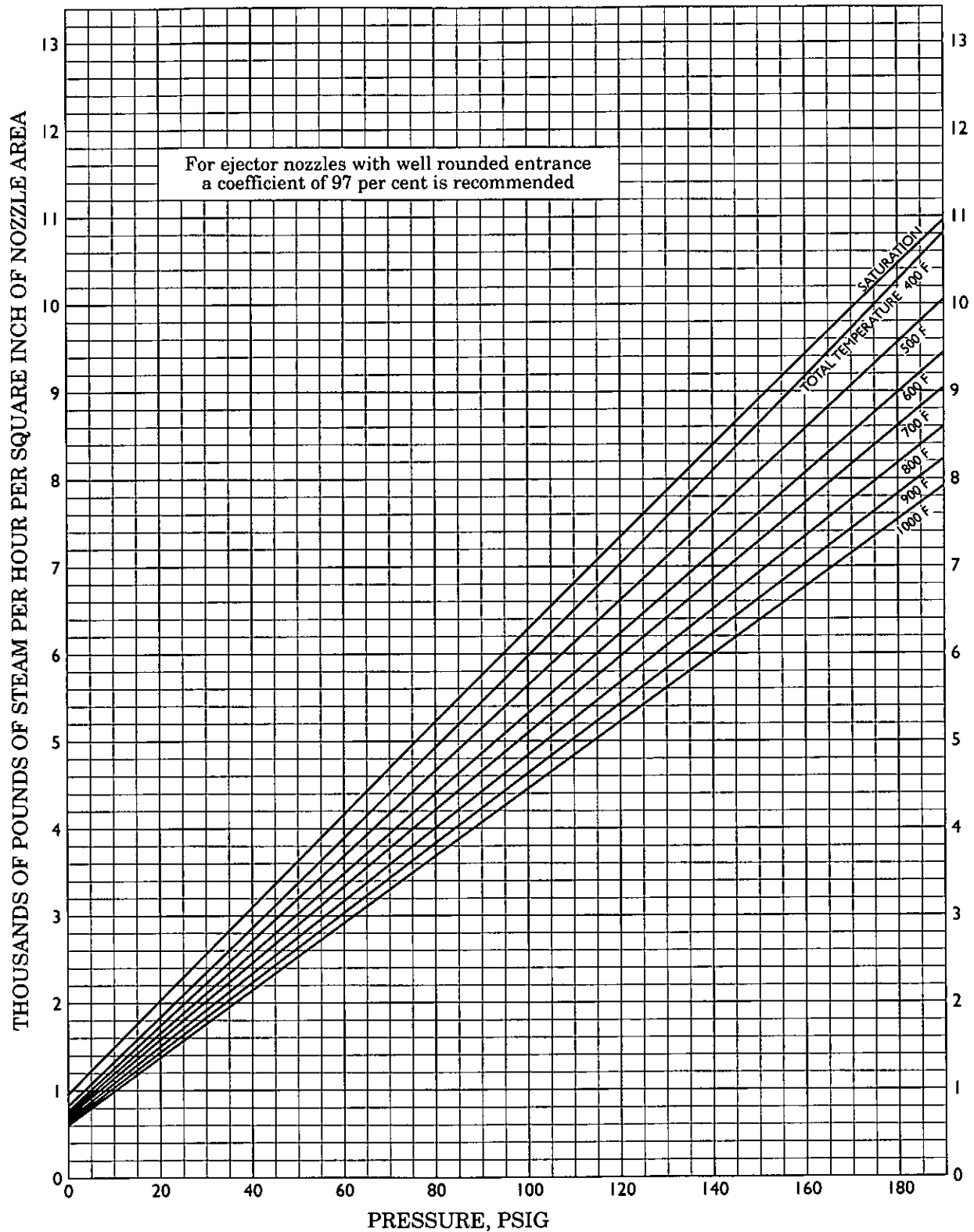


Figure 26



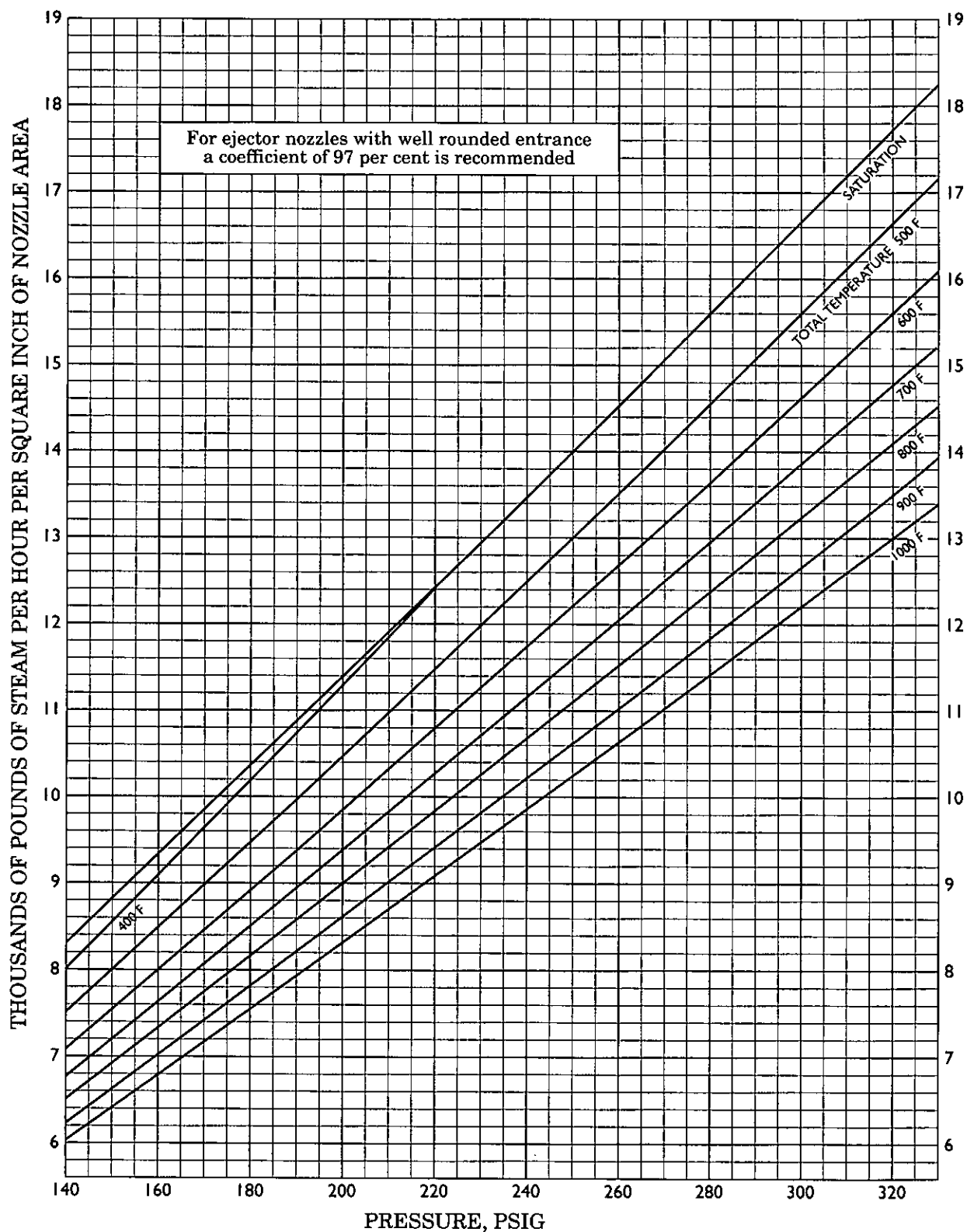
TEMPERATURE CORRECTION FOR SUB-CRITICAL FLOW OF AIR

Figure 27



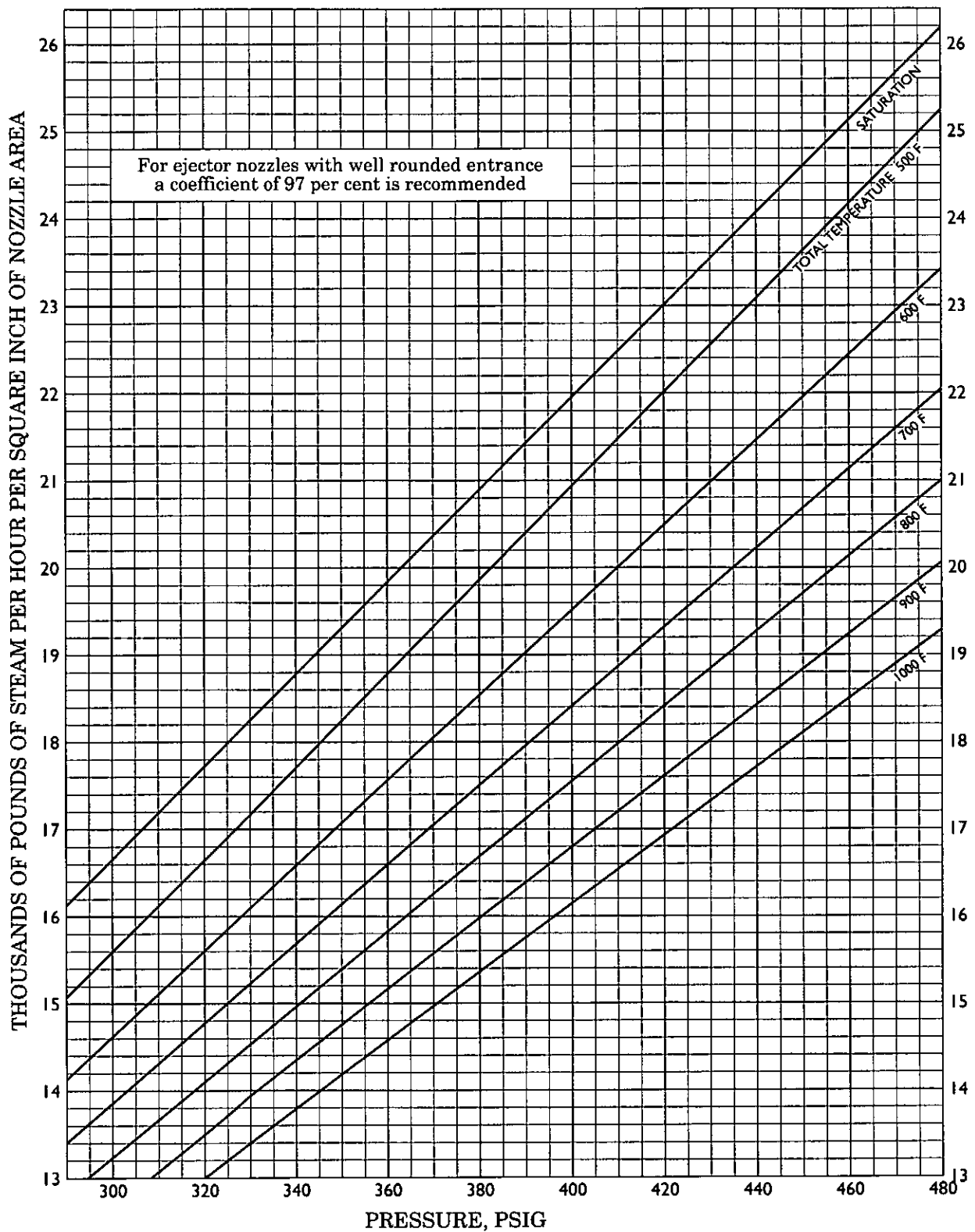
STEAM FLOW CURVES BASED ON 100 PER CENT COEFFICIENT

Figure 28



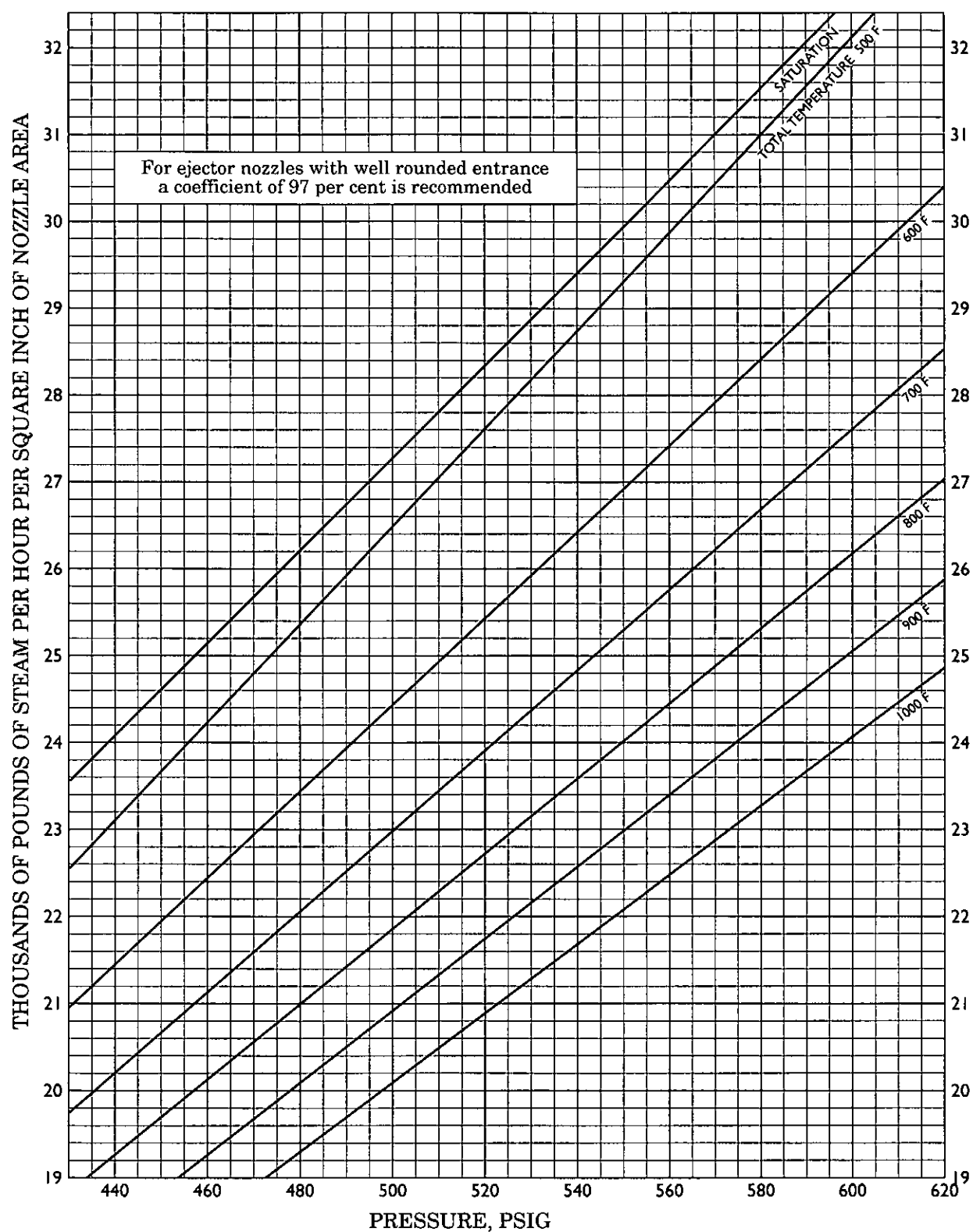
STEAM FLOW CURVES BASED ON 100 PER CENT COEFFICIENT

Figure 29



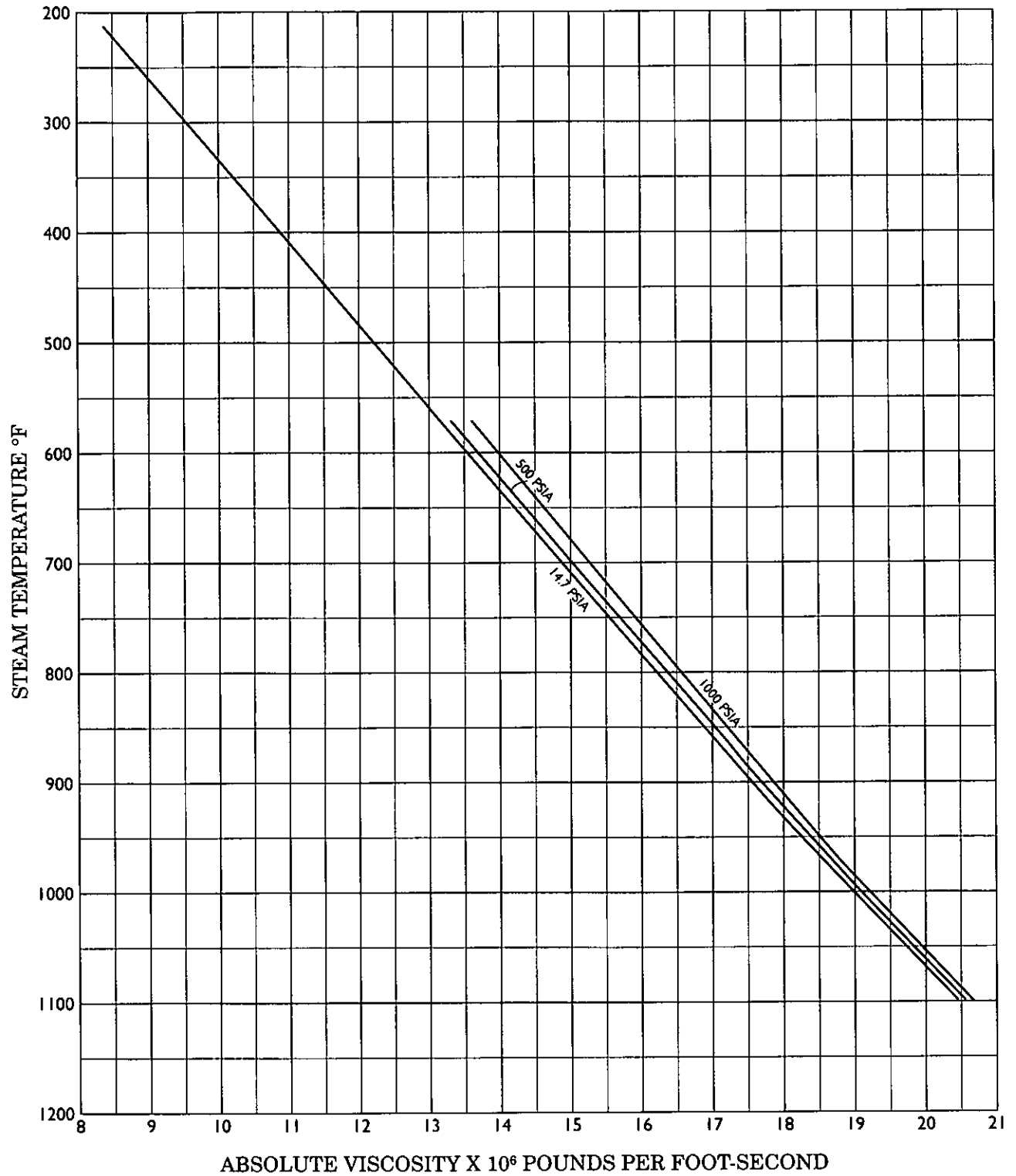
STEAM FLOW CURVES BASED ON 100 PER CENT COEFFICIENT

Figure 30



STEAM FLOW CURVES BASED ON 100 PER CENT COEFFICIENT

Figure 31



ABSOLUTE VISCOSITY OF STEAM

Figure 32

5.5 Temperature

5.5.1 General Precautions

The following precautions shall apply to all temperature measurements:

(a) The instruments shall be precise, accurate and readable within one degree Fahrenheit. The operating range shall be suitable for the temperatures to be measured.

(b) Thermowells shall be as thin as practical and their bore shall fit the instrument. The outside surface shall be clean and free of corrosion or oxide.

(c) When the temperatures being measured are for use in the final calculation of results, duplicate instruments shall be used.

(d) The temperature measuring device shall be installed in a flowing stream of the fluid being measured, and so located that no significant quantity of heat shall be transferred to it by radiation or conduction other than that of the medium being measured.

(e) When the fluid being measured is at high temperature, the pipe or vessel in which the instrument is installed shall be well insulated.

5.5.2 Suction Temperature

It is very difficult to measure accurately the temperature of low mass flows, such as the vapors entering an ejector suction. Wherever possible, this temperature shall be calculated from the conditions existing ahead of the measuring flow nozzle.

For air (see Paragraph 5.4.2), the temperature shall be measured upstream from the measuring flow nozzle. This temperature shall be used as the temperature entering the ejector suction. The change in temperature, due to expansion across the flow nozzle, is insignificant.

For steam (see Paragraph 5.4.3), the temperature shall be computed from the pressure and temperature existing ahead of the measuring flow nozzle using the steam tables or the Mollier Chart at constant enthalpy.

For a mixture of air and steam (see Paragraph 5.4.4), the temperature shall be calculated by using the following equation:

$$t_m = \frac{W_s C_{ps} t_s + W_a C_{pa} t_a}{W_s C_{ps} + W_a C_{pa}} \quad (6)$$

where:

t_m = Temperature of mixture at ejector suction, °F

W_s = Steam flow rate, pounds per hour

C_{ps} = Specific heat of steam at constant pressure corresponding to downstream absolute pressure (0.45 approximately)

t_s = Temperature of steam on downstream side of nozzle, °F

W_a = Air flow rate, pounds per hour

C_{pa} = Specific heat of air at constant pressure (0.24 approximately)

t_a = Ambient air temperature, °F

The following example illustrates the use of the above equation:

Upstream steam conditions	250 psig, 450°F.T.T.
Ambient air temperature	70°F
Steam flow	460 lbs per hr
Air flow	200 lbs per hr
Ejector suction pressure	1.4 in. HgA

For the above conditions, enthalpy of steam equals 1231.5 BTU per pound. Corresponding steam temperature at 1.4 in. Hg Absolute pressure and enthalpy of 1231.5 is 379°F. The temperature of the mixture is therefore:

$$t_m = \frac{(460 \times 0.45 \times 379) + (200 \times 0.24 \times 70)}{(460 \times 0.45) + (200 \times 0.24)} = 320^\circ\text{F}$$

5.6 Pressure Measurement

5.6.1 General

5.6.1.1 Any pressure device capable of a verifiable accuracy within the tolerances specified in this Standard, shall be considered satisfactory for measuring pressures in compliance with this test specification unless otherwise noted in the following paragraphs.

5.6.1.2 The following precautions shall apply to all subatmospheric pressure measurements:

5.6.1.2.1 Pressure measurements shall be taken at a pressure tap that is not subject to velocity effects and will therefore indicate static pressure.

5.6.1.2.2 Spring type vacuum gauges shall not be used.

5.6.1.2.3 Gauge tubes of either barometers or mercury columns shall have an inside bore diameter not less than 0.25 inches and preferably 0.5 inches at the section where the reading is made.

5.6.1.2.4 Gauge tubes shall be clean and free of any visible oxide, dirt, or collected moisture.

5.6.1.2.5 Mercury or other gauge liquid shall be pure, clean and free of dirt and oxide.

5.6.1.2.6 The line connecting the vacuum gauge to the ejector shall be purged periodically, by bleeding air through the line, to eliminate moisture. It shall be tested for leaks by isolating the line and gauge from the ejector to see that the gauge reading does not change.

5.6.1.2.7 The line connecting the vacuum gauge to the ejector shall have a minimum bore of 1/4 inches. If rubber tubing is used, it shall have a minimum wall thickness of 3/16 inches.

5.6.2 Barometric Pressure

5.6.2.1 A mercury barometer is the preferred instrument for normal barometric pressure measurement. The accuracy of this barometer shall be established by periodic checks against Standards as specified in the latest edition of the ASME Power Test Code, "Instruments and Apparatus", 19.2, Pressure Measurement.

When comparing the mercury column readings and barometer readings, both shall be corrected to 32°F in accordance with Figure 33.

Electronic precision manometers can be employed as an alternative if the reading tolerance is a maximum 0.2% of the reading.

5.6.2.2 The barometer shall be located near the test apparatus and substantially at the same elevation.

5.6.3 Suction Pressure

5.6.3.1 Suction pressure measurements shall be taken in the suction chamber of the ejector or in the suction line to the ejector (of the same pipe size, or larger, as the ejector suction connection). See figure 38 for location.

5.6.3.2 Absolute Pressure Measurement 4.0 inches to 30 inches of mercury.

5.6.3.2.1 Mercury columns or manometers are preferred in this range.

Mercury manometers shall have a scale graduated in 0.1 inches Hg (or 2.54 mm Hg) and readings estimated to 0.05 inches Hg (or to the nearest 2.54 mm Hg, if mm Hg scale is used).

5.6.3.2.2 The verifiable accuracy for this range must be 0.05 inches Hg or better.

5.6.3.3 Absolute Pressure 0.5 Inches to 4.0 Inches of Mercury

5.6.3.3.1 Precision electronic absolute pressure instrumentation is preferred for this range.

5.6.3.3.2 Alternatively, mercury columns or manometers, using straight tubes with scales graduated to 0.1 inches (or 2.54 mm Hg) and vernier readings to 0.01 inches (or 0.25 mm Hg) shall be used.

5.6.3.3.3 The verifiable accuracy for this range must be 0.02 inches Hg or better.

5.6.3.4 Absolute Pressure 1.0 mm to 12.7 mm of Mercury

5.6.3.4.1 Precision electronic absolute pressure instrumentation is preferred for this range.

5.6.3.4.2 The verifiable accuracy for this range must be 0.004 inches (0.1mm) Hg or better.

5.6.3.5 Absolute Pressure 50 Microns to 1.0 mm Hg

5.6.3.5.1 Precision electronic absolute pressure instrumentation is preferred for this range.

5.6.3.5.2 The verifiable accuracy for this range must be + 2% of reading or better.

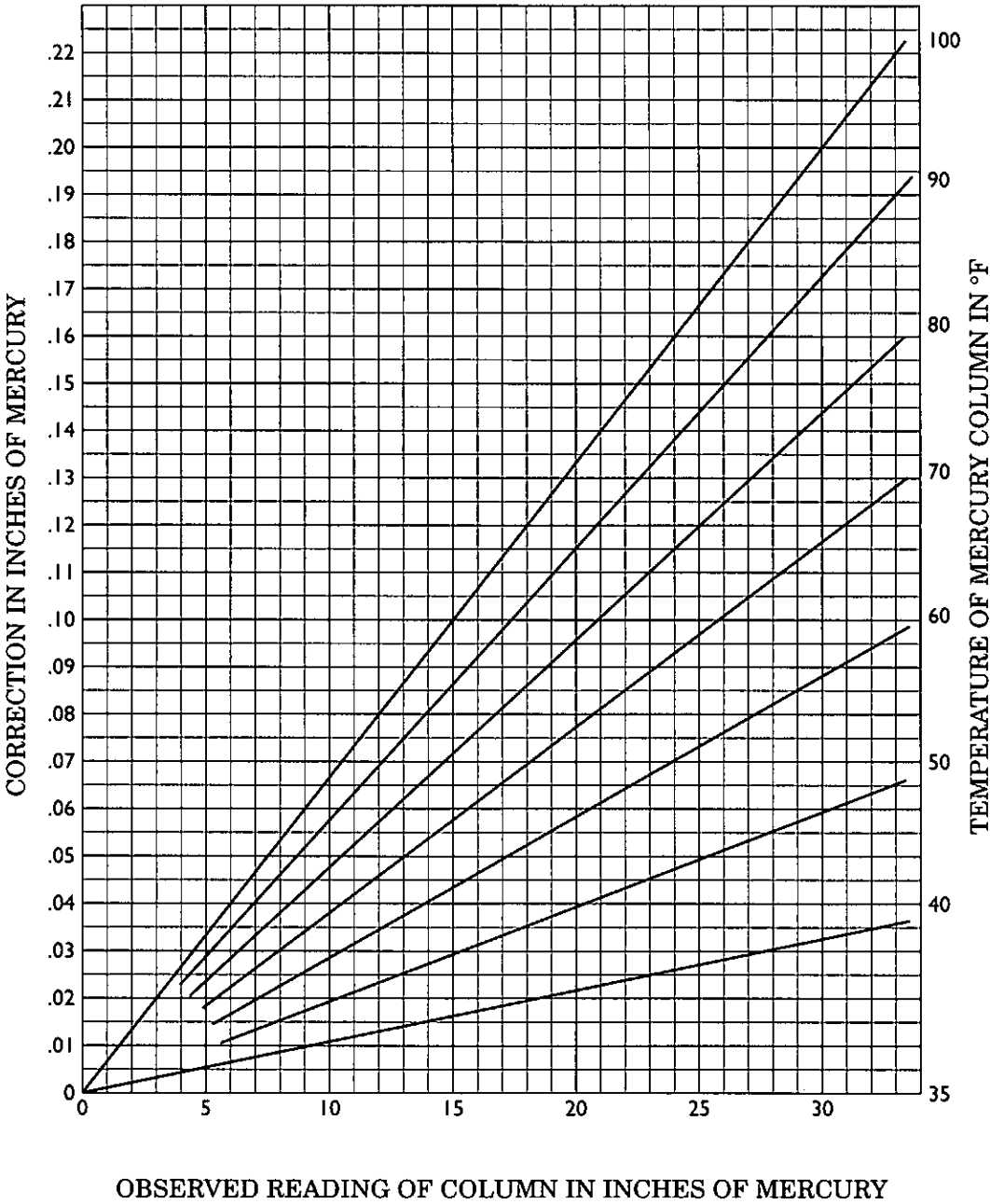
5.6.3.5.3 Alternatively, a suitable McLeod gauge shall be used.

The McLeod gauge shall be of multiple scale type allowing successive readings of the same sample at varying compression ratios. Duplication of reading within 4% for two successive compression ratios shall be evidence of lack of condensation in the sample.

5.6.3.5.4 A suitable indicating vacuum gauge shall be connected in parallel with the McLeod gauge and readings taken on the McLeod gauge only when the indicating gauge shows that the pressure being read is steady. The indicating gauge shall respond to changes in pressure at a rate not less than 5 seconds for 10% change in pressure.

TEMPERATURE CORRECTIONS FOR BAROMETER AND
VACUUM COLUMN READINGS TO STANDARD 32°F BASIS.

Note—Subtract correction from observed reading. This
corrects for thermal expansion of mercury and
brass scale from 32°F.



*For other scale materials, use appropriate chart.

Figure 33

5.6.3.5.5 Sufficient time shall lapse between readings to allow the pressure in all sections of the gauge to equalize. Duplication of three successive readings within 4% shall be evidence of satisfactory equalization of pressure.

5.6.3.5.6 All gauges used shall be verified or calibrated. These records must be available upon request.

5.6.3.5.7 The complete gauge system shall be periodically tested for leaks by blanking of system and measuring pressure rise. Pressure rise shall not exceed 2 microns per minute.

5.6.3.5.8 Rubber tubing shall not be used. Copper tubing or suitable plastic tubing with a minimum bore of 1/4 inch shall be used and the connections kept as short as possible. If plastic tubing is used, it shall have a minimum wall thickness of 1/4 inch.

5.6.4 Electronic Instrumentation

5.6.4.1 Scale ranges for any precision electronic manometer shall be chosen based on the maximum range recommended by the manufacturer.

5.6.4.2 Electronic instrumentation is normally calibrated in ranges 0 to 1000 mm HgA, 0 to 100 mm HgA, 0 to 10 mm HgA, 0 to 1.0 mm HgA. No measurements shall be considered satisfactory if taken outside the range suggested by the manufacturer.

5.6.4.3 Pressure transducers shall be mounted such that the gauge line shall have a negative slope towards the ejector.

The line connecting the vacuum gauge to the ejector shall be purged periodically, by bleeding air through the line to eliminate moisture.

5.6.4.4 The line connecting the vacuum gauge to the ejector shall have a minimum bore equal to the transducer connection but shall not be less than 1/4 inch.

5.6.4.5 Pressure transducers are subject to temperature variations, hence, transducers shall not be screwed directly into ejector inlet connection.

5.6.4.6 Pressure measurements shall not be considered valid if ambient temperatures are not within the range specified by the transducer manufacturer.

5.6.4.7 Before readings are performed, the transducer must be zeroed to correct for temperature variations in accordance with the manufacturer's recommendations.

5.6.4.8 Electronic manometers must have been calibrated to an NBS standard within two (2) years of the test. Calibration results should be available (upon request) at the time of test.

5.6.5 Discharge Pressure of Final Stage

5.6.5.1 The discharge pressure of the final stage of the steam jet ejector shall be measured with any of the following:

5.6.5.1.1 A manometer having suitable fluid to cover the range of pressures involved. The manometer shall be of the U-type or single leg type having a scale which shall be graduated in 0.1 inch divisions. Seal pots, or other means of trapping condensate in gauge lines, shall be employed.

5.6.5.1.2 An absolute pressure electronic pressure device with a verifiable accuracy better than 0.5% of reading.

5.6.5.1.3 A Bourdon gauge with a range of 0 to 15 psi and an accuracy of 0.1 psi may be used. The gauge shall be periodically checked against a dead-weight gauge tester.

5.6.5.2. Discharge Pressure Determination

With the steam jet ejector operating on design steam pressure and temperature, the discharge pressure for each capacity point shall be determined by throttling the discharge valve until the suction pressure shows definite positive increase. The discharge pressure under these conditions is the breaking pressure. After these conditions have been established, the discharge valve shall be slowly opened until the original suction pressure is reestablished. This discharge pressure is the recovery pressure and it shall be equal or greater than the specified discharge pressure.

5.6.6. Motive Steam Pressure

5.6.6.1 When the design steam pressure is above 15 PSIG, it shall be measured with a pressure gauge of the Bourdon tube type. The gauge shall be connected with water siphon or other suitable means to maintain the gauge at room temperature. The gauge shall be readable within 1% of the design steam pressure and shall be periodically calibrated on a dead-weight gauge tester.

5.6.6.2 When the design steam pressure is 15 PSIG or lower, it shall be measured with a manometer as outlined in Paragraph 5.6.5.1.

5.6.6.3 The pressure shall be measured as close to the ejector steam chest as possible.

5.6.6.4 Gauges should be selected such that the design pressure falls as close as possible to mid-scale of the gauge.

5.7 Steam Supply

5.7.1 Steam Pressure Measurement

Steam pressure measurement shall be per Paragraph 5.6.6.

5.7.2 Steam Temperature Measurement

Design steam temperature shall be measured with a thermometer, thermocouple or resistance thermometer. The precautions outlined in Paragraph 5.5.1 shall be observed.

5.7.3 Steam Consumption

Steam consumption for each ejector nozzle shall be calculated by using equation (5) in Paragraph 5.4.3 and a flow coefficient $C = 0.97$ for ejector steam nozzles having a well-rounded approach. Flow coefficients for ejector steam nozzles having other approach designs, shall be set by mutual agreement.

The steam consumption calculations can be simplified by using Figures 28, 29, 30, or 31. For example:

Steam pressure upstream of nozzle	300 psig
Steam temperature upstream of nozzle	500°F
Nozzle throat diameter	0.250 in.
Nozzle throat area	0.049 sq in.

From curve Figure 30 steam flow = 15,600 lb per hr, per sq in. of nozzle throat area

$$W_a = (0.97)(0.049)(15,600) = 741 \text{ lb per hr.}$$

5.8 Water Supply

5.8.1 Water Temperature Measurement

Water temperature shall be measured with a thermometer, thermocouple or resistance thermometer. The precautions outlined in Paragraph 5.5.1 shall be observed.

5.8.2 Water Consumption

The water consumption shall be measured with instruments of the indicating type, such as venturi tubes, flow nozzles, orifice plates or variable area meters. Weight tanks or volumetric tanks may also be used. The flow rate shall not deviate more than 5% from the specified value.

5.9 Test Arrangements

5.9.1 Introduction

Test arrangements described in this section are applicable to both factory testing and field testing. Space limitations and availability of test equipment may require modification of test arrangements for field testing purposes. Agreement shall be reached between the manufacturer and user on the modifications and their effect on the accuracy of the results obtained.

5.9.2 Factory Tests

Test arrangements for flow nozzles used to measure capacity points are illustrated schematically in Figures 34 through 37. Each figure shows the necessary control valves, the location of instruments, and the pressure taps. The air flow nozzles shall be ASME long radius, or HEI type, as shown in Figure 19.

5.9.2.1

Figure 34 illustrates the method of measuring air flow when the flow is subcritical. Regulation is obtained by adjusting the pressure differential across the nozzle. The nozzle flow coefficients, given in Figure 26, and the method of calculation, given in Paragraph 5.4.2.2, may be used provided the downstream pressure tap is located at $D/2$.

5.9.2.2

Figure 35 illustrates the method of measuring air flow when the flow is critical. Capacity variation is obtained by the selection of nozzles or combination of nozzles.

5.9.2.3

Figure 36 illustrates the method of measuring steam flow when the flow is critical. It also illustrates how an air load may be added to the critical flow steam load. Capacity variation can be obtained by regulating the upstream pressure on the steam nozzle or by varying the air nozzles.

5.9.3 Field Tests

Where it is possible, the ejector components should be isolated from the process or any adjacent equipment to conduct field performance tests.

The preferred method of isolation of the ejector or ejector components shall be the use of a gasketed flange or blank off plate between the process or system and equipment to be tested.

Other means of isolation will be acceptable if it is proven by test to be leak free. Some alternative means of isolation could involve valves or temporary closures.

Provisions should be made between isolation devices and the ejector system for introduction of test loads. All possible precautions should be taken to insure adequate diffusion of the load gas and to locate pressure taps where they will not be subject to velocity effects from the load and, therefore, indicate static pressure.

The loads for field testing shall not be generated by the system unless flows can be measured directly ahead of the ejector. If the system gases are used, the components and properties must be verified.

Preferred alternate load arrangement is shown in Figure 37. Other arrangements may be used upon mutual agreement.

Provisions should be made so that the ejector or ejector components discharge pressure does not exceed design conditions.

5.9.4 Ejectors and Intercondensers

Test arrangements for steam jet ejectors and intercondensers are shown schematically in Figures 38 through 41. Each figure shows the necessary control valves and location of instruments.

5.9.4.1

Figure 38 illustrates the arrangement for the test of a single stage ejector or for the individual stage tests of a multi-stage ejector.

5.9.4.2

Figure 39 illustrates the arrangement for a unit test of a multi-stage noncondensing ejector or for the noncondensing stages of a multi-stage ejector.

5.9.4.3

Figure 40 illustrates the arrangement for a unit test of a multi-stage ejector with intercondenser between stages.

5.9.4.4

Figure 41 illustrates the arrangement for testing precondensers and intercondensers.

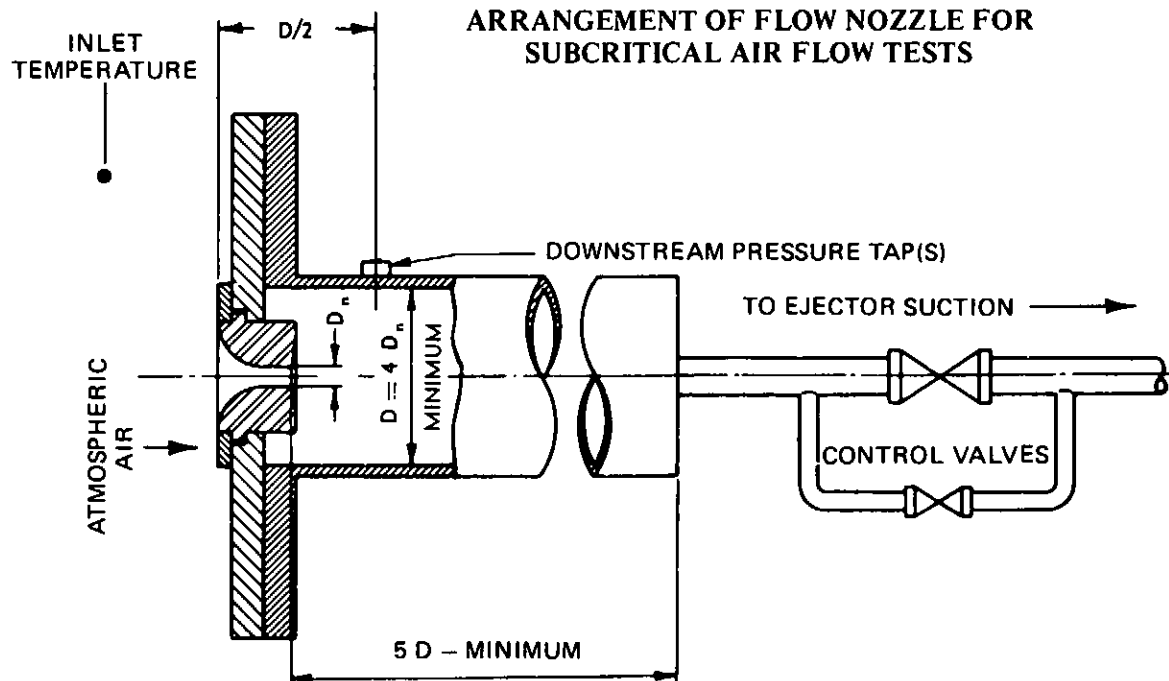
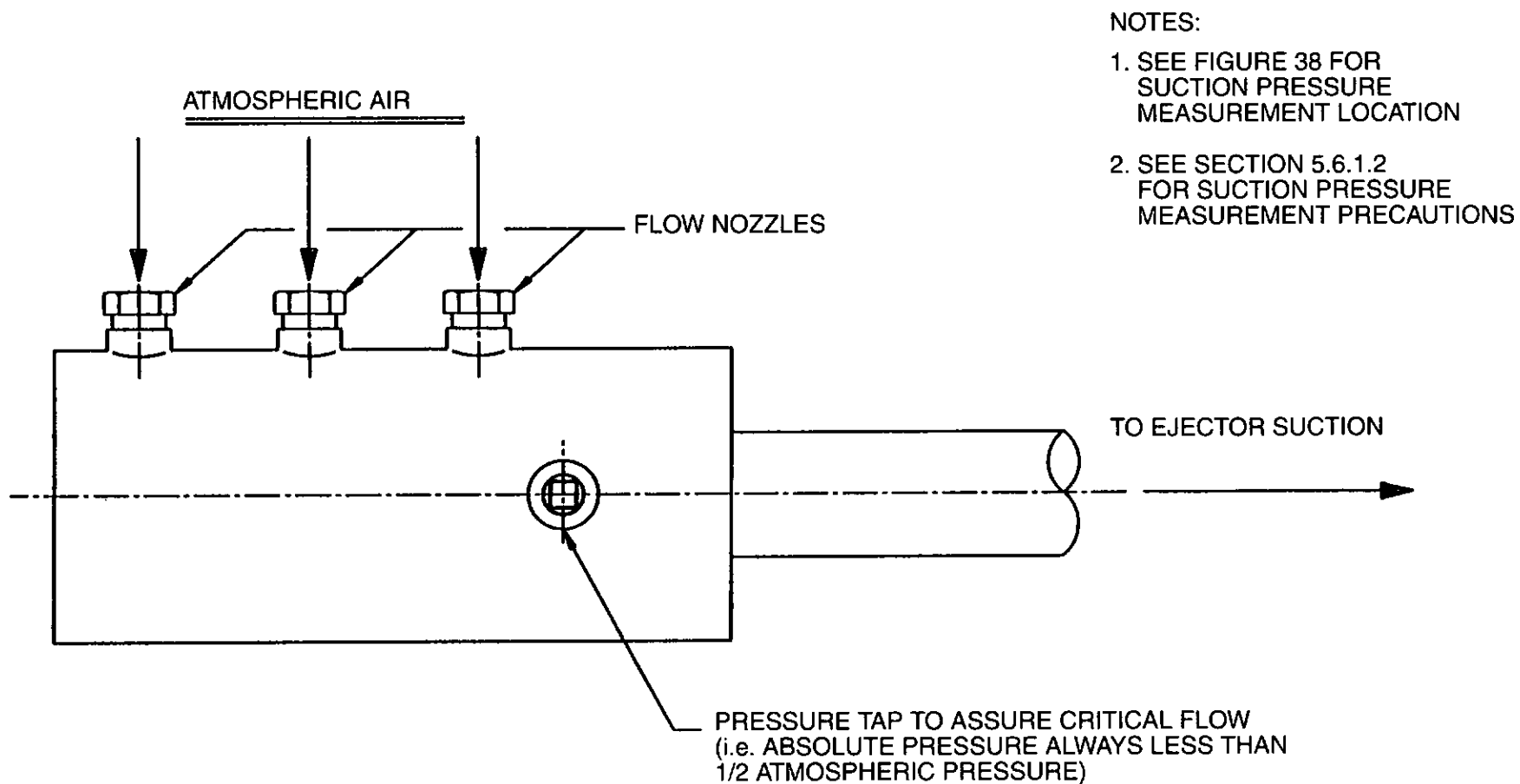


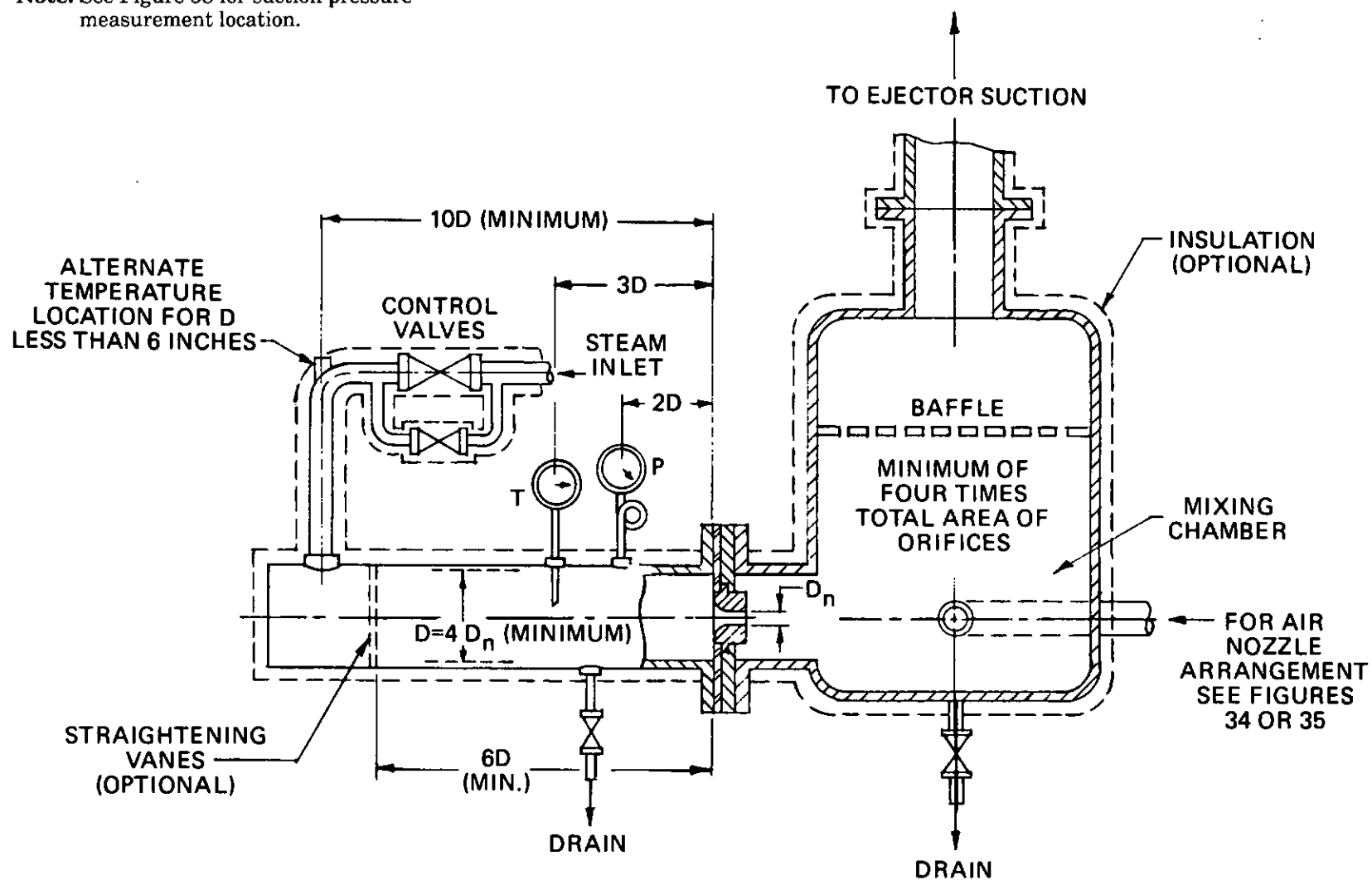
Figure 34



ARRANGEMENT OF FLOW NOZZLES FOR CRITICAL AIR FLOW TESTS

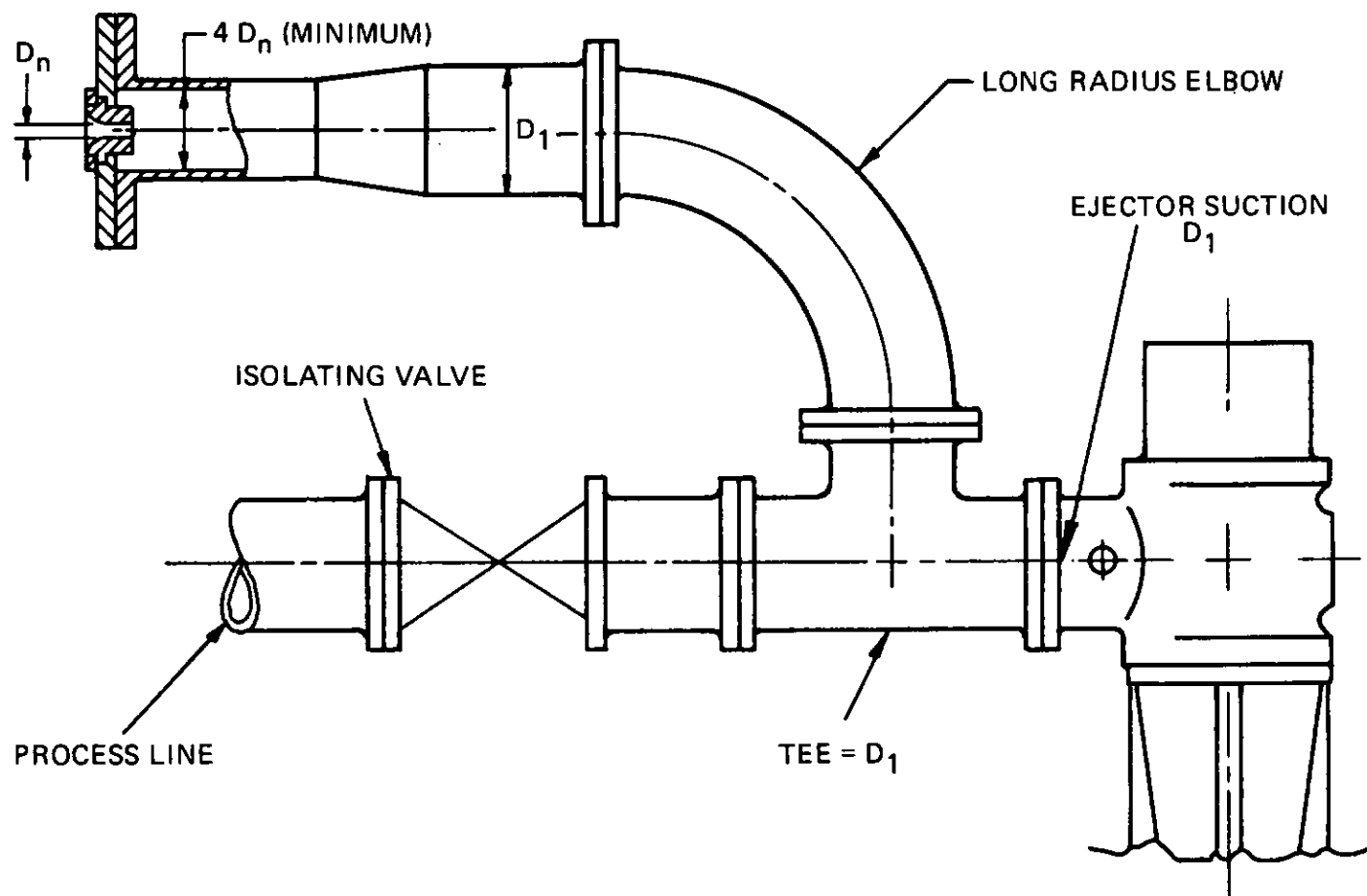
Figure 35

Note: See Figure 38 for suction pressure measurement location.



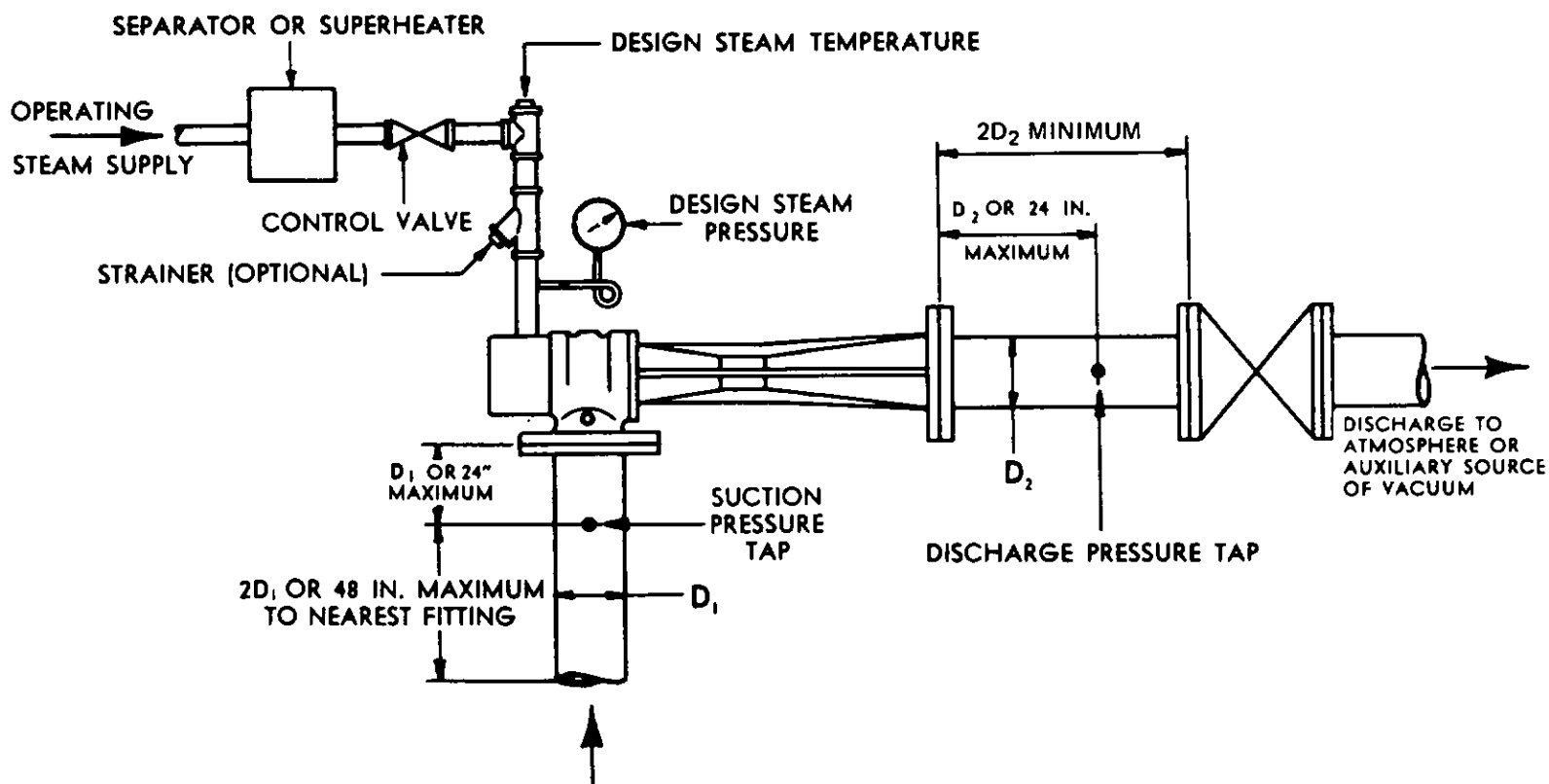
**ARRANGEMENT OF FLOW NOZZLES FOR STEAM AND AIR MIXTURE TESTS
AND CRITICAL STEAM FLOW TESTS**

Figure 36



ALTERNATE LOADING ARRANGEMENT FOR FIELD TESTING

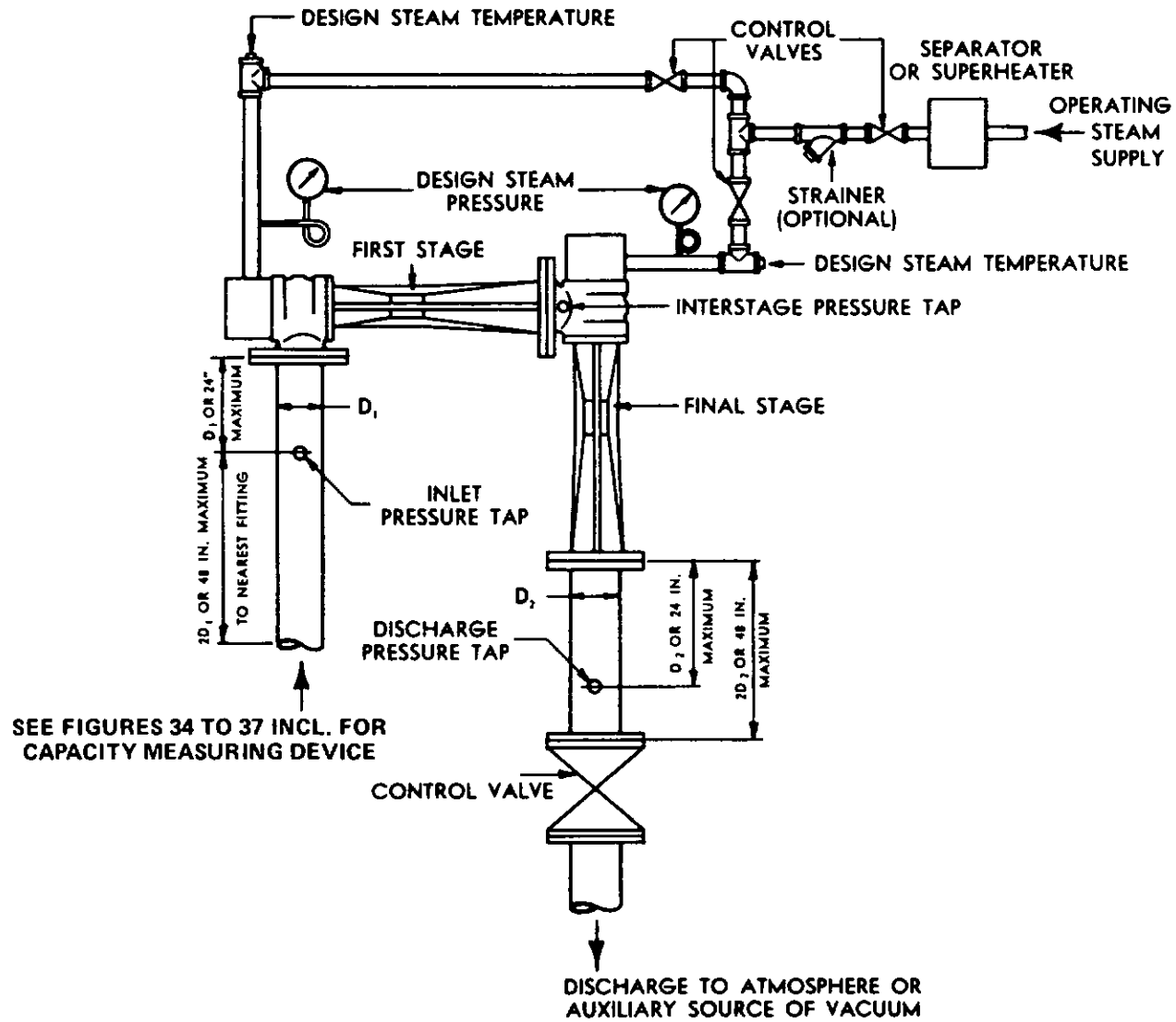
Figure 37



SEE FIGURES 34 TO 37 INCL. FOR CAPACITY MEASURING DEVICE

ARRANGEMENT FOR TEST OF A SINGLE STAGE EJECTOR
OR AN INDIVIDUAL STAGE OF A MULTI-STAGE EJECTOR

Figure 38



ARRANGEMENT FOR TEST OF A MULTI-STAGE NON-CONDENSING EJECTOR

Figure 39

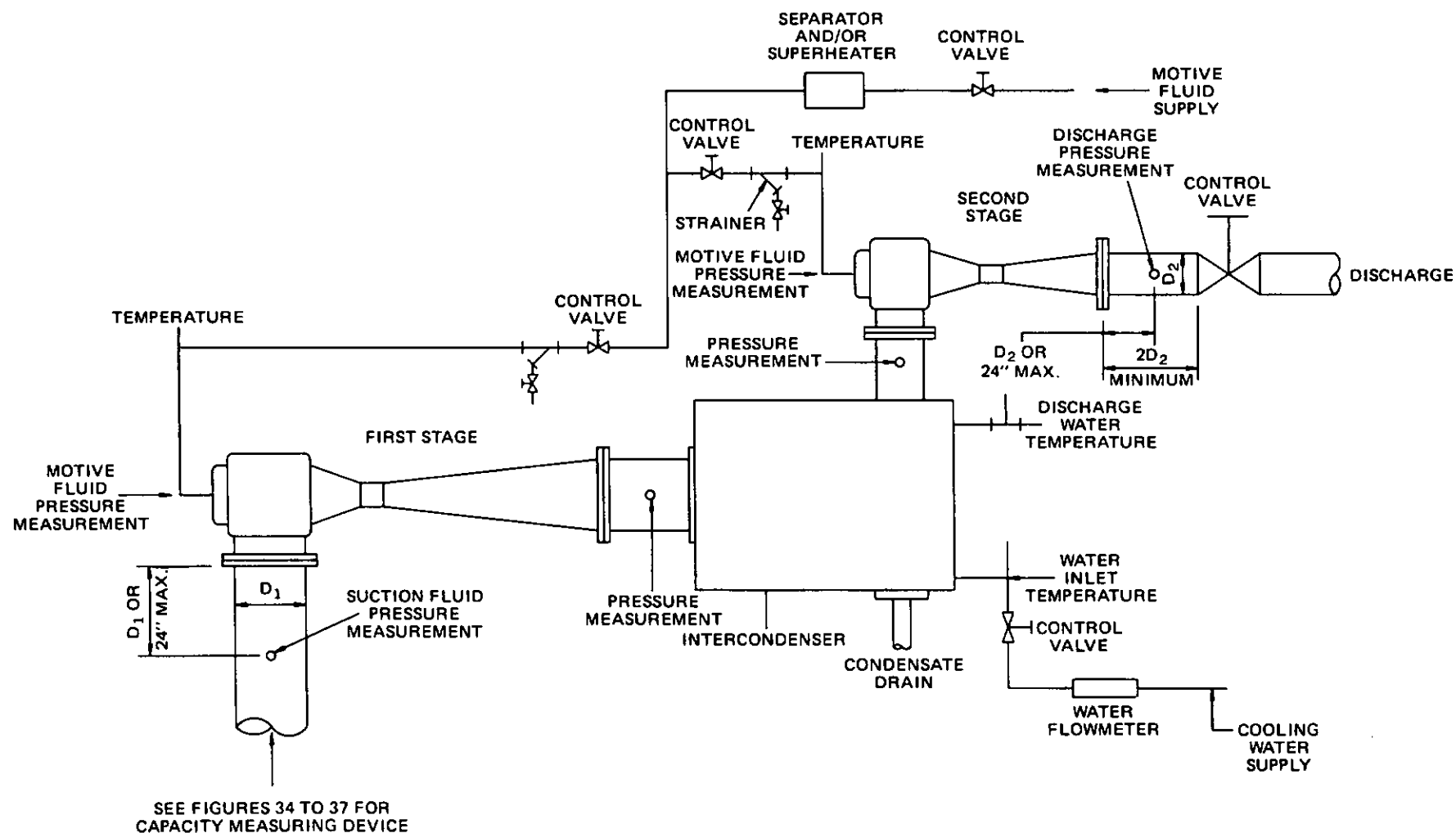


DIAGRAM OF TEST ARRANGEMENT FOR FOR A MULTI-STAGE CONDENSING EJECTOR SYSTEM

Figure 40

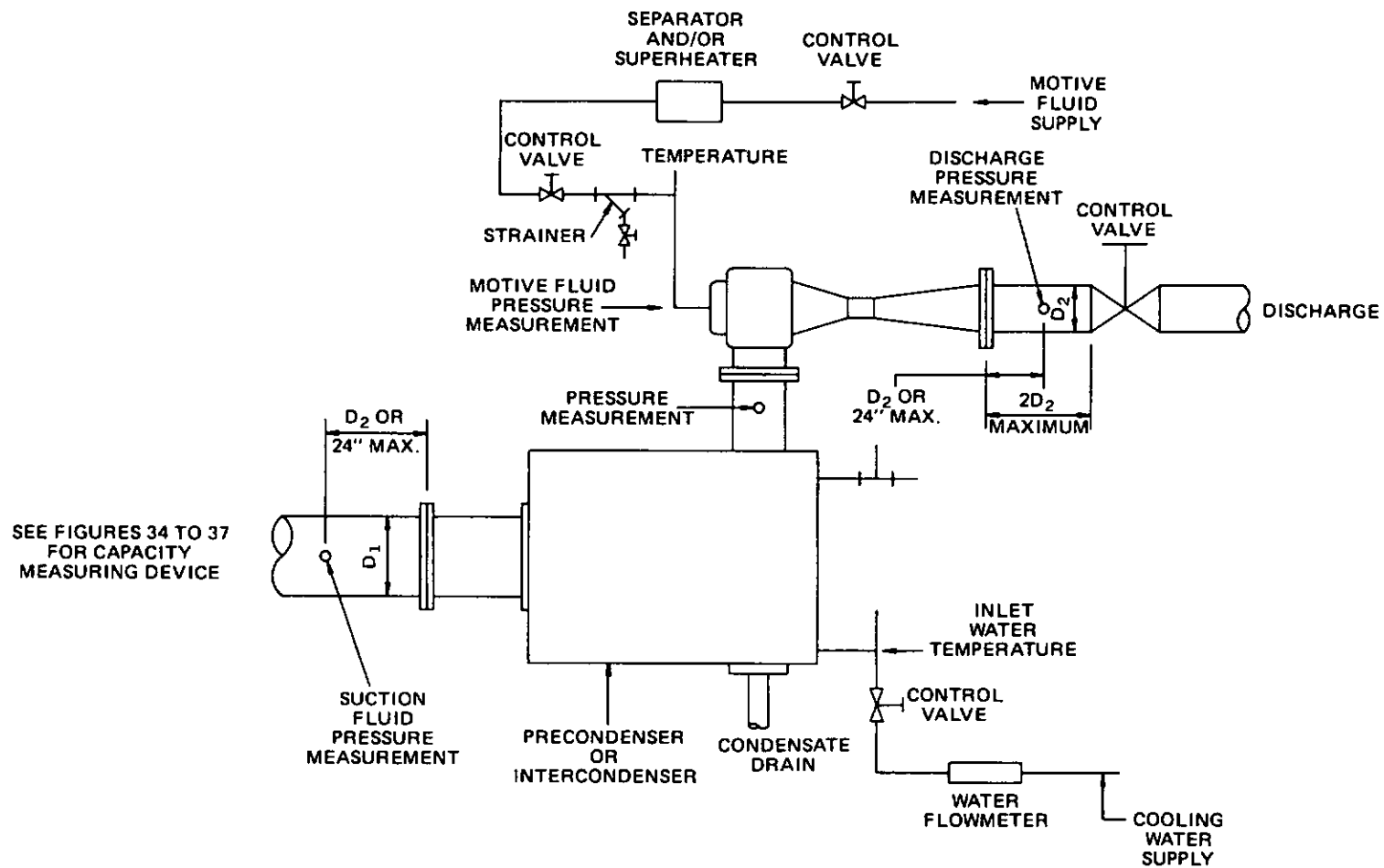


DIAGRAM OF TEST ARRANGEMENT FOR A PRECONDENSER OR INTERCONDENSER

Figure 41

5.10 Test Procedures

5.10.1 Leaks

Tightness of all apparatus and gauges shall be checked preceding any tests. All leaks shall be eliminated.

5.10.2 Test Conditions

Every effort shall be made to have the test conditions as near as possible to the design conditions. For tests in a manufacturer's shop, the test conditions will be able to be controlled more closely than for a field test. The more critical items are the motive steam pressure and temperature. For shop tests, the set point steam pressure shall be the design pressure, and total pressure fluctuation may be $\pm 2\%$. The steam temperature shall be set to within $\pm 5^\circ\text{F}$ of the design temperature. If the design steam pressure includes superheat, the test conditions will be as mutually agreed upon between manufacturer and purchaser. Field test conditions will be as mutually agreed upon by purchaser and manufacturer. Readings will not be meaningful unless stable operation is maintained.

5.10.3 Tests of Multi-Stage Condensing Ejector Systems

Tests of multi-stage condensing ejectors are conducted by taking the readings necessary to establish the following data.

5.10.3.1 Test Loads

If the specified design load of the ejector system is comprised of air or a mixture of air and steam then the test load points are determined as outlined in Paragraph 5.4. To determine the correct system test loading for design loads other than air and steam it is necessary to simulate (calculate) the effect of these components on each ejector stage within the system. This is done by using the appropriate vapor-liquid equilibrium relationships (as described in part below) and then calculating the system design load "70°F air equivalent" (per Paragraph 5.3) at each stage. The system test load (air and water vapor) "70°F air equivalent" is then calculated for each stage and compared with the design load values. As these values are not the same adjustments shall be made in the test load metered to the overall system and each ejector stage as described below.

5.10.3.1.1 Noncondensable Design Loads

If the specified design load of the ejector system is a mixture of noncondensable gases, the total gas and water vapor load to each stage shall be calculated. The test shall include supplying the differential air equivalent, or air and steam equivalent, of this calculated load directly to each stage. The quantity of condensing water to the intercondenser or intercondensers shall be adjusted to obtain the same temperature rise as calculated for the design condition. Where a mixture of non-condensable gases is

involved, the average molecular weight of the mixture is calculated and the total pounds per hour of the mixture and the average molecular weight of the mixture are used in the calculations the same as if the mixture were a pure gas having a molecular weight the same as the average molecular weight.

A corollary to Dalton's law of gaseous pressure states that with a mixture of gases, the pound moles of each gas bears the same relation to the total pound moles of the mixture as the partial pressure of each gas bears to the total absolute pressure, and the relationship between the pound moles is the same as between the partial pressures.

Thus the vapor of saturation for a noncondensable gas is calculated by using the following equation:

$$w_v = \frac{w_n \times M_v \times P_v}{M_n \times P_n} \quad (7)$$

(Corollary to Dalton's law)

where:

w_v = Flow rate of vapor of saturation, lbs per hr

w_n = Flow rate of noncondensable gas, lbs per hr

M_v = Molecular weight of vapor

P_v = Partial pressure of vapor, in. HgA

M_n = Molecular weight of noncondensable gas

P_n = Partial pressure of noncondensable gas in. HgA

For example, with a two stage condensing ejector system designed to handle 100 pounds per hour of hydrogen, molecular weight 2, the calculations to determine stage loads are as follows:

If the absolute pressure at the air outlet of the intercondenser is 4 inches mercury and the temperature there is 90°F, the partial pressure of water is 1.422 inches of mercury (corresponding to the vapor pressure of water at 90°F). The partial pressure of the hydrogen is: 4 inches - 1.422 inches = 2.578 inches Hg.

With hydrogen, the water vapor carryover is:

$$w_v = \frac{100 \times 18 \times 1.422}{2 \times 2.578} = 496.4 \text{ lbs per hr}$$

$$\begin{array}{r} 496.4 \div 18 = 27.58 \text{ lb moles per hr of water vapor} \\ 100.0 \div 2 = 50.00 \text{ lb moles per hr of hydrogen} \\ \hline 596.4 \qquad 77.58 \text{ total lb moles per hr} \end{array}$$

$$\text{Average molecular weight of stage load} = \frac{596.4}{77.58} = 7.68$$

$$\text{Air equivalent of stage load} = \frac{596.4}{50.2\%} \text{ (from Figure 16)} = 1188.1 \text{ lbs per hr}$$

The air equivalent of 100 lbs per hour of hydrogen is 555.6 lbs per hour of air. For the same conditions at the air outlet, the partial pressure of air is also 2.578 inches.

With air, the water vapor carryover is:

$$w_v = \frac{555.6 \times 18 \times 1.422}{29 \times 2.578} = 190.2 \text{ lbs per hr}$$

$$190.2 \div 18 = 10.57 \text{ lb moles per hr of water vapor}$$

$$\frac{555.6}{745.8} \div 29 = \frac{19.16}{29.73} \text{ lb moles per hr of air}$$

$$745.8 \quad 29.73 \text{ total lb moles per hr}$$

$$\text{Average molecular weight of stage load} = \frac{745.8}{29.73} = 25.1$$

$$\text{Air equivalent of stage load} = \frac{745.8}{94\%} \text{ (from Figure 16)} = 793.4 \text{ lbs per hr}$$

The above shows that, if the air ejector system is tested on only an air equivalent load of 555.6 lbs per hour to the first stage, the load to the second stage would be an air equivalent of 793.4 lbs per hour whereas, when handling hydrogen, the load to the second stage would be equivalent to an air load of 1188.1 lbs per hour. To test the second stage adequately, at the design point, an additional dry air load of $1188.1 - 793.4 = 394.7$ lbs per hour shall be admitted to the ejector unit between the intercondenser and the second stage.

Similarly, with a three stage condensing ejector to handle 100 lbs per hour of hydrogen, molecular weight 2, the calculations to determine the stage loads are as follows:

If the absolute pressure at the air outlet of the first intercondenser is 2.5 inches Hg Absolute and the temperature there is 90°F, the partial pressure of water is 1.422 inches Hg (corresponding to the vapor pressure of water at 90°F). The partial pressure of the hydrogen is: $2.5 \text{ inches} - 1.422 \text{ inches} = 1.078 \text{ inches}$.

With hydrogen, the water vapor carryover is:

$$w_v = \frac{100 \times 18 \times 1.422}{2 \times 1.078} = 1187.2 \text{ lbs per hr}$$

$$1187.2 \div 18 = 66 \text{ lb moles per hr of water vapor}$$

$$\frac{100.0}{1287.2} \div 2 = \frac{50}{116} \text{ lb moles per hr of hydrogen}$$

$$1287.2 \quad 116 \text{ total lb moles per hr}$$

$$\text{Average molecular weight of stage load} = \frac{1287.2}{116} = 11.1$$

$$\text{Air equivalent of stage load} = \frac{1287.2}{62.5\%} \text{ (from Figure 16)} = 2059.5 \text{ lbs per hr}$$

The air equivalent of 100 lbs per hour of hydrogen is 555.6 lbs per hour of air. For the same conditions at the air outlet, the partial pressure of air is also 1.078 inches.

With air, the water vapor carryover is:

$$w_v = \frac{555.6 \times 18 \times 1.422}{29 \times 1.078} = 454.9 \text{ lbs per hr}$$

$$454.9 \div 18 = 25.27 \text{ lb moles per hr of water vapor}$$

$$\frac{555.6}{1010.5} \div 29 = \frac{19.16}{44.43} \text{ lb moles per hr of hydrogen}$$

$$1010.5 \quad 44.43 \text{ total lb moles per hr}$$

$$\text{Average molecular weight of stage load} = \frac{1010.5}{44.43} = 22.7$$

$$\text{Air equivalent of stage load} = \frac{1010.5}{90\%} \text{ (from Figure 16)} = 1122.8 \text{ lbs per hr}$$

If the absolute pressure at the air outlet of the second intercondenser is 6 inches Hg Absolute and the temperature there is 90°F, the partial pressure of water is 1.422 inches Hg (corresponding to the vapor pressure of water at 90°F). The partial pressure of hydrogen is: $6 \text{ inches} - 1.422 \text{ inches} = 4.578 \text{ inches}$.

With hydrogen, the water vapor carryover is:

$$w_v = \frac{100 \times 18 \times 1.422}{2 \times 4.578} = 279.6 \text{ lbs per hr}$$

$$279.6 \div 18 = 15.5 \text{ lb moles per hr of water vapor}$$

$$\frac{100.0}{379.6} \div 2 = \frac{50.0}{65.5} \text{ lb moles per hr of hydrogen}$$

$$379.6 \quad 65.5 \text{ total lb moles per hr}$$

$$\text{Average molecular weight of stage load} = \frac{379.6}{65.5} = 5.8$$

$$\text{Air equivalent of stage load} = \frac{379.6}{41\%} \text{ (from Figure 16)} = 925.9 \text{ lbs per hr}$$

The partial pressure of the air equivalent of 555.6 lbs. per hour of the air is also 4.578 inches.

With air, the water vapor carryover is:

$$w_v = \frac{555.6 \times 18 \times 1.422}{29 \times 4.578} = 107.1 \text{ lbs per hr}$$

$$107.1 \div 18 = 5.95 \text{ lb moles per hr of water vapor}$$

$$\frac{555.6}{662.7} \div 29 = \frac{19.16}{25.11} \text{ lb moles per hr of hydrogen}$$

$$662.7 \quad 25.11 \text{ total lb moles per hr}$$

$$\text{Average molecular weight of stage load} = \frac{662.7}{25.11} = 26.4$$

$$\text{Air equivalent of stage load} = \frac{662.7}{96\%} \text{ (from Figure 16)} = 690.3 \text{ lbs per hr}$$

From the above it is apparent that, when testing the unit at the design point, when the load to the second stage is increased from 1122.9 lbs per hour to 2059.5 lbs per hour by the admission of an additional dry air load of 936.7 lbs per hour to the unit between the first intercondenser and the second stage, the third stage would be very badly overloaded and the additional load admitted between the first intercondenser and the second stage must be "steam equivalent" and not dry air. The amount of this "steam equivalent" is figured as follows:

Additional load in terms of air equivalent: $2059.5 - 1122.8 = 936.7$ lbs per hour. Ratio of "steam equivalent" to air equivalent (from Figure 16) is 81% to 100%. Amount of steam equivalent is: $936.7 \times 81\% =$

758.7 lbs per hour. If the temperature of the steam is higher than 70°F to 80°F, the amount of the steam should be corrected by multiplying by the temperature entrainment ratio (from Temperature Entrainment Ratio Curve, Figure 15) for the actual temperature.

To test the third stage adequately, at the design point, an additional dry air load of $925.9 - 690.3 = 235.6$ lbs per hour shall be admitted between the second intercondenser and the third stage. A system test for the design point for this ejector would therefore require:

(a) Admitting 555.6 lbs per hour dry air to the first stage.

(b) Admitting an additional load of 758.7 lbs per hour of steam (or the amount resulting from a correction for temperature) between the first intercondenser and the second stage.

(c) Admitting an additional dry air load of 235.6 lbs per hour between the second intercondenser and the third stage.

If, contrary to the above examples, the noncondensable gas or mixture of noncondensable gases which the ejector system is designed to handle has a molecular weight or average molecular weight higher than air, the stage load calculations for a unit test will show that part of the load to the first stage of a multi-stage condensing ejector must be steam equivalent in order not to load the succeeding stage or stages beyond their design load.

5.10.3.1.2 Condensable and Non-condensable Design Loads

If the specified design load of the ejector system is comprised of a mixture of condensable and noncondensable gases, the total load to each stage shall be calculated. The air equivalent or air and steam equivalent of the noncondensable gas portion of each stage load and steam equivalent of the condensable gas portion of each stage load shall be calculated. The test shall include supplying the calculated air and steam equivalent stage load to each stage, and the quantity of condensing water to the intercondenser or intercondensers shall be adjusted to obtain the same temperature rise as calculated for the design condition.

For example, with a three stage condensing ejector system to handle:

100 lbs per hour or air, mw = 29
300 lbs per hour of noncondensable oil vapor, mw = 58
500 lbs per hour of condensable oil vapor, mw = 142
1000 lbs per hour of steam, mw = 18

All at a temperature of 400°F.

The calculations to determine the test stage loads are as follows:

Test stage load to first stage

(a) Air equivalent calculations for noncondensable gases:

$100 \div 29 = 3.45$ lb moles per hr or air
 $300 \div 58 = 5.17$ lb moles per hr of noncondensable oil vapor

400 8.62 total lb mole per hr

Average molecular weight = $\frac{400}{8.62} = 46.4$

Correction for molecular weight = $\frac{400}{121\%}$ (from Figure 16) = 330.6 lbs per hr

Correction for 400°F temperature = $\frac{330.6}{92.1\%}$ (from air curve, Figure 15) = 359.0 lbs per hr

Therefore, the 70°F air equivalent of the noncondensable gases = 359.0 lbs per hr

(b) Air equivalent calculations for condensable vapors other than steam:

$500 \div 142 = 3.52$ lb moles per hr of condensable oil vapor

Correction for molecular weight = $\frac{500}{159.6\%}$ (from Figure 16) = 313.3 lbs per hr

Correction for temperature = $\frac{313.3}{92.1\%}$ (from air curve, Figure 15) = 340.2 lbs per hr

Therefore, the 70°F air equivalent of the condensable oil vapor is 340.2 lbs per hr

(c) Calculations to determine the 70°F steam equivalent of the steam load:

Correction for temperature = $\frac{1000}{89.2\%}$ (from steam curve, Figure 15) = 1121.0 lbs per hr

The test stage load must, however, be adjusted so that the succeeding ejector stage is not overloaded with noncondensable gases. To do this, the air equivalent of the condensable oil vapor is converted to its steam equivalent. The steam equivalent is $340.2 \times 81\%$ (from Figure 16) = 275.6 lbs per hour of steam.

The proper test stage load is therefore:

359.0 lbs per hour of dry air, plus
275.6 + 1121.0 or 1396.6 lbs per hour of steam.

Test stage load to second stage

The weight of condensable vapors that would be carried over from the first intercondenser to the second stage by partial pressure conditions is calculated as follows:

If the absolute pressure at the air outlet of the first intercondenser is 2 inches Hg, the temperature there is 85°F, and the vapor pressure of the condensable oil vapor at 85°F is 0.087 inches Hg Absolute, the total for the partial pressures of the two condensable gases is: 0.087 inches + 1.213 inches (vapor pressure of water at 85°F) = 1.3 inches Hg. The total for the partial pressures of the two noncondensable gases is :

2.0 inches – 1.3 inches = 0.7 inches Hg, and the sum of their pound moles is 8.62, so that for the gases the ejector is expected to handle:

The amount of water vapor carried over is:

$$8.62 \times \frac{1.213}{0.7} = 14.94 \text{ moles} \times 18 = 268.9 \text{ lbs per hr}$$

The amount of the condensable oil vapor carried over is:

$$8.62 \times \frac{0.087}{0.7} = 1.07 \text{ moles} \times 142 = 151.9 \text{ lbs per hr}$$

The air equivalent of the noncondensable gas load is 330.6 lbs per hour (the same as for the first stage without the temperature correction), and the steam equivalent of the condensable gas load is:

$$268.9 \div 18 = 14.94 \text{ lb moles per hr of water vapor}$$

$$151.9 \div 142 = 1.07 \text{ lb moles per hr of condensable oil vapor}$$

$$420.8 \quad 16.01 \text{ total lb moles per hr}$$

$$\text{Average molecular weight} = \frac{420.8}{16.01} = 26.3$$

Steam equivalent = $420.8 \times \frac{81\%}{95.75\%}$ (from Figure 16) = 356.0 lbs per hr

The water vapor carryover with the first stage test air load is:

$$\frac{359.0 \times 18 \times 1.213}{29 \times 0.787} = 343.4 \text{ lbs per hr}$$

The above shows that, to adequately test the second stage when a system test at the design point is being made, an additional steam load of $356.0 - 343.3 = 12.6$ lbs per hour (or the amount resulting from a correction for temperature) must be admitted between the first intercondenser and the second stage.

Similarly, if the absolute pressure at the air outlet of the second intercondenser is 6 inches Hg and the temperature there is 85°F, the total for the partial pressure of the two condensable gases is 1.3 inches Hg. The total for the partial pressures of the two noncondensable gases is 6.0 inches – 1.3 inches = 4.7 inches Hg, and for the gases the ejector is expected to handle:

The amount of water vapor carried over is:

$$8.62 \times \frac{1.213}{4.7} = 2.22 \text{ moles} \times 18 = 40 \text{ lbs per hr}$$

The amount of the condensable oil vapor carried over is:

$$8.62 \times \frac{0.087}{4.7} = 0.16 \text{ moles} \times 142 = 22.7 \text{ lbs per hr}$$

The air equivalent of the noncondensable gas load is 330.6 lbs per hour (the same as for the second stage), and the steam equivalent of the condensable gas load is:

$$40.0 \div 18 = 2.22 \text{ lb moles per hr of water vapor}$$

$$22.7 \div 142 = 0.16 \text{ lb moles per hr of condensable oil vapor}$$

$$62.7 \quad 2.38 \text{ total lb moles per hr}$$

$$\text{Average molecular weight} = \frac{62.7}{2.38} = 26.3$$

Steam equivalent = $62.7 \times \frac{81\%}{95.75\%}$ (from Figure 16) = 53.0 lbs per hr

The water vapor carryover with the first stage test air load is:

$$\frac{359.0 \times 18 \times 1.213}{29 \times 4.787} = 56.5 \text{ lbs per hr}$$

The above indicates that the third stage will have an excess load of $56.5 - 53.0 = 3.5$ lbs per hour of water vapor.

When stage load calculations, such as this, show that the water vapor carried over with the first stage test air load from either the first or the second intercondenser is greater than the water vapor carryover with the gases the ejector is expected to handle, the air load to the first stage is reduced by the amount necessary to produce the correct stage load on the second or third stage. The steam equivalent of this reduction in air load is then added to the steam test load of the first stage, and any similar adjustment that is necessary is made to the test loads of either the second or third stage.

Note that the above method of calculating carryover can only be used when the liquid phases of the condensable gases are not soluble in water or in each other. With water soluble liquid phases (such as the lower molecular weight alcohol and ketones), the vapor phase can be appreciably different in composition from the liquid phase. It is first necessary to determine the weight composition of the liquid in the intercondenser, then construct an equilibrium phase diagram applying to the temperature existing at the air outlet of the condenser, for the condensable gases involved, and from this determine the vapor composition by weight and the vapor pressure of this vapor composition. This vapor pressure and the average molecular weight of this vapor are then used in the above calculations the same as if the vapor were pure gas, and the total weight of this vapor carried over is calculated. This total weight is then separated into the weight flows of its components by using the vapor composition figures, and the air and steam equivalent of the next ejector stage can be determined.

5.10.3.2 Suction temperature of the first stage determined as outlined in Paragraph 5.5.

5.10.3.3 Suction pressure at the first stage measured as outlined in Section 5.6.3.

5.10.3.4 Discharge pressure of the final stage determined as outlined in Section 5.6.5.

5.10.3.5 Design steam pressure and temperature measured as outlined in Paragraph 5.6.6. and Section 5.7.

Test results for the first stage shall be calculated as outlined in Paragraph 5.4.1 and are then plotted as shown in Figure 18. The total steam consumption is calculated as outlined in Paragraph 5.7.3.

5.10.4 Individual Ejector Stages

Individual stages of a multi-stage condensing ejector shall be tested by taking the necessary readings to establish the following:

(a) Capacity points as determined in Section 5.4 and 5.10.3.

(b) Suction temperature as determined in Paragraph 5.5.

(c) Suction pressure as determined in Section 5.6.3.

(d) Discharge pressure as determined in Paragraph 5.6.5.

Stage test results shall be determined as outlined in Paragraph 5.4.1 and plotted as shown in Figure 18.

5.10.5 Non-condensing Ejector Stages

When noncondensing stages are tested as a unit, the procedure is the same as Paragraph 5.10.4 except that all capacity and suction data apply to the first stage of the assembly and the discharge pressure is measured at the final stage in the assembly.

5.10.6 Individual Condensers

Generally, tests of condensers on an individual basis are not normally required. The manufacturer's design data showing that the condenser will operate satisfactorily at design conditions is usually more meaningful than a test when the exact design conditions cannot be supplied. When these tests are required, the purpose shall be to establish the temperature of the gases leaving the condenser and the pressure drop through the condenser.

1. The load to the condenser will be air and steam. The specified noncondensable load to the condenser will be converted to equivalent air load per HEI methods. The specified condensable load shall be converted to equivalent steam load.
2. The temperature of the load must be equivalent to the specified condenser inlet temperature.
3. The temperature of the cooling water admitted to the condenser shall be as specified. (See Paragraph 5.8.1)
4. The quantity of the cooling water admitted to the condenser shall be as specified. (See Paragraph 5.8.2)
5. The stage or stages of the ejector system subsequent to the condenser being tested shall be used to serve the condenser during the test.
6. See Figure 41 for test arrangement.

5.10.7 Test Results and Presentation

5.10.7.1 Allowable Tolerance on the Agreed Design Point

The test results of this performance standard shall be compared to the agreed upon design point and will be found to be acceptable providing they are within the following limits:

<u>Variable</u>	<u>Unit</u>	<u>Tolerance</u>
Capacity	lb/hr	-3%
Steam Consumption	lb/hr	+3%

5.10.7.2 Ejector Test Report

The above collected data should be tabulated on the ejector test report found in Appendix "J".

6.0 VACUUM ENGINEERING DATA

6.1 Air Leakage In Vacuum Systems

6.1.1 Drop Test

The air leakage in an existing vacuum system may be determined by a drop test. This test is based on the fact that air leaks into the system at a constant rate as long as pressure within the system is less than 0.53 times atmospheric pressure (about 15 in. Hg Absolute). It is usually run with the system empty but with all agitators and other moving equipment in operation to duplicate leakage through seals and glands. The test should be run with the system at normal atmospheric temperature and the system should be free of any liquids.

Procedure:

1. Evacuate system to about 5 in. Hg Absolute using available ejector.
2. Close off isolating valve between system and ejector; then close steam supply to ejector.
3. Record elapsed time for pressure in system to rise from one observed pressure to a higher observed pressure. If leakage is low, a rise of one or two inches may take a long enough time to give an accurate estimate of leakage. However, do not permit pressure to rise above 15 in. Hg Absolute.
4. Knowing system volume, initial and final pressure and elapsed time, the total leakage rate into system may be calculated from the equation:

Leakage (lbs per hour) =

$$\frac{0.15 \times \text{Volume (cu. ft.)} \times \text{Pressure Rise (in. Hg)}}{\text{Time (minutes)}}$$

Example:

V = Volume, cubic feet = 300 cu ft

p₁ = Initial pressure in system, inches Hg Absolute = 5 in. HgA

p₂ = Final pressure in system, inches Hg Absolute = 9 in. HgA

T = Time, minutes = 6.5 minutes

$$\begin{aligned} \text{leakage} &= \frac{0.15 \times 300 \times (9 - 5)}{6.5} \\ &= 27.7 \text{ lbs per hr} \end{aligned}$$

5. In order to prove tightness of the isolating valve between system and ejector, the test should be repeated with the ejector operating. If the isolating valve is tight, the total calculated leakage for both tests will be identical. If the isolating valve is not tight the two values will be different by an amount equal to the leakage through the valve plus the air removed by the ejector under the pressure conditions existing across the leaking valve. For reliable tests of air leakage using the drop test, leakage through the isolating valve in the closed position should be proven negligible.

Development of equation:

Let: l = Leakage rate, lbs per hr

W₁ = Weight of air in system at initial pressure, lbs

W₂ = Weight of air in system at final pressure, lbs

T = Time, minutes

0.075 = Weight of air, lbs per cubic feet at 30 in. HgA, 70°F

60 = Minutes per hour

p₁ = Initial pressure in system, in. HgA

p₂ = Final pressure in system, in. HgA

30 = Standard atmospheric pressure (30 in. HgA)

$$l = (W_2 - W_1) \frac{60}{T}$$

$$W_1 = 0.075V \times \frac{p_1}{30}$$

$$W_2 = 0.075V \times \frac{p_2}{30}$$

$$W_2 - W_1 = \frac{0.075V}{30} (p_2 - p_1)$$

$$l = \frac{0.075V}{30} (p_2 - p_1) \frac{60}{T}$$

$$l = \frac{0.15V}{T} (p_2 - p_1)$$

Inspection of equation (8) shows that the absolute pressure at the start and finish of the test need not be known (as long as final pressure is not above 15 inches Hg Absolute). Only the pressure rise need be known. Therefore, the test may be run using a reliable vacuum gauge or mercury column without correction for barometer pressure.

6.1.2 Air Meters

If the air ejector serving the vacuum system is provided with a surface aftercondenser, the total non-condensable gases handled by the ejector can be

measured by means of a suitable air meter installed at the air outlet connection. The total gas load will consist of air leakage into the system plus noncondensable gases generated in the process plus air released from condensing water, if a direct contact condenser is used ahead of the ejector. Air meters are generally of two types:

1. Variable area type with constant pressure drop.
2. Fixed area type with variable pressure drop, such as a nozzle with water manometer for measuring head.

When using air meters, all the air shall be directed through the meter. Also, for accurate determination of air leakage, the temperature of the saturated air must be measured and suitable corrections made to meter readings to correct for mixture density and for the percentage of water vapor in the mixture.

6.1.3 Other Tests

Following installation, every complete vacuum system should be hydrostatically tested to locate and eliminate any points of leakage at flanged connections, valves, etc. On large installations, where hydrostatic testing becomes impractical, other types of testing for leaks, such as a halogen leak test, may be employed.

6.1.4 Commercially Tight Systems

For a vacuum system to be considered commercially tight, the air leakage should not exceed values shown in Figure 42. The maximum air leakage values shown for the five absolute pressure ranges are for a vacuum system without any agitator. For a system with agitator, having an ordinary commercial shaft seal, a reasonable amount of maintenance will keep the shaft leakage down to 5 lbs per hour. With a special high vacuum seal and good maintenance, shaft leakage can be kept to a negligible amount.

6.1.5 Selecting Ejector Capacity

The values of maximum air leakage should not be used for selecting the capacity of the ejector equipment. It is recommended that the design capacity of the ejector be equal to double the maximum estimated air leakage to which should be added the noncondensable gases produced in the process and any associated condensable vapors. For the recommended capacity of ejectors to serve the condensers of prime movers, see the Heat Exchange Institute Standards for Steam Surface Condensers and Standards for Direct Contact Barometric and Low Level Condensers, current editions.

6.2 Air And Vapor Water Mixtures

6.2.1 Air and Water Vapor Mixtures

Figures 43 through 46 show the relationship of air and water vapor in saturated mixtures in accordance with Dalton's Law.

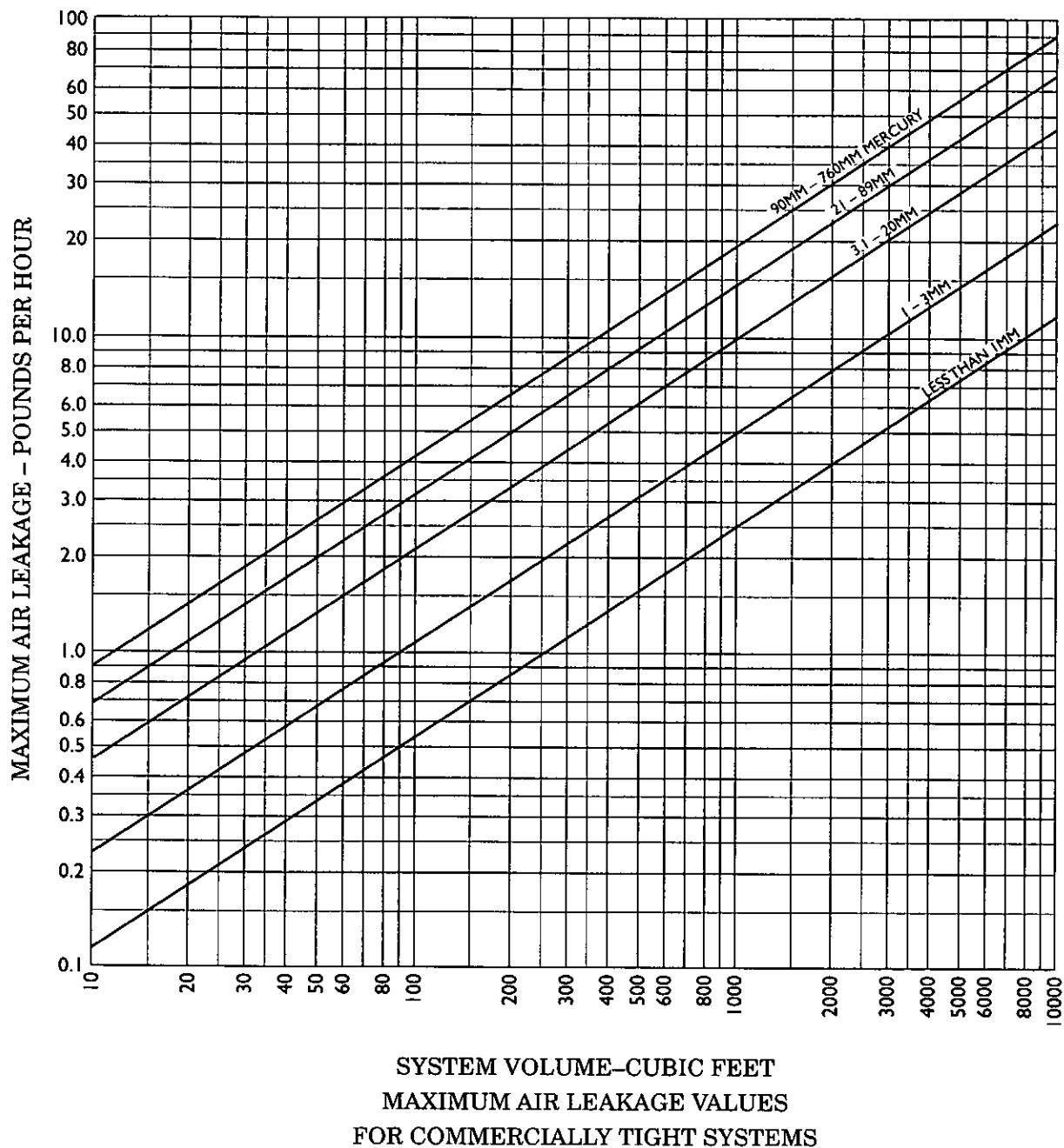
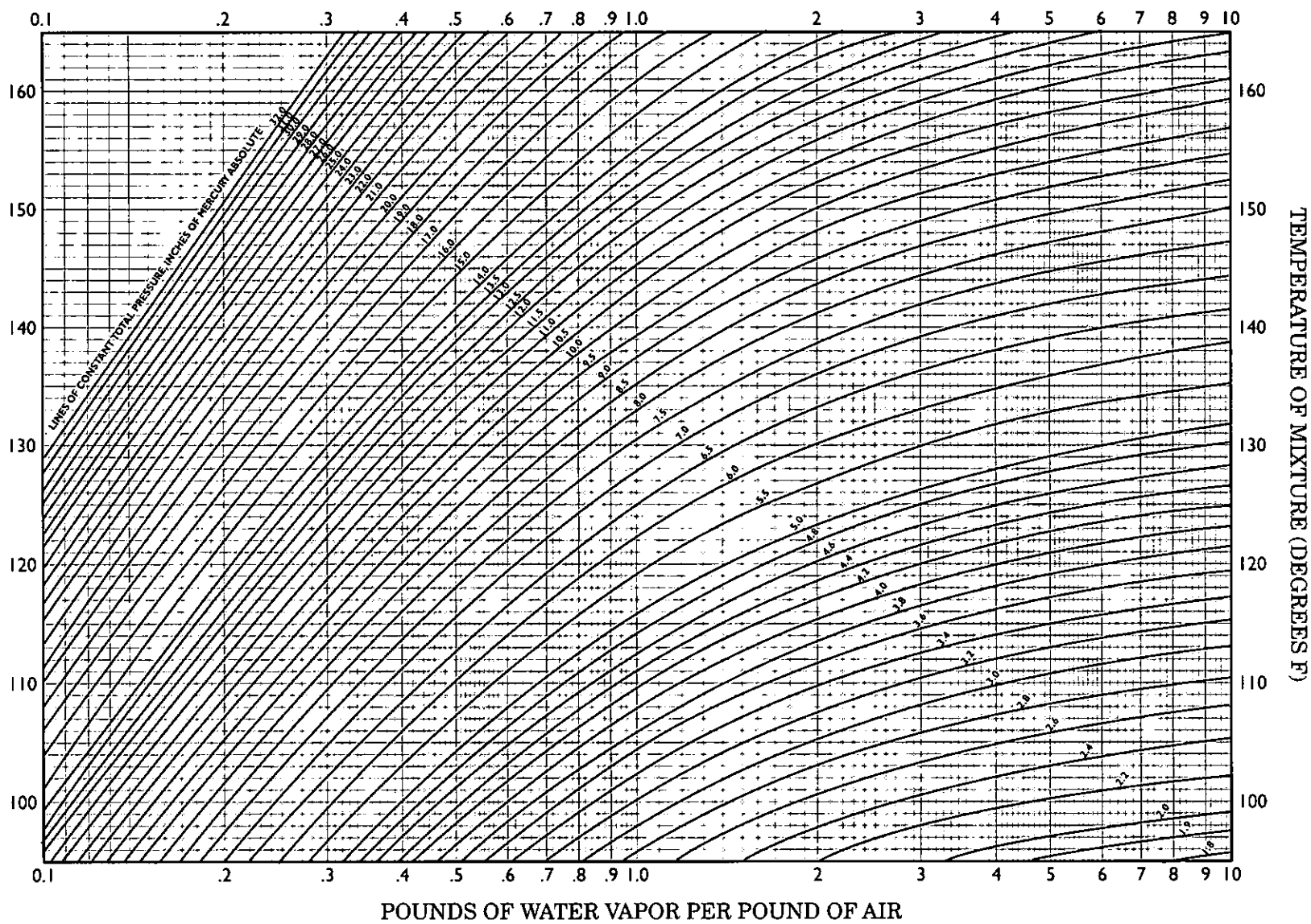


Figure 42

Notes

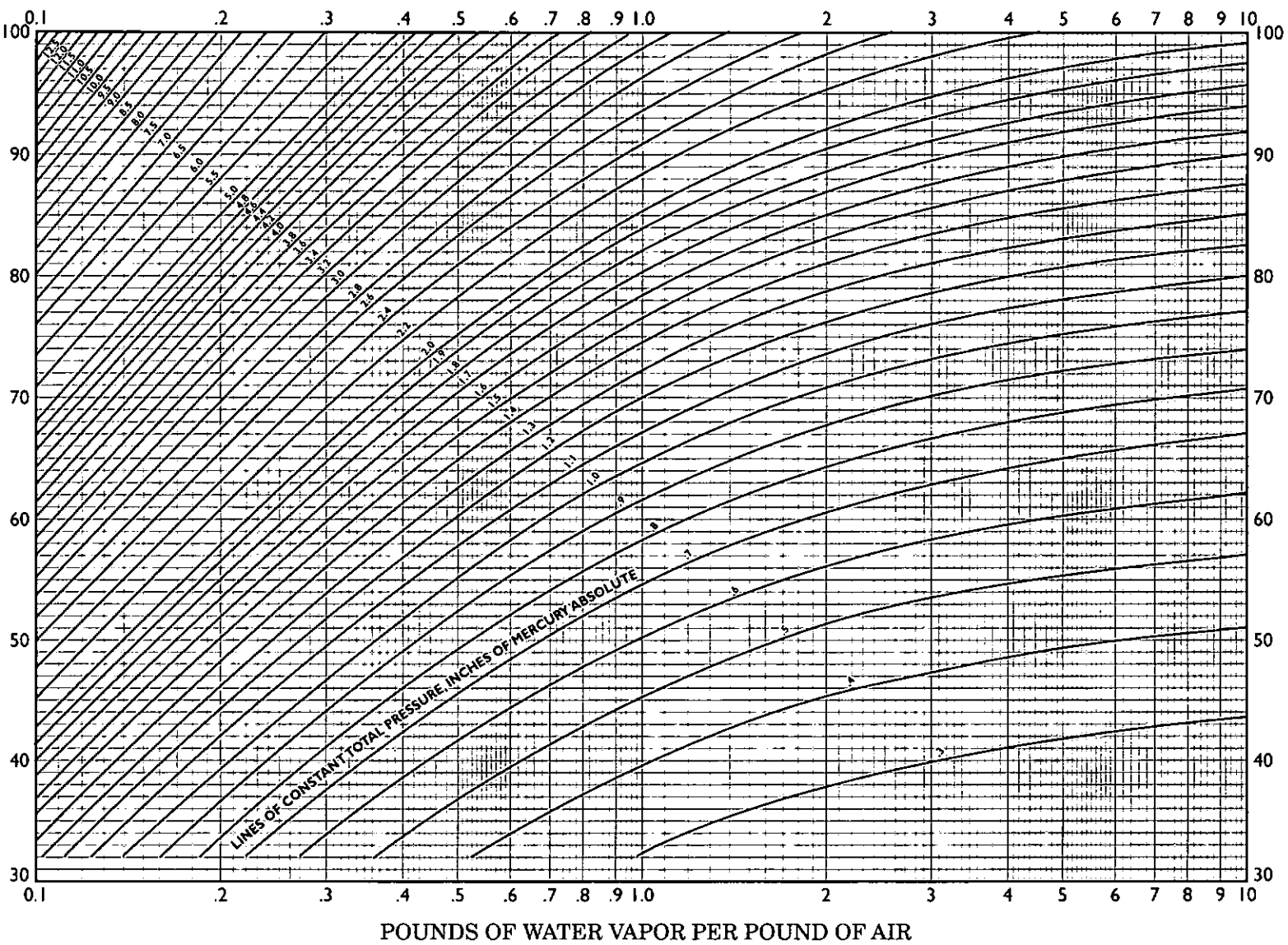
- (1) The air leakage rates indicated are guidelines only. In actual field practice, the air leakage may be significantly larger or smaller depending upon the condition of sealing, maintenance factors and applications.
- (2) For comparison purposes, alternate methods of air leakage estimation may be used. A selected bibliography is as follows:
 1. Compressed Air and Gas Handbook, Fifth Edition.
 2. Applied Process Design for Chemical and Petrochemical Plants, Volume 1, Second Edition.
 3. 'Selecting Vacuum Systems', Chemical Engineering, December 14, 1981.
 4. Theorie Und Praxis Der Vakuumtechnik, Max Wutz, Verlag Friedrich Vieweg U. Sohn Braunschweig, 1965.
 5. Tabellenbuch Der Vakuumverfahrenstechnik In Der Grundstoffindustrie. E. L. Holland-Mertern, Veb Deutscher Verlag Fuer Grundstoffindustrie Leipzig, 1964.



AIR AND WATER VAPOR MIXTURE DATA (DALTON'S LAW)

Figure 43

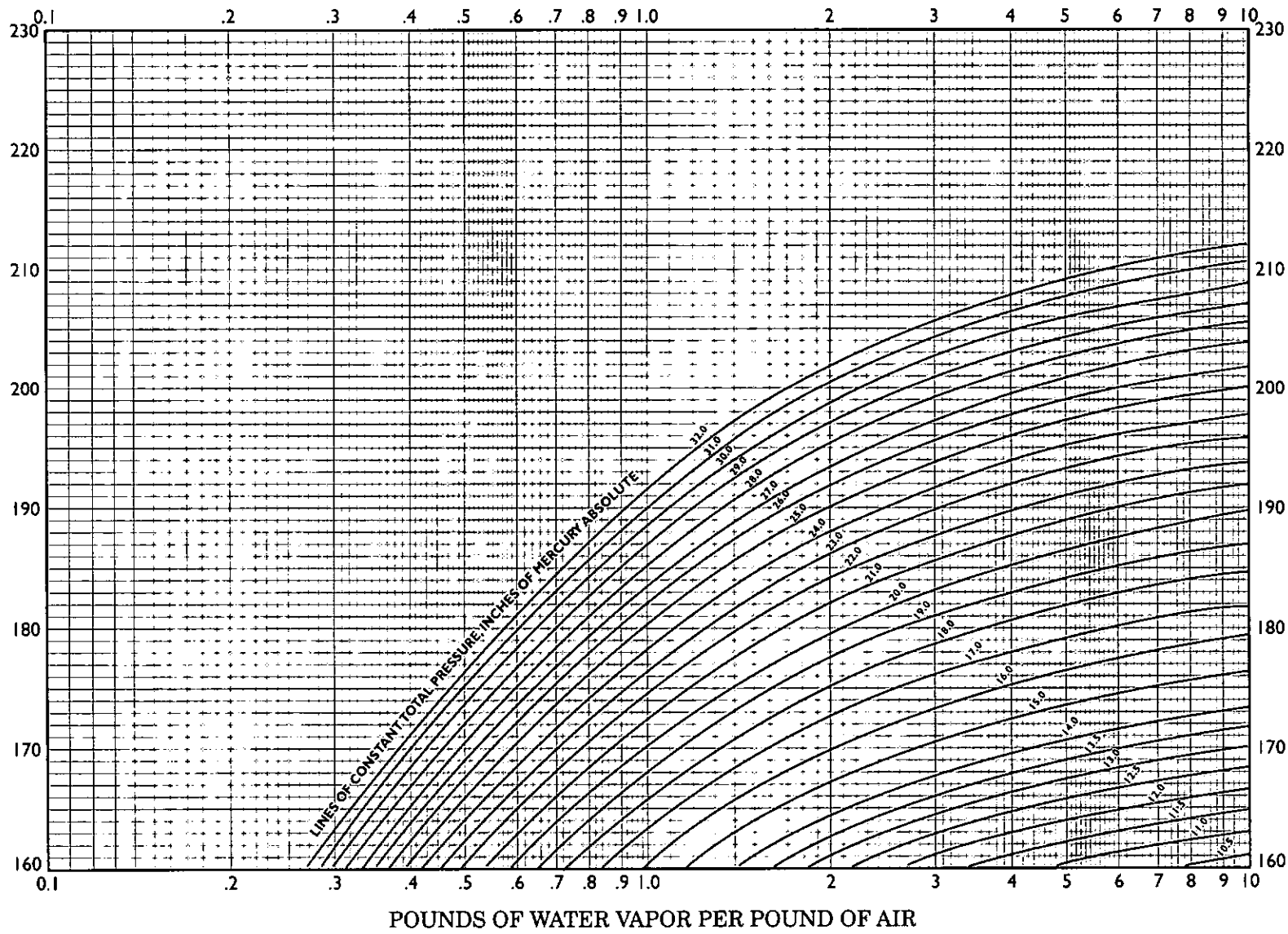
TEMPERATURE OF MIXTURE (DEGREES F)



AIR AND WATER VAPOR MIXTURE DATA (DALTON'S LAW)

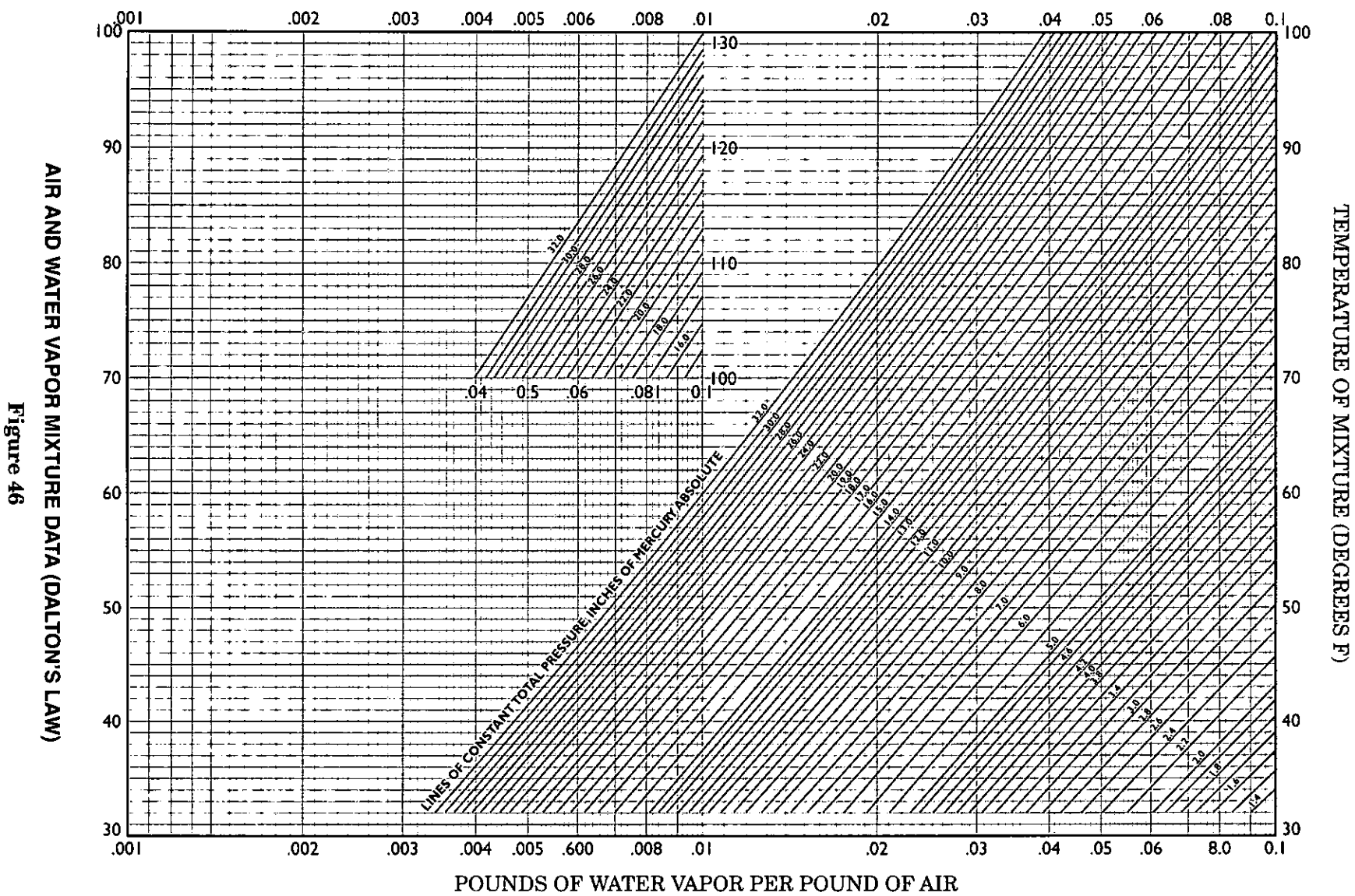
Figure 44

TEMPERATURE OF MIXTURE (DEGREES F)



AIR AND WATER VAPOR MIXTURE DATA (DALTON'S LAW)

Figure 45



6.3 Pressure Drop In Vacuum

6.3.1 Turbulent Flow of Air or Steam

Figure 47* can be used to determine the diameter of the cylindrical pipe required for a low pressure drop with turbulent flow of air or steam at a subatmospheric pressure, provided the pressure drop is limited to 10 percent of the final pressure. The lower limit for the application of this data is determined by the limit of the ratio:

$$\frac{w}{d} \geq 20$$

where:

w = flow rate, pounds per hour
d = inside diameter of pipe, inches

If the ratio is less than 20, the flow is streamline and Figure 47 will not apply.

For example:

Pipe length = 300 ft
Pipe diameter = 12 in. nominal
Steam flow = 275 lbs per hr
Steam temperature = 400°F
Initial pressure = 0.5 in. HgA

Pressure drop is determined as follows:

$$F = \frac{(F_1 \times C_{D1} \times C'_{T1}) + (F_2 \times C_{D2} \times C'_{T2})}{P_1}$$

w = 275 lbs per hr
F₁ = 1.78 x 10⁻²
F₂ = 8.45 x 10⁻²
d = 12.09 in.
C_{D1} = 4.10 x 10⁻¹
C_{D2} = 4.25 x 10⁻¹
t = 400°F
C'_{T1} = 2.61
C'_{T2} = 2.515

Then,

$$F = \frac{300}{100} \times \frac{[(1.78 \times 10^{-2})(4.10 \times 10^{-1})(2.61)] + [(8.45 \times 10^{-2})(4.25 \times 10^{-1})(2.515)]}{0.5}$$

F = $\frac{0.656}{13.6^{**}}$ = 0.048 in. Hg and the pressure drop is 9.60 per cent of the final pressure. Note that $\frac{w}{d} = 22.8$.

**13.6 is conversion factor for in. H₂O to in. Hg.

If the pressure drop is greater than 10% of the final pressure, it is possible to contain the error introduced by the excessive pressure drop by separating the length of given pipe into increments such that the pressure drop in each increment is less than the tolerable 10% of the final pressure.

For example:

Pipe length = 100ft
Pipe diameter = 6 in. nominal
Steam flow = 180 lbs per hr
Steam temperature = 100°F
Initial pressure = 0.5 in. HgA

Pressure drop is determined as follows:

w = 180 lbs per hr
F₁ = 7.7 x 10⁻³
F₂ = 4.1 x 10⁻²
d = 6 in.
C_{D1} = 12.7
C_{D2} = 11.1
t = 100°F
C'_{T1} = 1.700
C'_{T2} = 1.455

Then,

$$F = \frac{100}{100} \times \frac{[(7.7 \times 10^{-3})(12.7)(1.700)] + [(4.1 \times 10^{-2})(11.1)(1.455)]}{0.5}$$

$$F = 1.657 \text{ in. H}_2\text{O} \\ = \frac{1.657}{13.6} = 0.1216 \text{ in. Hg}$$

and,

the pressure drop is 32.14% of the final pressure.

Since this pressure drop exceeds the 10% limit for which the equation is suitable, the pressure drop should be calculated by the increment method.

The constants from Figure 47 do not change and may be combined as the constant 0.8284. This reduces the equation to the form

$$F = \frac{L \times 0.8284}{100 \times p_1 \times 13.6}$$

Then, introduce incremental lengths of 25 feet

$$1. \frac{25 \times 0.0608}{100 \times 0.50} = 0.0304 \text{ in. Hg} \\ 0.5000 - 0.0304 = 0.4696 \text{ in. Hg}$$

$$2. \frac{25 \times 0.0608}{100 \times 0.4696} = 0.0324 \text{ in. Hg} \\ 0.4696 - 0.0324 = 0.4372$$

$$3. \frac{25 \times 0.0608}{100 \times 0.4372} = 0.0348 \text{ in. Hg} \\ 0.4372 - 0.0348 = 0.4024$$

$$4. \frac{25 \times 0.0608}{100 \times 0.4024} = 0.0378 \text{ in. Hg} \\ 0.4024 - 0.0378 = 0.3646$$

*The basis for this data is given in "A Graphical Representation of the Frictional Losses in Commercial Pipe of Air and Steam Flowing Turbulently at Low Pressure", W.C. Knapp and J.W. Metzger, *ASME Transactions*, Volume 77, No. 15, July 1955, pages 675-681.

The total pressure drop will be:

$$0.0304 + 0.0324 + 0.0348 + 0.0378 = 0.1354 \text{ in Hg.}$$

and the final pressure will be:

$$0.500 - 0.1354 = 0.3646 \text{ in. Hg.}$$

6.3.2 Streamline Flow of Air

Calculations to determine the diameter of the cylindrical pipe with streamline flow of air at any initial absolute pressure between 50 microns and 1 millimeter of mercury can be made by using the proper value of "f" from Figure 48* in the Fanning equation provided the pressure drop is limited to 10% of the final pressure.

For example, the calculations to determine the size pipe required to limit the pressure drop to around 9 microns for a flow of 5 lbs per hour of 70°F air at 100 microns Hg Absolute pressure through a 15 foot length of pipe would be as follows:

Assume 18 inch O.D. Standard Weight pipe (17.182 inch I.D.) would be required and calculate Reynolds number.

$$R_D = \frac{Dv\rho}{\mu} \quad (10)$$

where:

D = Inside diameter of pipe, feet

v = Average velocity, feet per second

ρ = Average density, pounds per cubic foot

μ = Absolute viscosity of air, pounds per foot-second

Since D = 17.182 inches or 1.432 feet,
the area of the cross section of pipe
= 1.610 sq feet

The specific volume at 70°F and average pressure of 95.5 microns = 106,206 cu ft per lb

$$\begin{aligned} \text{Average velocity} &= \frac{5 \times 106206}{3600 \times 1.610} \\ &= 91.6 \text{ ft per sec} \end{aligned}$$

$$\begin{aligned} \text{Average density} &= \frac{1}{106206} \\ &= 94.16 \times 10^{-7} \text{ lb per cu ft} \end{aligned}$$

Viscosity at 70°F = 122×10^{-7} lbs per ft-sec* and therefore:

$$R_D = \frac{1.432 \times 91.6 \times 94.16 \times 10^{-7}}{122 \times 10^{-7}} = 101$$

For $R_D = 101$

f = 0.48 (from Figure 48)

The Fanning equation is:

$$P_1 - P_2 = \frac{4fLv\rho v^2}{2gD \times 144} \quad (11)$$

where:

P_1 = Upstream static pressure, pounds per square inch absolute

P_2 = Downstream static pressure, pounds per square inch absolute

f = Friction factor, dimensionless

L = Length of pipe, feet

ρ = Average density, lbs per cu ft

v = Average velocity, ft per sec

g = Acceleration due to gravity
= 32.17 ft. per sec²

D = Inside diameter of pipe, feet

then:

$$\begin{aligned} P_1 - P_2 &= \frac{4 \times 0.48 \times 15 \times 94.16 \times 10^{-7} \times 91.6^2}{2 \times 32.17 \times 1.432 \times 144} \\ &= 1.715 \times 10^{-4} \text{ lbs per sq in.} \\ &= 1.715 \times 10^{-4} \times 51714.7 \text{ (from Appendix M)} \\ &= 8.87 \text{ microns} \end{aligned}$$

*These friction factors were developed as a result of an extensive investigation of pressure drops at low absolute pressures which was reported in detail in "Fanning Friction Factors for Air Flow at Low Absolute Pressures in Cylindrical Pipes." W.J. Bohnet and L.S. Stinson, *ASME Transactions*, Volume 77, No. 15, July, 1955, pages 683-692.

* Values for viscosity should be taken from Figure 21, to correspond to the viscosity values used in Figure 48.

Corrigendum to
Heat Exchange Institute's
5th Edition, Standards for Steam Jet Vacuum Systems
October, 2000

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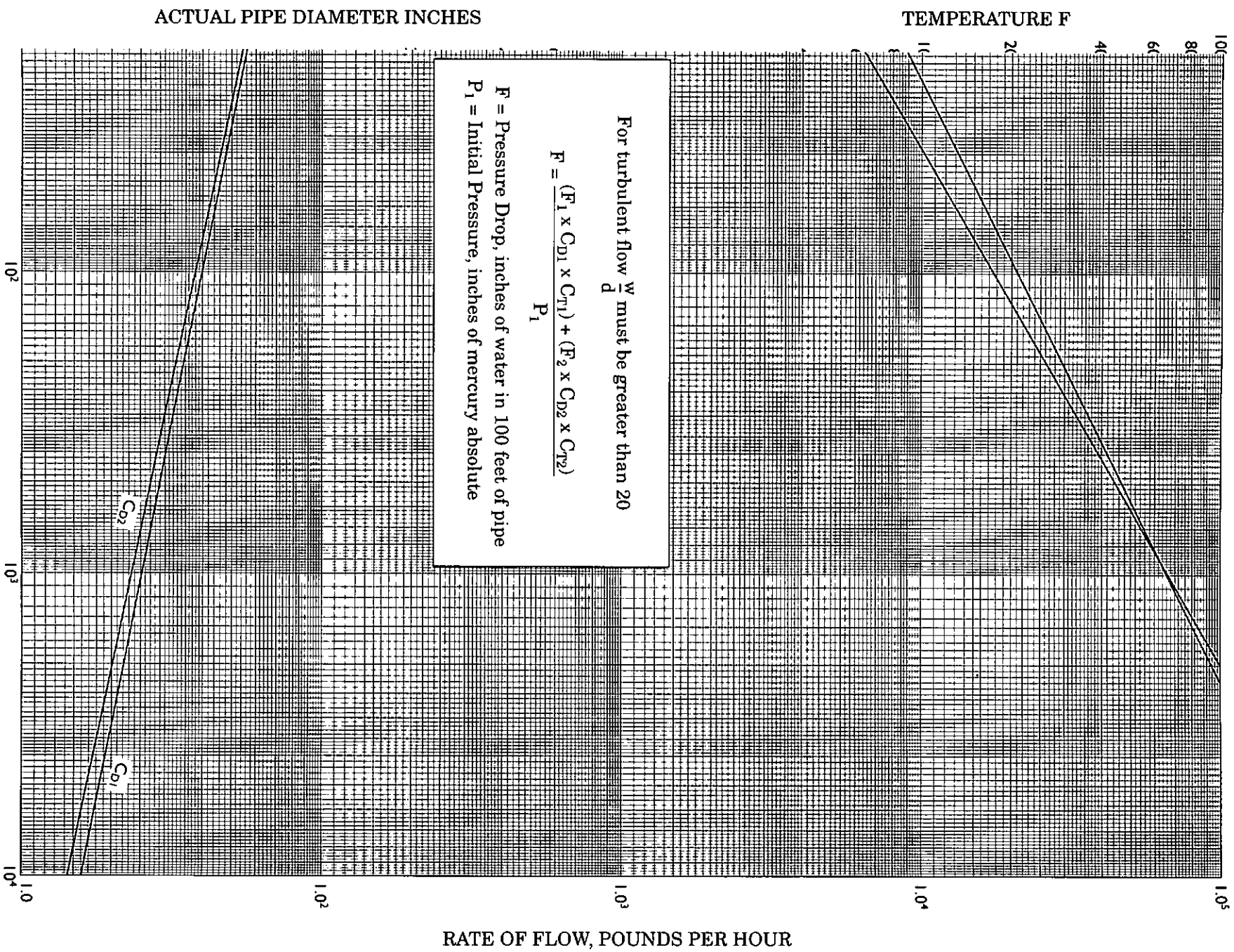
Figure 47 Evaluation Curves for Friction Losses of Air and Steam Flowing Turbulently in Commercial Pipe at Low Pressures

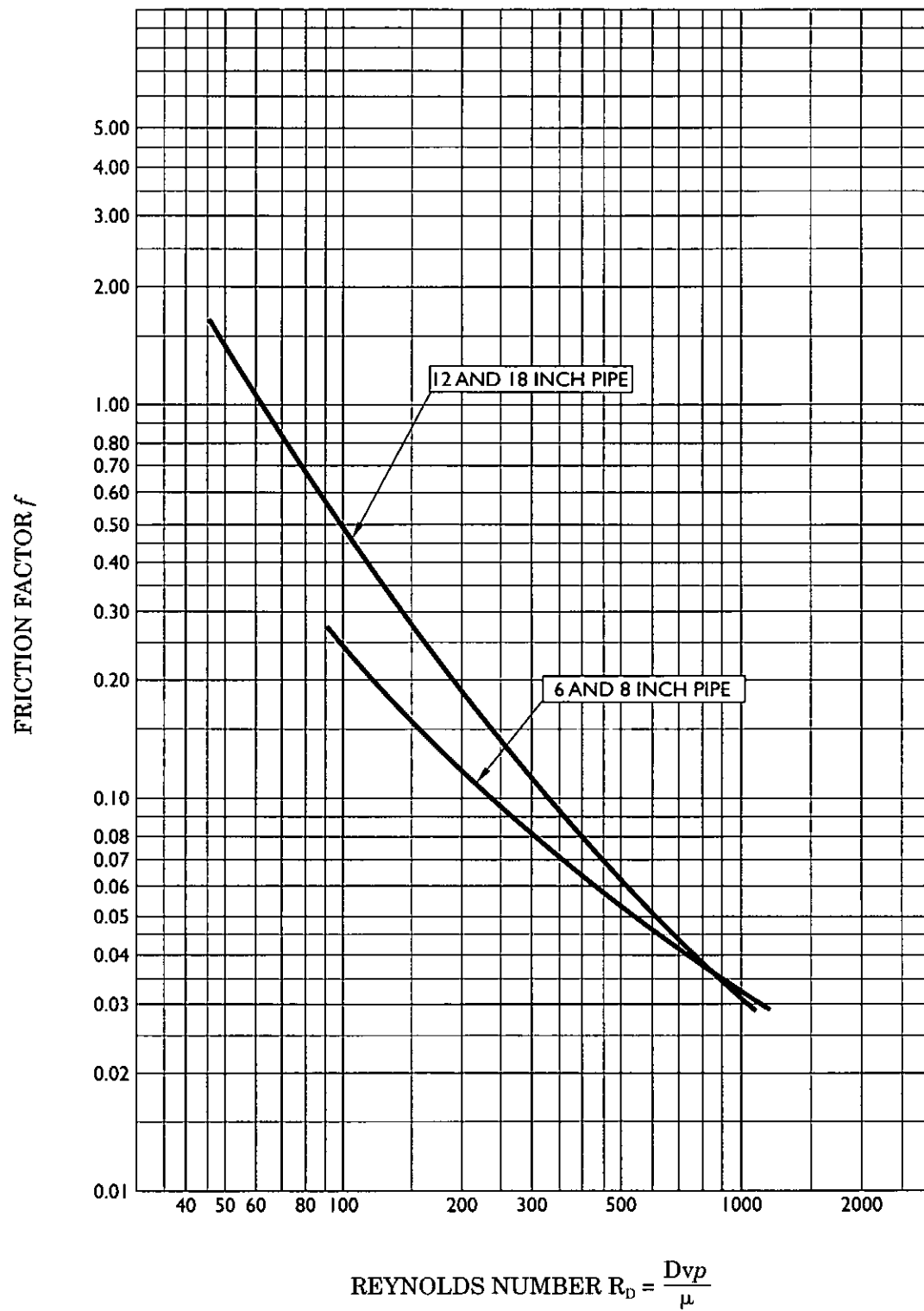
Replace

*1.0^{-5} , 1.0^{-4} , 1.0^{-3} , 1.0^{-2} , 1.0^{-1} on the x-axis of the figure with
 10^{-5} , 10^{-4} , 10^{-3} , 10^{-2} , 10^{-1} , respectively*

Replace

*1.0 , 1.0^2 , 1.0^3 , 1.0^4 , 1.0^5 on the y-axis of the figure with
 10 , 10^2 , 10^3 , 10^4 , 10^5 , respectively*





FRICTION FACTOR FOR STREAMLINE FLOW OF AIR AT ABSOLUTE PRESSURES FROM 50 MICRONS MERCURY TO 1 MILLIMETER MERCURY

Figure 48

6.3.3 Equivalent Length of Pipe

The equivalent length of pipe for various valves and fittings can be determined from existing data as published in many handbooks.

6.3.4 Hydraulic Loss

(a) The hydraulic loss (condenser friction) through a condenser must also be considered and curves in Figures 49 through 54 show friction losses that may be expected in properly designed condensers with new and clean 18 BWG tubes.

(b) Figure 49 covers the loss of head in feet through new and clean 18 BWG tubes per foot of travel with an average cooling water temperature of 77.5°F (based on an assumed 15°F temperature rise). To correct this computed loss for average water temperature other than 77.5°F, multiply the friction loss obtained from Figure 49 by the appropriate correction factor obtained from Figure 50. For tube gauges other than 18 BWG, multiply the value obtained from Figure 49 by the gauge correction factor shown in the included table. Alternatively use the following equation which includes gauge correction factors:

$$F = \frac{.00642V^{1.75}}{d^{1.25}}$$

where:

F = Friction loss in feet of water/foot of length

V = Velocity, ft./sec.

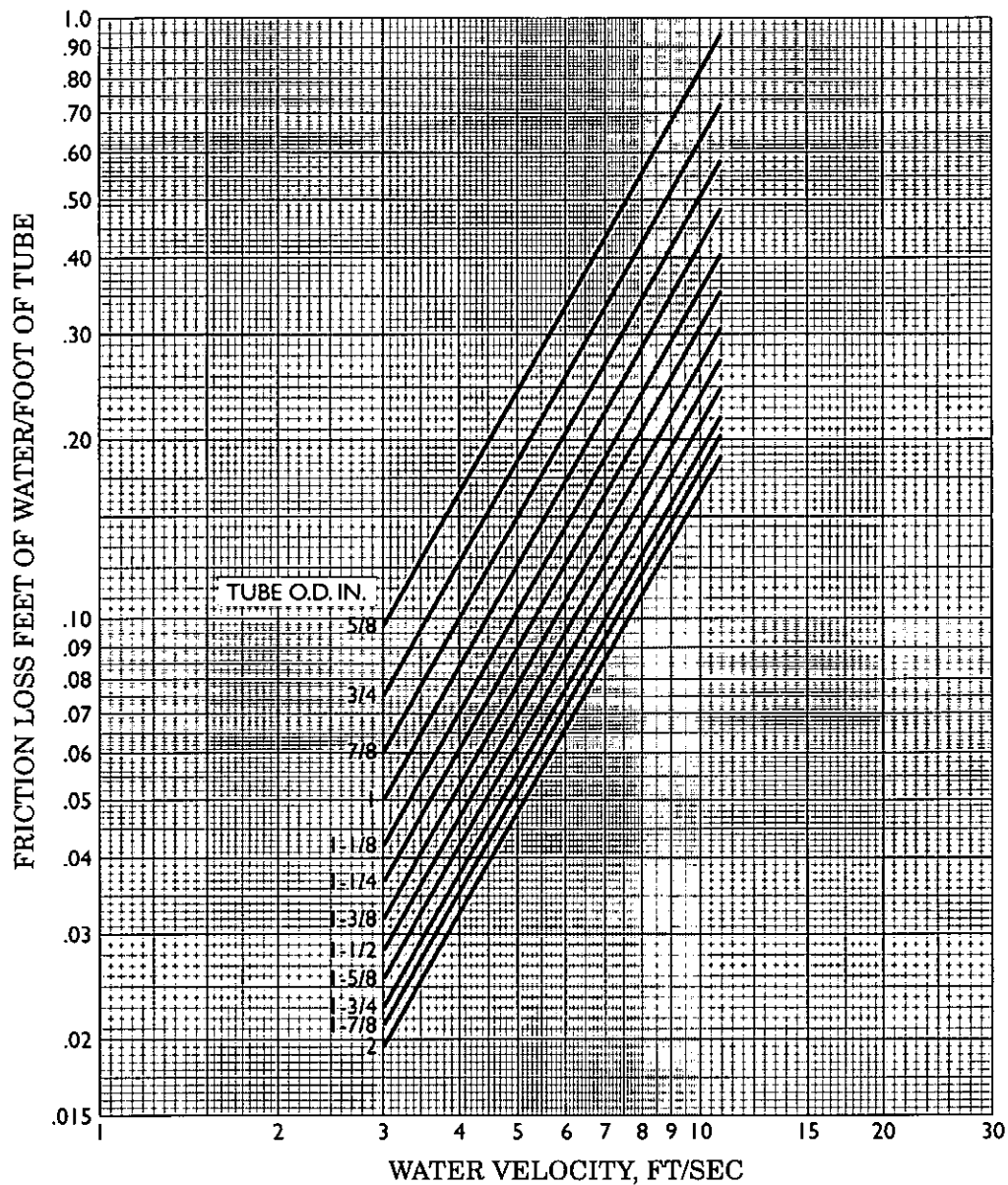
d = Inside diameter of pipe, in.

(c) Figures 51 through 54 cover the head losses to be expected in waterboxes and tube entrances and exits of single pass, two pass, three pass and four pass condensers, respectively. For single pass condensers, the inlet and outlet waterbox losses should be determined from the curves in Figure 51 using the actual nozzle water velocity in each case. The tube inlet and outlet losses are combined in one curve in Figure 51 and the value for these losses should be taken directly from the curve using the actual water velocity in the tubes.

For two pass condensers, the above procedure should be followed using the curves in Figure 52. The same procedure should be followed for three and four pass units using the appropriate curve.

(d) The total condenser friction is determined by adding the corrected values obtained from Figure 49 and the values from Figures 51, 52, 53 or 54.

FRICTION LOSS FOR WATER FLOWING IN 18 BWG TUBES



GAUGE CORRECTION FACTOR FOR FRICTION LOSS

Tube O.D. In.	12 BWG	14 BWG	16 BWG	18 BWG	20 BWG	22 BWG	24 BWG
0.625	1.38	1.21	1.10	1.00	0.94	0.91	0.89
0.750	1.28	1.16	1.06	1.00	0.95	0.93	0.90
0.875	1.25	1.13	1.06	1.00	0.96	0.94	0.92
1.000	1.19	1.11	1.05	1.00	0.96	0.94	0.93
1.125	1.16	1.09	1.04	1.00	0.97	0.95	0.94
1.250	1.14	1.08	1.04	1.00	0.97	0.96	0.94
1.375	1.13	1.07	1.03	1.00	0.97	0.96	0.94
1.500	1.12	1.06	1.03	1.00	0.97	0.96	0.95
1.625	1.10	1.05	1.02	1.00	0.97	0.96	0.95
1.750	1.10	1.05	1.02	1.00	0.98	0.97	0.96
1.875	1.09	1.05	1.02	1.00	0.98	0.97	0.96
2.000	1.08	1.04	1.02	1.00	0.98	0.97	0.96

Figure 49

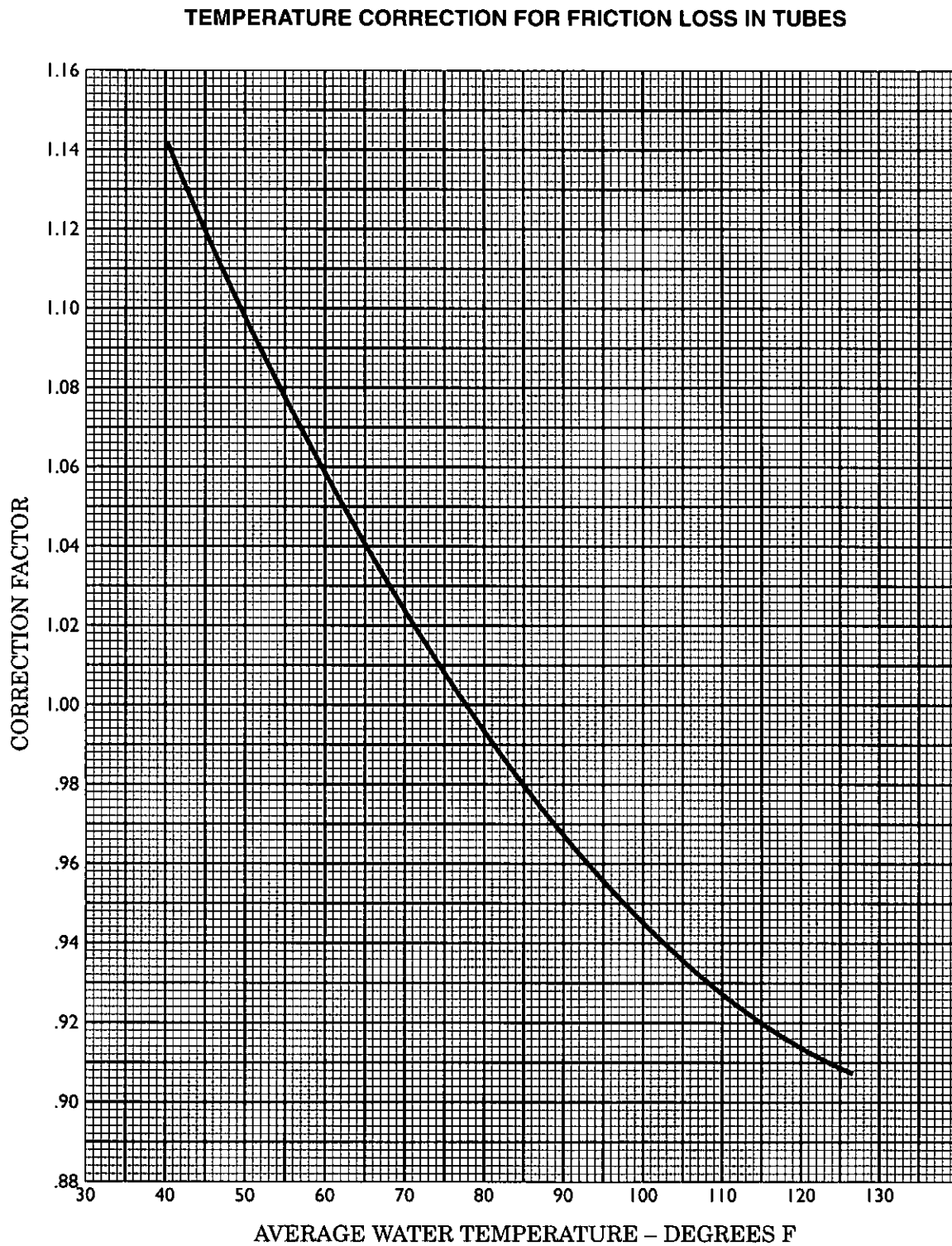


Figure 50

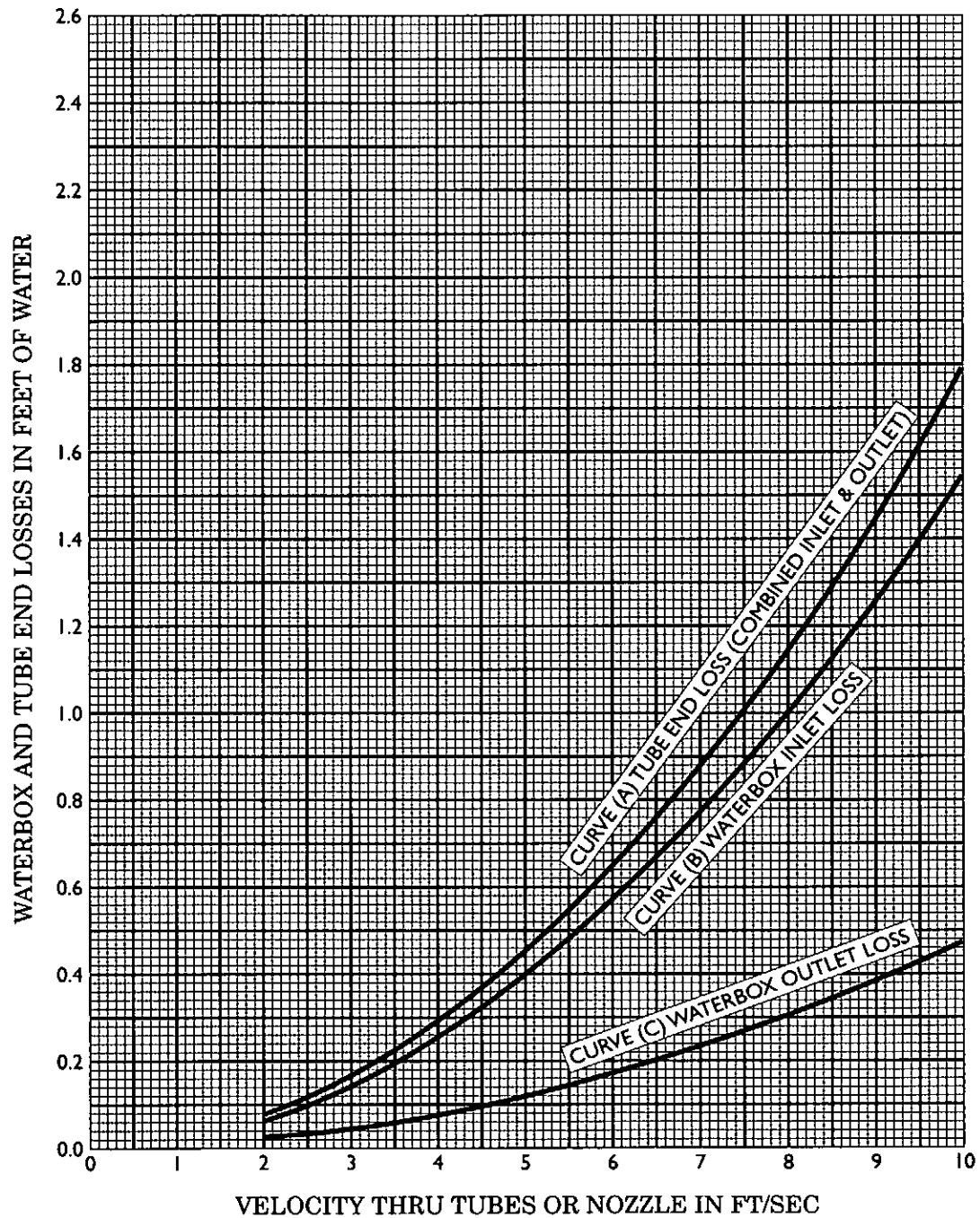
WATERBOX AND TUBE END LOSSES
SINGLE PASS CONDENSERS

Figure 51

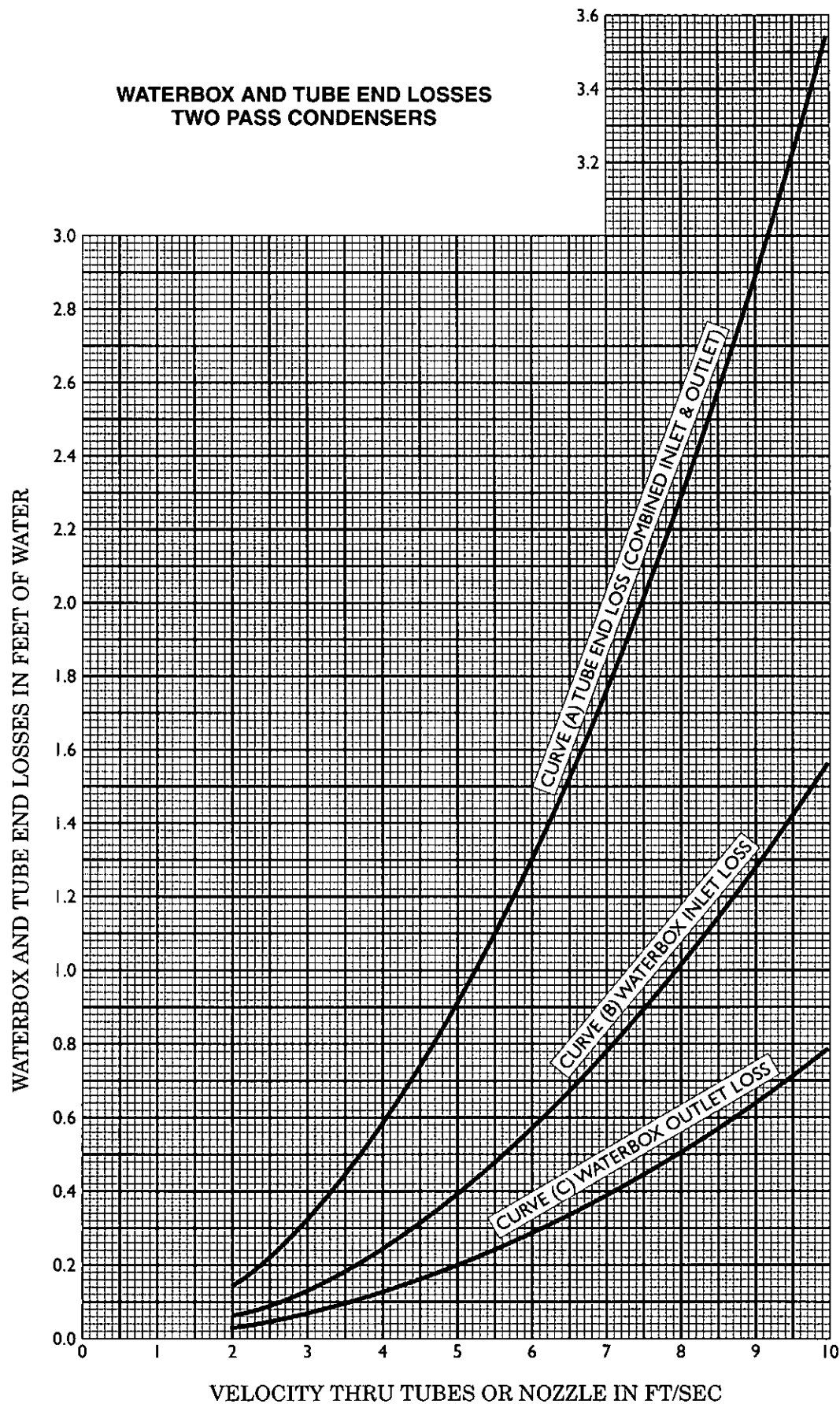


Figure 52

WATERBOX AND TUBE END LOSSES THREE PASS CONDENSERS

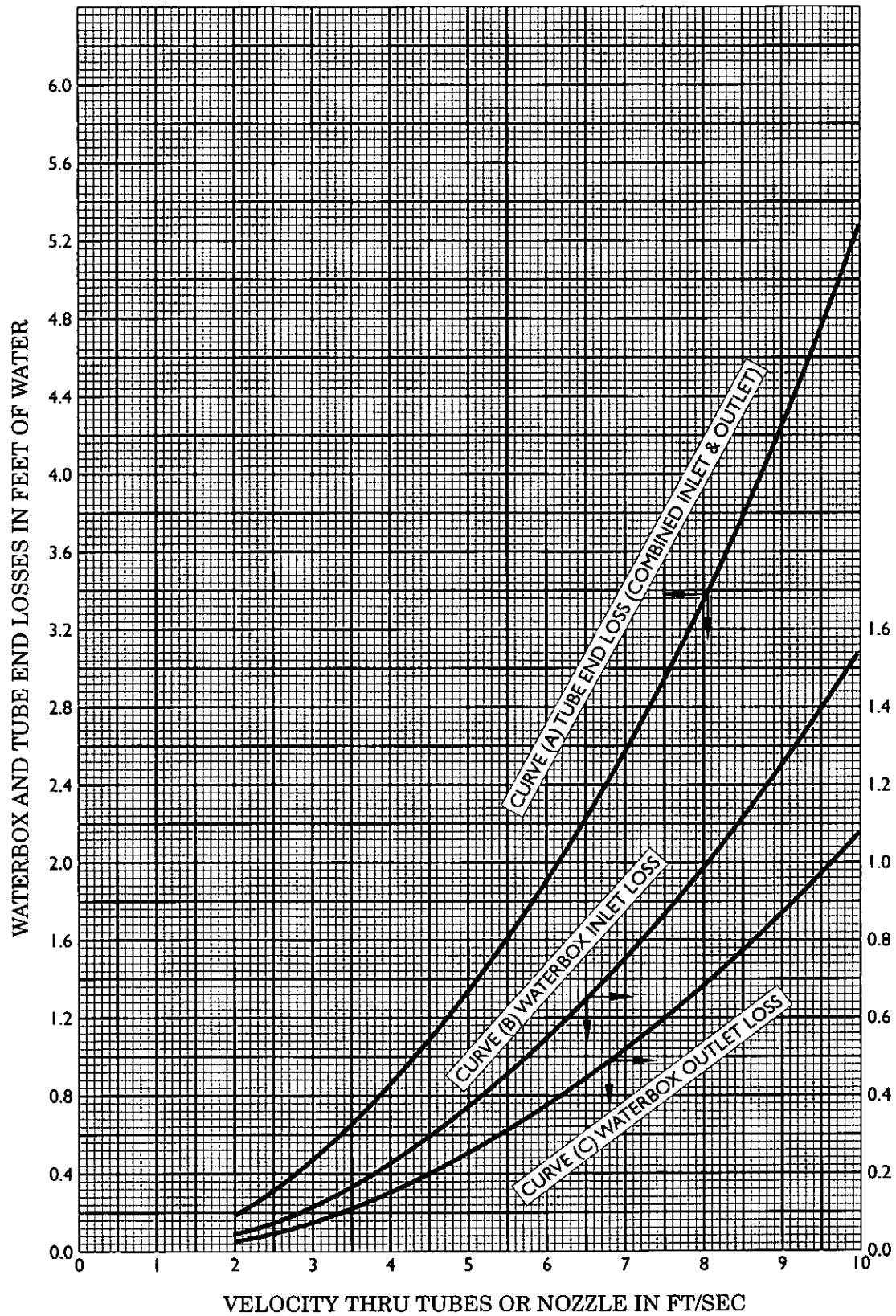


Figure 53

WATERBOX AND TUBE END LOSSES FOUR PASS CONDENSERS

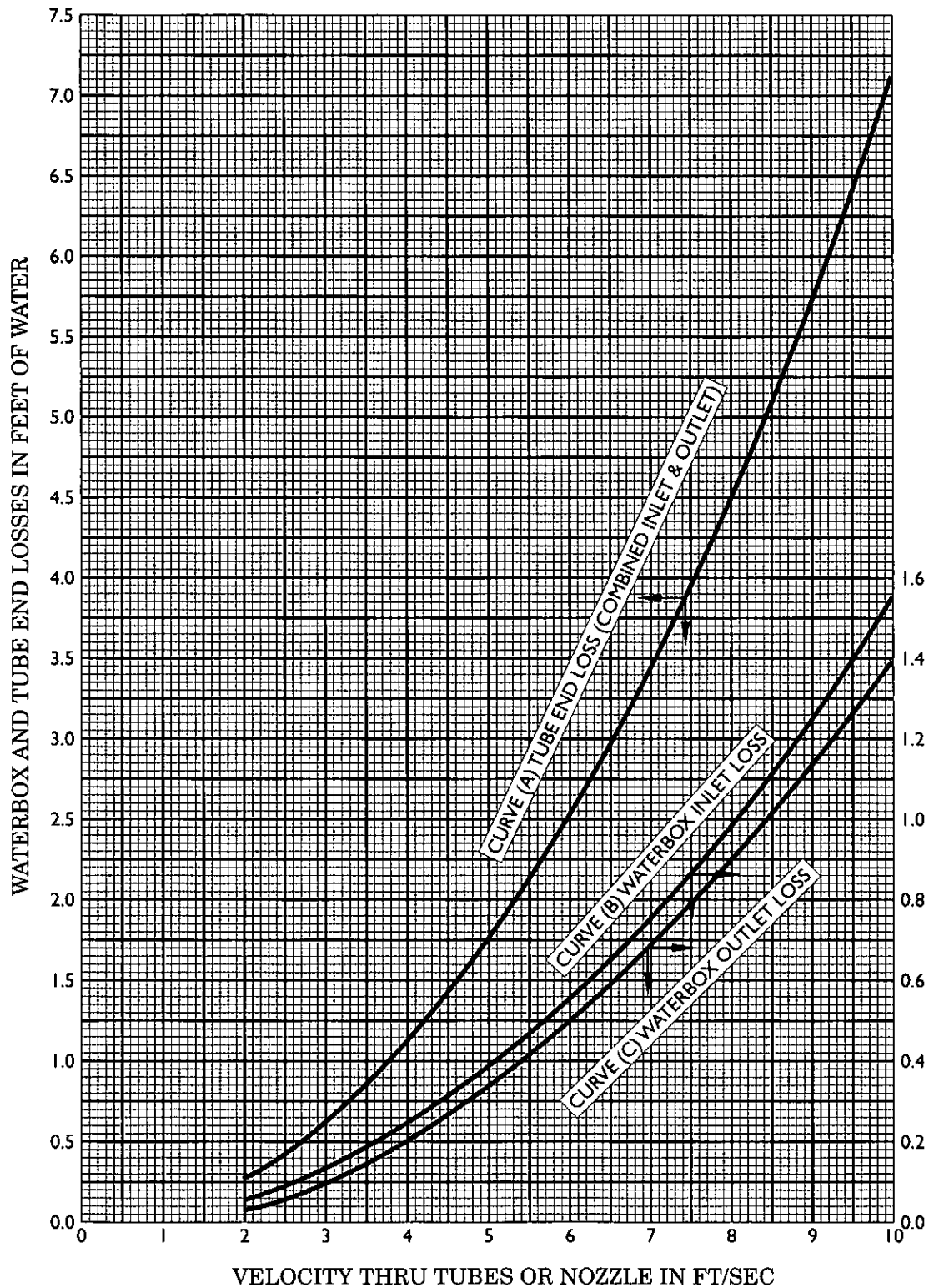


Figure 54

7.0 TROUBLESHOOTING STEAM JET VACUUM SYSTEMS

Steam Jet Vacuum Systems are fundamentally reliable vacuum producers as they have no moving parts. If the steam supply is dry, the cooling water clean and the materials of construction matched properly to the corrosive nature of the process fluids Steam Jet

Systems can and do last indefinitely. However the reality of some operating environments creates problem conditions (both short term as well as long term) listed here from the most common to the least common, all resulting in loss of stable design vacuum.

PROBLEM	CAUSE	SOLUTION
1. Plugged (completely or partially) steam nozzles	Foreign material in the steam supply (particularly from pipe fabrication at installation).	Disassemble, inspect and clean.
2. Wear of internal working surfaces of nozzles and diffuser.	Wet steam.	Install a separator and trap at ejector system. Insulate lines, trap low spots, set line sizes for 150ft/sec. Superheat steam (50° F max).
3. Insufficient energy supply.	Lower steam pressure than the design minimum pressure.	Raise steam pressure (at the ejector) above the design minimum (or ask manufacturer to redesign).
4. Suction flow overload and increased suction pressure.	Excessive air leaks and unexpected process loads.	Find and correct leaks and overloads.
5. Insufficient condensing and cooling. High condensing pressure.	Higher cooling water temperature than the design maximum.	Correct supply temperature.
6. Insufficient condensing and cooling. High condensing pressure.	Lower cooling water flow than the design value.	Increase water flow.
7. Too much friction in ejectors and/or too little heat transfer rate in condensers and/or blockage of the condensate drain.	Fouling of internal working surfaces (process fluids or cooling water).	Clean parts.
8. Too much compression required given the design energy provided.	Higher system discharge pressure than the design maximum.	Decrease discharge pressure drop or redesign z stage.
9. Too much pressure drop between vacuum user and vacuum producer.	Suction pipe conditions – smaller size than connection – partially closed block valves – fouling – liquid traps – undersized in-line equipment	Correct suction pipe condition.
10. Flooding of condensers.	Insufficient condensate removal provisions.	Clean tail pipe, check for air leaks. Assure operation of installed mechanical equipment.
11. Too much or too little steam flow.	Excessive steam pressure and/or temperature.	Limit overpressure to approx. 125%. Limit superheat to approx. 50° F.

The primary difficulties in troubleshooting a Steam Jet System (i.e. finding and fixing the cause of a problem) result from:

1. Not understanding how ejector systems work.
2. Not being able to easily observe the operation (fluids flowing inside).
3. Becoming confused by the interaction of components.

There are three corresponding methods to use in simplifying the troubleshooting process:

1. Study the appropriate parts of this standard and any available manufacturers literature on how systems work and how ejectors behave.
2. Use the appropriate pressure and temperature gauges to determine fluid conditions and flow meters to determine their rates.
3. Isolate and check the system and its components.

This last method is the essence of the main troubleshooting procedure as follows:

1. Check the operational history of the overall system (vacuum user and vacuum producer). Check for feed rate changes, trends or abnormalities in the suction pressure being produced, operation of valves, gages, and meters.
2. Isolate the vacuum producer (steam jet vacuum system) from the vacuum user by closing off the suction valve or installing a blind flange on the jet system suction connection (assure that no liquid is trapped in the isolated section). If the no load suction pressure (for a system designed to be stable at no load) is approximately per the table below the steam jet system is most likely working.

Number of Operating Stages	No Load Suction Pressure
1	35-50 mm Hg Abs
2	5 mm Hg Abs
3	1 mm Hg Abs
4	50-100 microns Hg Abs
5	5-10 microns Hg Abs

3. If the typical no load suction pressure is not obtained keep the system isolated and install a blank on the last stage (z) ejector and turn on its steam only (leave the water on to all condensers). Check the z stage no load suction pressure per the above table (one stage operating). If it works, put the blank on the next stage up (y) and turn steam on to the z stage first (to check for interstage leaks) and then to y and z stages. Check two stage no load suction pressure per the above table. Continue on until unsatisfactory results occur.

4. As you discover unsatisfactory operation realize that an ejector requires that only four basic mechanical conditions are satisfied.

- A. No plugs (stoppage or fouling) in the nozzle or diffuser.
- B. No leaks from the atmosphere or steam at the steam nozzle connection (inside the suction head).
- C. The internal working surfaces of the nozzle and diffuser are reasonably smooth.
- D. The correct parts are in place.

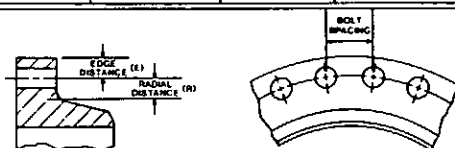
Similarly inter and after shell and tube condensers require these four mechanical conditions be satisfied.

- A. Reasonably clean tube surfaces (inside and out).
- B. No blockage to fluid flow.
- C. No leaks from the atmosphere (including condensate drains) or from the water side to the condensing side.
- D. No flooding (of the condensing side).

5. Call the manufacturer with the information you've obtained from (all or part of) the above procedure. They will be able to lead you to the problem cause most effectively. 99% of all troubleshooting issues can be handled over the phone.

APPENDIX A BOLTING DATA

Nominal Bolt Size (in)	Thread Data			Heavy Hex Nut Dimensions		Minimum Dimensions		
	No. of Threads per in n	Root Area (in ²) A _b	Pitch Diameter (in) D _i	Across Flats (in) D _o	Across Corners (in)	Bolt Spacing (in)	Radial Distance (in) R	Edge Distance (in) E
1/2	13	0.126	.4485	0.875	0.969	1 1/4	13/16	5/8
5/8	11	0.202	.5644	1.062	1.175	1 1/2	15/16	3/4
3/4	10	0.302	.6832	1.250	1.382	1 3/4	1 1/8	13/8
7/8	9	0.419	.8009	1.438	1.589	2 1/8	1 1/4	1 5/16
1	8	0.551	.9168	1.625	1.796	2 1/4	1 3/8	1 1/2
1 1/8	8	0.728	1.0417	1.812	2.002	2 1/2	1 1/2	1 1/8
1 1/4	8	0.929	1.1667	2.000	2.209	2 3/8	1 3/4	1 1/4
1 3/8	8	1.155	1.2916	2.188	2.416	3 1/8	1 7/8	1 3/8
1 1/2	8	1.405	1.4166	2.375	2.622	3 1/4	2	1 1/2
1 5/8	8	1.680	1.5416	2.562	2.828	3 1/2	2 1/8	1 5/8
1 3/4	8	1.980	1.6665	2.750	3.035	3 3/4	2 1/4	1 3/4
1 7/8	8	2.304	1.7915	2.938	3.242	4	2 3/8	1 7/8
2	8	2.652	1.9165	3.125	3.449	4 1/4	2 1/2	2
2 1/4	8	3.423	2.1664	3.500	3.862	4 3/4	2 3/4	2 1/4
2 1/2	8	4.292	2.4164	3.875	4.275	5 1/4	3 1/8	2 3/8
2 3/4	8	5.259	2.6663	4.250	4.688	5 3/4	3 3/8	2 5/8
3	8	6.324	2.9162	4.625	5.102	6 1/4	3 5/8	2 7/8
3 1/4	8	7.487	3.1662	5.000	5.515	6 3/4	3 7/8	3
3 1/2	8	8.749	3.4162	5.375	5.928	7 1/8	4 1/8	3 1/4
3 3/4	8	10.108	3.6661	5.750	6.341	7 5/8	4 3/8	3 1/2
4	8	11.566	3.9161	6.125	6.755	8 1/8	4 5/8	3 5/8



NUT DIMENSIONS ARE PER ANSI B18.2.2
THREAD DIMENSIONS ARE PER ANSI B1.1

A1.0 Calculation of Applied Torque Based on Lubricated Surfaces

Caution—The torque values derived from the following equation are not intended to be those for gasket seating. User should refer to the manufacturer's operation instruction manual for the proper gasket seating torques.

The following equation may be used to calculate the applied torque on the nut to develop the stress in the bolts:

$$T = \text{Torque} = \frac{SA_b F}{12}, \text{ ft-lbf}$$

Where:

S = Bolt stress (psi)

$$F = \frac{U_1 D_i}{2} + \frac{1}{2\pi n} + \frac{\pi U_2}{12A_n} (D_o^3 - D_i^3), \text{ in}$$

$$A_n = \frac{\pi}{4} (D_o^2 - D_i^2), \text{ in}^2$$

U₁ = Factor for friction between nut and stud

U₂ = Factor for friction between nut surface and bearing surface

Typical value of the factor for friction for lubricated surfaces is .15; however, this value may vary between manufacturers.

APPENDIX B

MECHANICAL CHARACTERISTICS OF STEEL TUBING

Nominal Tube OD (in)	External Surface per Ft of Tube (ft ²)	Nominal Thick- ness (in)	Nominal Tube ID (in)	Internal Area (in ²)	Ratio OD/ID	Constant C*	Wt/Ft (Steel) (lbm/ft)	Transverse Metal Area (in ²)	Moment of Inertia (in ⁴)
5/8	.1636	.150	.325	.0830	1.923	129.	.762	.2238	.006942
		.135	.355	.0990	1.761	154.	.707	.2078	.006711
		.125	.375	.1104	1.667	172.	.668	.1963	.006519
		.110	.405	.1288	1.543	201.	.606	.1780	.006169
		.105	.415	.1353	1.506	211.	.584	.1715	.006034
		.095	.435	.1486	1.437	232.	.538	.1582	.005733
		.085	.455	.1626	1.374	254.	.491	.1442	.005386
		.075	.475	.1772	1.316	276.	.441	.1296	.004991
		.065	.495	.1924	1.263	300.	.389	.1144	.004543
		.060	.505	.2003	1.238	312.	.362	.1065	.004298
		.055	.515	.2083	1.214	325.	.335	.0985	.004037
		.050	.525	.2165	1.190	338.	.307	.0903	.003761
3/4	.1963	.150	.450	.1590	1.667	248.	.962	.2827	.013519
		.135	.480	.1810	1.562	282.	.888	.2608	.012926
		.125	.500	.1963	1.500	306.	.835	.2454	.012464
		.110	.530	.2206	1.415	344.	.753	.2212	.011658
		.105	.540	.2290	1.389	357.	.724	.2128	.011358
		.095	.560	.2463	1.339	384.	.665	.1955	.010704
		.085	.580	.2642	1.293	412.	.604	.1776	.009977
		.075	.600	.2827	1.250	441.	.541	.1590	.009170
		.065	.620	.3019	1.210	471.	.476	.1399	.008278
		.060	.630	.3117	1.190	486.	.443	.1301	.007799
		.055	.640	.3217	1.172	502.	.409	.1201	.007296
		.050	.650	.3318	1.154	518.	.374	.1100	.006769
7/8	.2291	.150	.575	.2597	1.522	405.	1.163	.3416	.023408
		.135	.605	.2875	1.446	448.	1.068	.3138	.022198
		.125	.625	.3068	1.400	479.	1.002	.2945	.021284
		.110	.655	.3370	1.336	526.	.900	.2644	.019739
		.105	.665	.3473	1.316	542.	.864	.2540	.019174
		.095	.685	.3685	1.277	575.	.792	.2328	.017966
		.085	.705	.3904	1.241	609.	.718	.2110	.016648
		.075	.725	.4128	1.207	644.	.641	.1885	.015212
		.065	.745	.4359	1.174	680.	.563	.1654	.013653
		.060	.755	.4477	1.159	698.	.523	.1536	.012824
		.055	.765	.4596	1.144	717.	.482	.1417	.011962
		.050	.775	.4717	1.129	736.	.441	.1296	.011066
1	.2618	.150	.700	.3848	1.429	600.	1.363	.4006	.037301
		.135	.730	.4185	1.370	653.	1.248	.3669	.035147
		.125	.750	.4418	1.333	689.	1.169	.3436	.033556
		.110	.780	.4778	1.282	745.	1.047	.3076	.030918
		.105	.790	.4902	1.266	765.	1.005	.2952	.029968
		.095	.810	.5153	1.235	804.	.919	.2701	.027957
		.085	.830	.5411	1.205	844.	.831	.2443	.025791
		.075	.850	.5674	1.176	885.	.742	.2179	.023463
		.065	.870	.5945	1.149	927.	.650	.1909	.020965
		.060	.880	.6082	1.136	949.	.603	.1772	.019650
		.055	.890	.6221	1.124	970.	.556	.1633	.018289
		.050	.900	.6362	1.111	992.	.508	.1492	.016881

*Liquid velocity in feet/second = $\frac{\text{pounds per tube per hour}}{C \times \text{specific gravity of liquid}}$ Specific gravity of water at 60 deg. F = 1.0

APPENDIX C MECHANICAL CHARACTERISTICS OF TUBING

Tube OD (in)	Nominal Surface per Ft. of Tube (ft ²)	External BWG Gauge	Thick-ness (in)	Nominal Tube ID (in)	Nominal Internal Area (in ²)	Ratio OD/ID	Constant C°	Wt/Ft (Steel) (lbm/ft)	Trans-verse Metal Area (in ²)	Moment of Inertia (in ⁴)
3/8	.0982	10	.134	.107	.0090	3.505	14.	.345	.1015	.000964
		11	.120	.135	.0143	2.778	22.	.327	.0961	.000954
		12	.109	.157	.0194	2.389	30.	.310	.0911	.000941
		13	.095	.185	.0269	2.027	42.	.284	.0836	.000913
		14	.083	.209	.0343	1.794	54.	.259	.0761	.000877
		15	.072	.231	.0419	1.623	65.	.233	.0685	.000831
		16	.065	.245	.0471	1.531	74.	.216	.0633	.000794
		17	.058	.259	.0527	1.448	82.	.197	.0578	.000750
		18	.049	.277	.0603	1.354	94.	.171	.0502	.000682
		19	.042	.291	.0665	1.289	104.	.150	.0439	.000619
		20	.035	.305	.0731	1.230	114.	.127	.0374	.000546
		21	.032	.311	.0760	1.206	119.	.117	.0345	.000512
		22	.028	.319	.0799	1.176	125.	.104	.0305	.000462
		23	.025	.325	.0830	1.154	129.	.093	.0275	.000431
		24	.022	.331	.0860	1.133	134.	.083	.0244	.000389
		25	.020	.335	.0881	1.119	137.	.076	.0223	.000359
1/2	.1309	10	.134	.232	.0423	2.155	66.	.524	.1541	.002926
		11	.120	.260	.0531	1.923	83.	.487	.1433	.002844
		12	.109	.282	.0625	1.773	97.	.456	.1339	.002758
		13	.095	.310	.0755	1.613	118.	.411	.1209	.002615
		14	.083	.334	.0876	1.497	137.	.370	.1087	.002457
		15	.072	.356	.0995	1.404	155.	.329	.0968	.002280
		16	.065	.370	.1075	1.351	168.	.302	.0888	.002148
		17	.058	.384	.1158	1.302	181.	.274	.0805	.002001
		18	.049	.402	.1269	1.244	198.	.236	.0694	.001786
		19	.042	.416	.1359	1.202	212.	.206	.0604	.001598
		20	.035	.430	.1452	1.163	227.	.174	.0511	.001390
		21	.032	.436	.1493	1.147	233.	.160	.0470	.001294
		22	.028	.444	.1548	1.126	242.	.141	.0415	.001160
		23	.025	.450	.1590	1.111	248.	.127	.0373	.001075
		24	.022	.456	.1633	1.096	255.	.112	.0330	.000963
		25	.020	.460	.1662	1.087	259.	.103	.0302	.000886

*Liquid velocity in feet/second = $\frac{\text{pounds per tube per hour}}{C \times \text{specific gravity of liquid}}$ Specific gravity of water at 60 deg. F = 1.0

For weights of other materials, multiply carbon steel weights by the following factors:

90-10 CuNi UNS C70600-1.140
70-30 CuNi UNS C71500-1.140
Arsenical Cu UNS C14200-1.140
Admiralty UNS C444300-1.088
Muntz UNS C28000-1.088
Al Brass UNS C68700-1.060

Al Bronze UNS C60800-1.042
Copper Iron UNS C19400-1.119
300 Series Stainless Steel-1.013
Titanium per ASTM B338-.573

APPENDIX C (cont'd) MECHANICAL CHARACTERISTICS OF TUBING

Nominal Tube OD (in)	External Surface per Ft. of Tube (ft ²)	BWG Gauge	Nominal Thick- ness (in)	Nominal Tube ID (in)	Internal Area (in ²)	Ratio OD/ID	Constant C*	Wt/Ft (Steel) (lbm/ft)	Trans- verse Metal Area (in ²)	Moment of Inertia (in ⁴)
5/8	.1636	10	.134	.357	.1001	1.751	156.	.703	.2067	.006693
		11	.120	.385	.1164	1.623	182.	.648	.1904	.006412
		12	.109	.407	.1301	1.536	203.	.601	.1767	.006143
		13	.095	.435	.1486	1.437	232.	.538	.1582	.005733
		14	.083	.459	.1655	1.362	258.	.481	.1413	.005311
		15	.072	.481	.1817	1.299	283.	.426	.1251	.004863
		16	.065	.495	.1924	1.263	300.	.389	.1144	.004543
		17	.058	.509	.2035	1.228	317.	.352	.1033	.004195
		18	.049	.527	.2181	1.186	340.	.302	.0887	.003704
		19	.042	.541	.2299	1.155	359.	.262	.0769	.003285
		20	.035	.555	.2419	1.125	377.	.221	.0649	.002833
		21	.032	.561	.2472	1.114	386.	.203	.0596	.002528
		22	.028	.569	.2543	1.098	397.	.179	.0525	.002345
		23	.025	.575	.2597	1.087	405.	.160	.0471	.002164
		24	.022	.581	.2651	1.076	414.	.142	.0417	.001932
		25	.020	.585	.2688	1.068	419.	.129	.0380	.001773
3/4	.1963	10	.134	.482	.1825	1.556	285.	.882	.2593	.012882
		11	.120	.510	.2043	1.471	319.	.808	.2375	.012211
		12	.109	.532	.2223	1.410	347.	.747	.2195	.011600
		13	.095	.560	.2463	1.339	384.	.655	.1955	.010704
		14	.083	.584	.2679	1.284	418.	.592	.1739	.009822
		15	.072	.606	.2884	1.238	450.	.522	.1534	.008912
		16	.065	.620	.3019	1.210	471.	.476	.1399	.008278
		17	.058	.634	.3157	1.183	492.	.429	.1261	.007601
		18	.049	.652	.3339	1.150	521.	.367	.1079	.006661
		19	.042	.666	.3484	1.126	543.	.318	.0934	.005874
		20	.035	.680	.3632	1.103	567.	.268	.0786	.005036
		21	.032	.686	.3696	1.093	577.	.246	.0722	.004661
		22	.028	.694	.3783	1.081	590.	.216	.0635	.004145
		23	.025	.700	.3848	1.071	600.	.194	.0569	.003815
		24	.022	.706	.3915	1.062	611.	.171	.0503	.003398
		25	.020	.710	.3959	1.056	618.	.156	.0459	.003114
7/8	.2291	10	.134	.607	.2894	1.442	451.	1.061	.3119	.022110
		11	.120	.635	.3167	1.378	494.	.969	.2846	.020793
		12	.109	.657	.3390	1.332	529.	.893	.2623	.019628
		13	.095	.685	.3685	1.277	575.	.792	.2328	.017966
		14	.083	.709	.3948	1.234	616.	.703	.2065	.016370
		15	.072	.731	.4197	1.197	655.	.618	.1816	.014758
		16	.065	.745	.4359	1.174	680.	.563	.1654	.013653
		17	.058	.759	.4525	1.153	706.	.507	.1489	.012484
		18	.049	.777	.4742	1.126	740.	.433	.1272	.010882
		19	.042	.791	.4914	1.106	767.	.374	.1099	.009558
		20	.035	.805	.5090	1.087	794.	.314	.0924	.008161
		21	.032	.811	.5166	1.079	806.	.288	.0847	.007539
		22	.028	.819	.5268	1.068	822.	.254	.0745	.006689
		23	.025	.825	.5346	1.061	834.	.227	.0668	.006147
		24	.022	.831	.5424	1.053	846.	.201	.0590	.005465
		25	.020	.835	.5476	1.048	854.	.183	.0537	.005003

*Liquid velocity in feet/second = $\frac{\text{pounds per tube per hour}}{C \times \text{specific gravity of liquid}}$ Specific gravity of water at 60 deg. F = 1.0

APPENDIX C (cont'd) MECHANICAL CHARACTERISTICS OF TUBING

Nominal Tube OD (in)	External Surface per Ft. of Tube (ft ²)	BWG Gauge	Nominal Thick- ness (in)	Nominal Tube ID (in)	Internal Area (in ²)	Ratio OD/ID	Constant C*	Wt/Ft (Steel) (lbm/ft)	Trans- verse Metal Area (in ²)	Moment of Inertia (in ⁴)
1	.2618	10	.134	.732	.4208	1.366	657.	1.241	.3646	.034994
		11	.120	.760	.4536	1.316	708.	1.129	.3318	.032711
		12	.109	.782	.4803	1.279	749.	1.038	.3051	.030731
		13	.095	.810	.5153	1.235	804.	.919	.2701	.027957
		14	.083	.834	.5463	1.199	852.	.814	.2391	.025339
		15	.072	.856	.5755	1.168	898.	.714	.2099	.022732
		16	.065	.870	.5945	1.149	927.	.650	.1909	.020965
		17	.058	.884	.6138	1.131	957.	.584	.1716	.019111
		18	.049	.902	.6390	1.109	997.	.498	.1464	.016594
		19	.042	.916	.6590	1.092	1028.	.430	.1264	.014529
		20	.035	.930	.6793	1.075	1060.	.361	.1061	.012367
		21	.032	.936	.6881	1.068	1073.	.331	.0973	.011411
		22	.028	.944	.6999	1.059	1092.	.291	.0855	.010106
		23	.025	.950	.7088	1.053	1106.	.260	.0766	.009275
		24	.022	.956	.7178	1.046	1120.	.230	.0676	.008236
		25	.020	.960	.7238	1.042	1129.	.209	.0616	.007533
1 1/8	.2945	10	.134	.857	.5768	1.313	900.	1.420	.4172	.052150
		11	.120	.885	.6151	1.271	960.	1.289	.3789	.048516
		12	.109	.907	.6461	1.240	1008.	1.184	.3479	.045409
		13	.095	.935	.6866	1.203	1071.	1.046	.3074	.041113
		14	.083	.959	.7223	1.173	1127.	.925	.2717	.037110
		15	.072	.981	.7558	1.147	1179.	.811	.2382	.033167
		16	.065	.995	.7776	1.131	1213.	.737	.2165	.030516
		17	.058	1.009	.7996	1.115	1247.	.662	.1944	.027750
		18	.049	1.027	.8284	1.095	1292.	.564	.1656	.024021
		19	.042	1.041	.8511	1.081	1328.	.486	.1429	.020982
		20	.035	1.005	.8742	1.066	1364.	.408	.1199	.017818
		21	.032	1.061	.8841	1.060	1379.	.374	.1099	.016423
		22	.028	1.069	.8975	1.052	1400.	.328	.0965	.014525
		23	.025	1.075	.9076	1.047	1416.	.294	.0864	.013317
		24	.022	1.081	.9178	1.041	1431.	.259	.0762	.011814
		25	.020	1.085	.9246	1.037	1442.	.236	.0694	.010797
1 1/4	.3272	10	.134	.982	.7574	1.273	1182.	1.599	.4698	.074195
		11	.120	1.010	.8012	1.238	1250.	1.450	.4260	.068762
		12	.109	1.032	.8365	1.211	1305.	1.330	.3907	.064164
		13	.095	1.060	.8825	1.179	1377.	1.173	.3447	.057871
		14	.083	1.084	.9229	1.153	1440.	1.035	.3043	.052064
		15	.072	1.106	.9607	1.130	1499.	.907	.2665	.046392
		16	.065	1.120	.9852	1.116	1537.	.823	.2420	.042602
		17	.058	1.134	1.0100	1.102	1576.	.739	.2172	.038667
		18	.049	1.152	1.0423	1.085	1626.	.629	.1849	.033389
		19	.042	1.166	1.0678	1.072	1666.	.542	.1594	.029110
		20	.035	1.180	1.0936	1.059	1706.	.455	.1336	.024673
		21	.032	1.186	1.1047	1.054	1723.	.417	.1224	.022722
		22	.028	1.194	1.1197	1.047	1747.	.366	.1075	.020075
		23	.025	1.200	1.1310	1.042	1764.	.327	.0962	.018390
		24	.022	1.206	1.1423	1.036	1782.	.289	.0849	.016301
		25	.020	1.210	1.1499	1.033	1794.	.263	.0773	.014891

*Liquid velocity in feet/second = $\frac{\text{pounds per tube per hour}}{C \times \text{specific gravity of liquid}}$ Specific gravity of water at 60 deg. F = 1.0

APPENDIX C (cont'd) MECHANICAL CHARACTERISTICS OF TUBING

Nominal Tube OD (in)	External Surface per Ft. of Tube (ft ²)	BWG Gauge	Nominal Thick- ness (in)	Nominal Tube ID (in)	Internal Area (in ²)	Ratio OD/ID	Constant C*	Wt/Ft (Steel) (lbm/ft)	Trans- verse Metal Area (in ²)	Moment of Inertia (in ⁴)
1½	.3927	10	.134	1.232	1.1921	1.218	1860.	1.957	.5750	.135418
		11	.120	1.260	1.2469	1.190	1945.	1.770	.5202	.124781
		12	.109	1.282	1.2908	1.170	2014.	1.621	.4763	.115911
		13	.095	1.310	1.3478	1.145	2103.	1.427	.4193	.103943
		14	.083	1.334	1.3977	1.124	2180.	1.257	.3695	.093054
		15	.072	1.356	1.4441	1.106	2253.	1.099	.3230	.082543
		16	.065	1.370	1.4741	1.095	2300.	.997	.2930	.075582
		17	.058	1.384	1.5044	1.084	2347.	.894	.2628	.068405
		18	.049	1.402	1.5438	1.070	2408.	.760	.2234	.058851
		19	.042	1.416	1.5748	1.059	2457.	.655	.1924	.051161
		20	.035	1.430	1.6061	1.049	2505.	.548	.1476	.043240
		21	.032	1.436	1.6196	1.045	2527.	.502	.1611	.039774
		22	.028	1.444	1.6377	1.039	2555.	.441	.1295	.035083
		23	.025	1.450	1.6513	1.034	2576.	.394	.1158	.032100
		24	.022	1.456	1.6650	1.030	2597.	.347	.1022	.028419
		25	.020	1.460	1.6742	1.027	2611.	.316	.0930	.025939
2	.5236	10	.134	1.732	2.3561	1.155	3675.	2.673	.7855	.343663
		11	.120	1.760	2.4328	1.136	3795.	2.412	.7087	.314398
		12	.109	1.782	2.4940	1.122	3891.	2.203	.6475	.290403
		13	.095	1.810	2.5730	1.105	4014.	1.935	.5685	.258551
		14	.083	1.834	2.6417	1.091	4121.	1.701	.4999	.230047
		15	.072	1.856	2.7055	1.078	4221.	1.484	.4361	.202917
		16	.065	1.870	2.7465	1.070	4284.	1.345	.3951	.185142
		17	.058	1.884	2.7877	1.062	4349.	1.204	.3539	.166964
		18	.049	1.902	2.8413	1.052	4432.	1.022	.3003	.142989
		19	.042	1.916	2.8832	1.044	4498.	.879	.2584	.123865
		20	.035	1.930	2.9255	1.036	4564.	.735	.2161	.104317
		21	.032	1.936	2.9437	1.033	4592.	.673	.1978	.095808
		22	.028	1.944	2.9681	1.029	4630.	.590	.1735	.084339
		23	.025	1.950	2.9865	1.026	4658.	.528	.1551	.077050
		24	.022	1.956	3.0049	1.022	4687.	.465	.1367	.068111
		25	.020	1.960	3.0172	1.020	4706.	.423	.1244	.062105

*Liquid velocity in feet/second = $\frac{\text{pounds per tube per hour}}{C \times \text{specific gravity of liquid}}$ Specific gravity of water at 60 deg. F = 1.0

APPENDIX D **METRIC CONVERSION FACTORS** **NOMENCLATURE**

NAME		SYMBOL	OTHER UNITS
inch/inches		in	
foot/feet		ft	
meter	(SI)	m	
millimeter		mm	
square inch		in ²	
square foot		ft ²	
square meter	(SI)	m ²	
square centimeter		cm ²	
square millimeter		mm ²	
cubic inch		in ³	
cubic foot		ft ³	
gallon (US liquid)		gal	
cubic meter	(SI)	m ³	
liter		L	
pound mass (avoirdupois)		lbm	
kilogram	(SI)	kg	
pound force (avoirdupois)		lbf	
kilogram force		kgf	
newton	(SI)	N	m · kg/s ²
degree Fahrenheit		°F	
kelvin	(SI)	K	
degree Celsius	(SI)	°C	
British thermal unit (International Table)		Btu	
kilocalorie (International Table)		kcal	
joule	(SI)	J	N · m, m ² · kg/s ²
kilojoule		kJ	
second (customary)		sec	
second	(SI)	s	
minute		min	
hour (customary)		hr	
hour (metric)		h	
watt	(SI)	W	J/s, N · m/s, m ² · kg/s ³
pound force/square inch		psi	lbf/in ²
inches of mercury		in Hg	
feet of water		ft H ₂ O	
pascal	(SI)	Pa	N/m ² , kg/(m · s ²)
kilopascal		kPa	
bar		bar	
millimeter of mercury		mmHg	
torr		torr	
centipoise		cp	

Notes:

1. (SI) Denotes an "International System of Units" unit.
2. Pressure should always be designated as gage or absolute.
3. The acceleration of gravity, *g*, is taken as 9.80665 m/s².
4. One gallon (U S liquid) equals 231 in³

APPENDIX D (cont'd)

PREFIXES DENOTING DECIMAL MULTIPLES OR SUBMULTIPLES

PREFIX	SYMBOL	MULTIPLICATION FACTOR
micro	μ	0.000 001 = 10^{-6}
milli	m	0.001 = 10^{-3}
centi	c	0.01 = 10^{-2}
deci	d	0.1 = 10^{-1}
deca	da	10 = 10^1
hecto	h	100 = 10^2
kilo	k	1 000 = 10^3
mega	M	1 000 000 = 10^6
giga	G	1 000 000 000 = 10^9

CONVERSION FACTORS

LENGTH

MULTIPLY	BY	TO OBTAIN
in	2.540 $\times 10^{-2}$	m (SI)
in	2.540 $\times 10^1$	mm
ft	3.048 $\times 10^{-1}$	m (SI)
ft	3.048 $\times 10^2$	mm

AREA

MULTIPLY	BY	TO OBTAIN
in ²	6.451600 $\times 10^{-4}$	m ² (SI)
in ²	6.451600 $\times 10^2$	mm ²
ft ²	9.290304 $\times 10^{-2}$	m ² (SI)
ft ²	9.290304 $\times 10^4$	mm ²

VOLUME

MULTIPLY	BY	TO OBTAIN
in ³	1.638706 $\times 10^{-5}$	m ³ (SI)
in ³	1.638706 $\times 10^{-2}$	L
ft ³	2.831685 $\times 10^{-2}$	m ³ (SI)
ft ³	2.831685 $\times 10^1$	L
gal	3.785412 $\times 10^{-3}$	m ³ (SI)
gal	3.785412	L

MASS

MULTIPLY	BY	TO OBTAIN
lbm	4.535924 $\times 10^{-1}$	kg (SI)

FORCE

MULTIPLY	BY	TO OBTAIN
lbf	4.448222	N (SI)
lbf	4.535924 $\times 10^{-1}$	kgf
kgf	9.806650	N (SI)

TEMPERATURE

$$K = (^{\circ}F + 459.67)/1.8 \quad (SI)$$

$$^{\circ}C = (^{\circ}F - 32)/1.8 \quad (SI)$$

$$^{\circ}F = 1.8 K - 459.67$$

$$^{\circ}F = 1.8 ^{\circ}C + 32$$

ENERGY, WORK OR QUANTITY OF HEAT

MULTIPLY	BY	TO OBTAIN
Btu	1.055056 $\times 10^3$	J (SI)
Btu	2.519958 $\times 10^{-1}$	kcal
ft·lbf	1.355818	J (SI)
ft·lbf	3.238316 $\times 10^{-4}$	kcal

APPENDIX D (cont'd)**POWER (ENERGY/TIME)**

MULTIPLY	BY	TO OBTAIN	
Btu/hr	2.930711×10^{-1}	W	(SI)

PRESSURE OR STRESS (FORCE/AREA)

MULTIPLY	BY	TO OBTAIN	
psi	6.894757×10^3	Pa	(SI)
psi	6.894757	kPa	
psi	6.894757×10^{-2}	bar	
psi	7.030696×10^{-2}	kgf/cm ²	
lbf/ft ²	4.788026×10^1	Pa	(SI)
lbf/ft ²	4.788026×10^{-2}	kPa	
lbf/ft ²	4.882428	kgf/m ²	
inHg (32°F)	3.38638×10^3	Pa	(SI)
inHg (32°F)	3.38638	kPa	
inHg (32°F)	3.38638×10^{-2}	bar	
inHg (32°F)	3.45315×10^{-2}	kgf/cm ²	
inHg (32°F)	2.540×10^1	mmHg	
torr (0°C)	1.33322×10^2	Pa	(SI)
torr (0°C)	1.0	mmHg	
ftH ₂ O (39.2°F)	2.98898×10^3	Pa	(SI)
ftH ₂ O (39.2°F)	2.98898	kPa	
ftH ₂ O (39.2°F)	3.047915×10^2	kgf/m ²	

VELOCITY (LENGTH/TIME)

MULTIPLY	BY	TO OBTAIN	
ft/sec	3.048000×10^{-1}	m/s	(SI)
ft/min	5.080000×10^{-3}	m/s	(SI)

MASS FLOW RATE (MASS/TIME)

MULTIPLY	BY	TO OBTAIN	
lbm/hr	1.259979×10^{-4}	kg/s	(SI)
lbm/hr	4.535924×10^{-1}	kg/h	

VOLUME FLOW RATE (VOLUME/TIME)

MULTIPLY	BY	TO OBTAIN	
ft ³ /min	4.719474×10^{-4}	m ³ /s	(SI)
ft ³ /min	1.699011	m ³ /h	
gal/min	6.309020×10^{-5}	m ³ /s	(SI)
gal/min	2.271247×10^{-1}	m ³ /h	
gal/min	3.785412	L/min	

MASS VELOCITY (MASS/TIME-AREA)

MULTIPLY	BY	TO OBTAIN	
lbm/(hr · ft ²)	1.35623×10^{-3}	kg/(s · m ²)	(SI)
lbm/(hr · ft ²)	4.882428	kg/(h · m ²)	
lbm/(sec · ft ²)	4.882428	kg/(s · m ²)	(SI)

SPECIFIC VOLUME (VOLUME/MASS)

MULTIPLY	BY	TO OBTAIN	
ft ³ /lbm	6.242797×10^{-2}	m ³ /kg	(SI)
ft ³ /lbm	6.242797×10^1	L/kg	
gal/lbm	8.345406×10^{-3}	m ³ /kg	(SI)
gal/lbm	8.345406	L/kg	

APPENDIX D (cont'd)**DENSITY (MASS/VOLUME)**

MULTIPLY	BY	TO OBTAIN	
lbm/in ³	2.767990×10^4	kg/m ³	(SI)
lbm/in ³	2.767990×10^1	kg/L	
lbm/ft ³	1.601846×10^1	kg/m ³	(SI)
lbm/ft ³	1.601846×10^{-2}	kg/L	
lbm/gal	1.198264×10^2	kg/m ³	(SI)
lbm/gal	1.198264×10^{-1}	kg/L	

ENTHALPY (ENERGY/MASS)

MULTIPLY	BY	TO OBTAIN	
Btu/lbm	2.326000×10^3	J/kg	(SI)
Btu/lbm	2.326000	kJ/kg	
Btu/lbm	5.555556×10^{-1}	kcal/kg	

HEAT CAPACITY AND ENTROPY (ENERGY/MASS-TEMPERATURE)

MULTIPLY	BY	TO OBTAIN	
Btu/(lbm · °F)	4.186800×10^3	J/(kg · K)	(SI)
Btu/(lbm · °F)	4.186800	kJ/(kg · K)	
Btu/(lbm · °F)	1.000000	kcal/(kg · °C)	

THERMAL CONDUCTIVITY (ENERGY-LENGTH/TIME-AREA-TEMPERATURE)

MULTIPLY	BY	TO OBTAIN	
Btu · in/(hr · ft ² · °F)	1.442279×10^{-1}	W/(m · K)	(SI)
Btu · in/(hr · ft ² · °F)	1.240137×10^{-1}	kcal · m/(h · m ² · K)	
Btu · ft/(hr · ft ² · °F)	1.730735	W/(m · K)	(SI)
Btu · ft/(hr · ft ² · °F)	1.488164	kcal · m/(h · m ² · K)	

DYNAMIC VISCOSITY (MASS/TIME-LENGTH OR FORCE-TIME/AREA)

MULTIPLY	BY	TO OBTAIN	
cp	1.000000×10^{-3}	Pa · s	(SI)
lbm/(hr · ft)	4.133789×10^{-4}	Pa · s	(SI)
lbm/(hr · ft)	4.133789×10^{-1}	cp	
lbm/(sec · ft)	1.488164	Pa · s	(SI)
lbm/(sec · ft)	1.488164×10^3	cp	
lbf · sec/ft ²	4.788026×10^1	Pa · s	(SI)
lbf · sec/ft ²	4.788026×10^4	cp	

HEAT FLUX DENSITY (ENERGY/TIME-AREA)

MULTIPLY	BY	TO OBTAIN	
Btu/(hr · °ft ²)	3.154591	W/m ²	(SI)
Btu/(hr · °ft ²)	2.712460	kcal/(h · m ²)	

HEAT TRANSFER COEFFICIENT (ENERGY/TIME-AREA-TEMPERATURE)

MULTIPLY	BY	TO OBTAIN	
Btu/(hr · ft ² · °F)	5.678263	W/(m ² · K)	(SI)
Btu/(hr · ft ² · °F)	4.882428	kcal/(h · m ² · K)	

FOULING RESISTANCE (TIME-AREA-TEMPERATURE/ENERGY)

MULTIPLY	BY	TO OBTAIN	
hr · ft ² · °F/Btu	1.761102×10^{-1}	m ² · K/W	(SI)
hr · ft ² · °F/Btu	2.048161×10^{-1}	h · m ² · K/kcal	

APPENDIX E

PIPE FLANGES AND FLANGED FITTINGS

TABLE 1A LIST OF MATERIAL SPECIFICATIONS

Material Group	Nominal Designation	Pressure-Temperature Rating Table	Applicable ASTM Specifications ¹		
			Forgings	Castings	Plates
1.1	C-Si C-Mn-Si C-Mn-Si-V	2-1.1	A 105 A 350 Gr. LF2 A 350 Gr. LF6 Cl. 1	A 216 Gr. WCB	A 515 Gr. 70 A 516 Gr. 70 A 537 Cl. 1
1.2	C-Mn-Si C-Mn-Si-V 2½Ni 3½Ni	2-1.2	 A 350 Gr. LF6 Cl. 2 A 350 Gr. LF3	A 216 Gr. WCC A 352 Gr. LCC A 352 Gr. LC2 A 352 Gr. LC3	 A 203 Gr. B A 203 Gr. E
1.3	C-Si C-Mn-Si 2½Ni 3½Ni	2-1.3		A 352 Gr. LCB	A 515 Gr. 65 A 516 Gr. 65 A 203 Gr. A A 203 Gr. D
1.4	C-Si C-Mn-Si	2-1.4	A 350 Gr. LF1 Cl. 1		A 515 Gr. 60 A 516 Gr. 60
1.5	C-½Mo	2-1.5	A 182 Gr. F1	A 217 Gr. WC1 A 352 Gr. LC1	A 204 Gr. A A 204 Gr. B
1.7	C-½Mo ½Cr-½Mo Ni-½Cr-½Mo ¾Ni-¾Cr-1Mo	2-1.7	A 182 Gr. F2	 A 217 Gr. WC4 A 217 Gr. WC5	A 204 Gr. C
1.9	1Cr-½Mo 1½Cr-½Mo 1½Cr-½Mo-Si	2-1.9	A 182 Gr. F12 Cl. 2 A 182 Gr. F11 Cl. 2	A 217 Gr. WC6	A 387 Gr. 11 Cl. 2
1.10	2¼Cr-1Mo	2-1.10	A 182 Gr. F22 Cl. 3	A 217 Gr. WC9	A 387 Gr. 22 Cl. 2
1.13	5Cr-½Mo	2-1.13	A 182 Gr. F5 A 182 Gr. F5a	A 217 Gr. C5	
1.14	9Cr-1Mo	2-1.14	A 182 Gr. F9	A 217 Gr. C12	
1.15	9Cr-1Mo-V	2-1.15	A 182 Gr. F91	A 217 Gr. C12A	A 387 Gr. 91 Cl. 2
2.1	18Cr-8Ni	2-2.1	A 182 Gr. F304 A 182 Gr. F304H	A 351 Gr. CF3 A 351 Gr. CF8	A 240 Gr. 304 A 240 Gr. 304H
2.2	16Cr-12Ni-2Mo 18Cr-13Ni-3Mo 19Cr-10Ni-3Mo	2-2.2	A 182 Gr. F316 A 182 Gr. F316H	A 351 Gr. CF3M A 351 Gr. CF8M A 351 Gr. CG8M	A 240 Gr. 316 A 240 Gr. 316H A 240 Gr. 317
2.3	18Cr-8Ni 16Cr-12Ni-2Mo	2-2.3	A 182 Gr. F304L A 182 Gr. F316L		A 240 Gr. 304L A 240 Gr. 316L
2.4	18Cr-10Ni-Ti	2-2.4	A 182 Gr. F321 A 182 Gr. F321H		A 240 Gr. 321 A 240 Gr. 321H

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 1A LIST OF MATERIAL SPECIFICATIONS (CONT'D)

Material Group	Nominal Designation	Pressure-Temperature Rating Table	Applicable ASTM Specifications ¹		
			Forgings	Castings	Plates
2.5	18Cr-10Ni-Cb	2-2.5	A 182 Gr. F347 A 182 Gr. F347H A 182 Gr. F348 A 182 Gr. F348H	A 351 Gr. CF8C	A 240 Gr. 347 A 240 Gr. 347H A 240 Gr. 348 A 240 Gr. 348H
2.6	25Cr-12Ni 23Cr-12Ni	2-2.6		A 351 Gr. CH8 A 351 Gr. CH20	A 240 Gr. 309S A 240 Gr. 309H
2.7	25Cr-20Ni	2-2.7	A 182 Gr. F310	A 351 Gr. CK20	A 240 Gr. 310S A 240 Gr. 310H
2.8	20Cr-18Ni-6Mo 22Cr-5Ni-3Mo-N 25Cr-7Ni-4Mo-N 24Cr-10Ni-4Mo-V 25Cr-5Ni-2Mo-3Cu 25Cr-7Ni-3.5Mo-W-Cb 25Cr-7Ni-3.5Mo-N-Cu-W	2-2.8	A 182 Gr. F44 A 182 Gr. F51 A 182 Gr. F53 A 182 Gr. F55	A 351 Gr. CK3MCuN A 351 Gr. CE8MN A 351 Gr. CD4MCu A 351 Gr. CD3MWCuN	A 240 Gr. S31254 A 240 Gr. S31803 A 240 Gr. S32750 A 240 Gr. S32760
3.1	35Ni-35Fe-20Cr-Cb	2-3.1	B 462 Gr. N08020		B 463 Gr. N08020
3.2	99.0Ni	2-3.2	B 160 Gr. N02200		B 162 Gr. N02200
3.3	99.0Ni-Low C	2-3.3	B 160 Gr. N02201		B 162 Gr. N02201
3.4	67Ni-30Cu 67Ni-30Cu-S	2-3.4	B 564 Gr. N04400 B 164 Gr. N04405		B 127 Gr. N04400
3.5	72Ni-15Cr-8Fe	2-3.5	B 564 Gr. N06600		B 168 Gr. N06600
3.6	33Ni-42Fe-21Cr	2-3.6	B 564 Gr. N08800		B 409 Gr. N08800
3.7	65Ni-28Mo-2Fe	2-3.7	B 335 Gr. N10665		B 333 Gr. N10665
3.8	54Ni-16Mo-15Cr 60Ni-22Cr-9Mo-3.5Cb 62Ni-28Mo-5Fe 70Ni-16Mo-7Cr-5Fe 61Ni-16Mo-16Cr 42Ni-21.5Cr-3Mo-2.3Cu	2-3.8	B 564 Gr. N10276 B 564 Gr. N06625 B 335 Gr. N10001 B 573 Gr. N10003 B 574 Gr. N06455 B 564 Gr. N08825		B 575 Gr. N10276 B 443 Gr. N06625 B 333 Gr. N10001 B 434 Gr. N10003 B 575 Gr. N06455 B 424 Gr. N08825
3.9	47Ni-22Cr-9Mo-18Fe	2-3.9	B 572 Gr. N06002		B 435 Gr. N06002
3.10	25Ni-46Fe-21Cr-5Mo	2-3.10	B 672 Gr. N08700		B 599 Gr. N08700
3.11	44Fe-25Ni-21Cr-Mo	2-3.11	B 649 Gr. N08904		B 625 Gr. N08904
3.12	26Ni-43Fe-22Cr-5Mo 47Ni-22Cr-20Fe-7Mo	2-3.12	B 621 Gr. N08320 B 581 Gr. N06985		B 620 Gr. N08320 B 582 Gr. N06985

(Table 1A continues on next page; Notes follow at end of Table)

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 1A LIST OF MATERIAL SPECIFICATIONS (CONT'D)

Material Group	Nominal Designation	Pressure-Temperature Rating Table	Applicable ASTM Specifications ¹		
			Forgings	Castings	Plates
3.13	49Ni-25Cr-18Fe-6Mo Ni-Fe-Cr-Mo-Low Cu	2-3.13	B 581 Gr. N06975 B 564 Gr. N08031		B 582 Gr. N06975 B 625 Gr. N08031
3.14	47Ni-22Cr-19Fe-6Mo	2-3.14	B 581 Gr. N06007		B 582 Gr. N06007
3.15	33Ni-42Fe-21Cr	2-3.15	B 564 Gr. N08810		B 409 Gr. N08810
3.16	35Ni-19Cr-1¼Si	2-3.16	B 511 Gr. N08330		B 536 Gr. N08330
3.17	29Ni-20.5Cr-3.5Cu-2.5Mo	2-3.17		A 351 Gr. CN7M	

GENERAL NOTES:

(a) For temperature limitations, see Notes in Table 2.

(b) Plate materials are listed only for use as blind flanges (see para. 5.1). Additional plate materials listed in ASME B16.34 may also be used with corresponding B16.34 Standard Class ratings.

(c) Material Groups not listed in Table 1A are intended for use in valves. See ASME B16.34.

NOTE:

(1) ASME Boiler and Pressure Vessel Code, Section II materials, which also meet the requirements of the listed ASTM specifications, may also be used.

APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 1B LIST OF BOLTING SPECIFICATIONS
Applicable ASTM Specifications¹⁵

Bolting Materials [Note (1)]											
High Strength [Note (2)]			Intermediate Strength [Note (3)]			Low Strength [Note (4)]			Nickel and Special Alloy [Note (5)]		
Spec. No.	Grade	Notes	Spec. No.	Grade	Notes	Spec. No.	Grade	Notes	Spec. No.	Grade	Notes
A 193	B7	...	A 193	B5	...	A 193	B8 Cl.1	(6)	B 164	...	(7)(8)(9)
A 193	B16	...	A 193	B6	...	A 193	B8C Cl.1	(6)			
			A 193	B6X	...	A 193	B8M Cl.1	(6)	B 166	...	(7)(8)(9)
A 320	L7	(10)	A 193	B7M	...	A 193	B8T Cl.1	(6)			
A 320	L7A	(10)	A 193	B8 Cl.2	(11)	A 193	B8A	(6)	B 335	N10665	(7)
A 320	L7B	(10)	A 193	B8C Cl.2	(11)	A 193	B8CA	(6)			
A 320	L7C	(10)	A 193	B8M Cl.2	(11)	A 193	B8MA	(6)	B 408	...	(7)(8)(9)
A 320	L43	(10)	A 193	B8T Cl.2	(11)	A 193	B8TA	(6)			
									B 473	...	(7)
A 354	BC	...	A 320	B8 Cl.2	(11)	A 307	B	(12)	B 574	N10276	(7)
A 354	BD	...	A 320	B8C Cl.2	(11)						
			A 320	B8F Cl.2	(11)	A 320	B8 Cl.1	(6)			
A 540	B21	...	A 320	B8M Cl.2	(11)	A 320	B8C Cl.1	(6)			
A 540	B22	...	A 320	B8T Cl.2	(11)	A 320	B8M Cl.1	(6)			
A 540	B23	...				A 320	B8T Cl.1	(6)			
A 540	B24	...	A 449	...	(13)						
			A 453	651	(14)						
			A 453	660	(14)						

GENERAL NOTE: Bolting material shall not be used beyond temperature limits specified in the governing code.

NOTES:

- (1) Repair welding of bolting material is prohibited.
- (2) These bolting materials may be used with all listed materials and gaskets.
- (3) These bolting materials may be used with all listed materials and gaskets, provided it has been verified that a sealed joint can be maintained under rated working pressure and temperature.
- (4) These bolting materials may be used with all listed materials but are limited to Classes 150 and 300 joints. See para. 5.4.1 for required gasket practices.
- (5) These materials may be used as bolting with comparable nickel and special alloy parts.
- (6) This austenitic stainless material has been carbide solution treated but not strain hardened. Use A 194 nuts of corresponding material.
- (7) Nuts may be machined from the same material or may be of a compatible grade of ASTM A 194.
- (8) Maximum operating temperature is arbitrarily set at 500°F, unless material has been annealed, solution annealed, or hot finished because hard temper adversely affects design stress in the creep rupture range.
- (9) Forging quality not permitted unless the producer last heating or working these parts tests them as required for other permitted conditions in the same specification and certifies their final tensile, yield, and elongation properties to equal or exceed the requirements for one of the other permitted conditions.
- (10) This ferritic material is intended for low temperature service. Use A 194 Grade 4 or Grade 7 nuts.
- (11) This austenitic stainless material has been carbide solution treated and strain hardened. Use A 194 nuts of corresponding material.
- (12) This carbon steel fastener shall not be used above 400°F or below -20°F. See also Note (4). Bolts with drilled or undersized heads shall not be used.
- (13) Acceptable nuts for use with quenched and tempered bolts are A 194 Grades 2 and 2H. Mechanical property requirements for studs shall be the same as those for bolts.
- (14) This special alloy is intended for high temperature service with austenitic stainless steel.
- (15) ASME Boiler and Pressure Vessel Code, Section II materials, which also meet the requirements of the listed ASTM specifications, may also be used.

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 1C FLANGE BOLTING DIMENSIONAL RECOMMENDATIONS

Product	Carbon Steel	Alloy Steel
Stud bolts	ASME B18.2.1	ASME B18.2.1
Bolts smaller than $\frac{3}{4}$ in.	ASME B18.2.1, square or heavy hex head	ASME B18.2.1, heavy hex head
Bolts equal to or larger than $\frac{3}{4}$ in.	ASME B18.2.1, square or hex head	ASME B18.2.1, heavy hex head
Nuts smaller than $\frac{3}{4}$ in.	ASME B18.2.2, heavy hex	ASME B18.2.2, heavy hex
Nuts equal to or larger than $\frac{3}{4}$ in.	ASME B18.2.2, hex or heavy hex	ASME B18.2.2, heavy hex
Male threads	ASME B1.1, Cl. 2A course series	ASME B1.1, Cl. 2A course series up through 1 in.; eight thread series for larger bolts
Female threads	ASME B1.1, Cl. 2B course series	ASME B1.1, Cl. 2B course series up through 1 in.; eight thread series for larger bolts

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLES 2
PRESSURE-TEMPERATURE RATINGS FOR
GROUPS 1.1 THROUGH 3.17 MATERIALS

TABLE 2-1.1 RATINGS FOR GROUP 1.1 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C-Si	A 105 (1)	A 216 Gr. WCB (1)	A 515 Gr. 70 (1)
C-Mn-Si	A 350 Gr. LF2 (1)		A 516 Gr. 70 (1)(2) A 537 Cl. 1 (3)
C-Mn-Si-V	A 350 Gr. LF6 Cl. 1 (4)		

NOTES:

(1) Upon prolonged exposure to temperatures above 800°F, the carbide phase of steel may be converted to graphite. Permissible, but not recommended for prolonged use above 800°F.

(2) Not to be used over 850°F.

(3) Not to be used over 700°F.

(4) Not to be used over 500°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	285	740	990	1480	2220	3705	6170
200	260	675	900	1350	2025	3375	5625
300	230	655	875	1315	1970	3280	5470
400	200	635	845	1270	1900	3170	5280
500	170	600	800	1200	1795	2995	4990
600	140	550	730	1095	1640	2735	4560
650	125	535	715	1075	1610	2685	4475
700	110	535	710	1065	1600	2665	4440
750	95	505	670	1010	1510	2520	4200
800	80	410	550	825	1235	2060	3430
850	65	270	355	535	805	1340	2230
900	50	170	230	345	515	860	1430
950	35	105	140	205	310	515	860
1000	20	50	70	105	155	260	430

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.2 RATINGS FOR GROUP 1.2 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C-Mn-Si	A 350 Gr. LF6 Cl. 2 (3)	A 216 Gr. WCC (1) A 352 Gr. LCC (2)	A 203 Gr. B (1)
C-Mn-Si-V			
2½Ni		A 352 Gr. LC2	
3½Ni	A 350 Gr. LF3	A 352 Gr. LC3	A 203 Gr. E (1)

NOTES:

- (1) Upon prolonged exposure to temperatures above 800°F, the carbide phase of steel may be converted to graphite. Permissible, but not recommended for prolonged use above 800°F.
 (2) Not to be used over 650°F.
 (3) Not to be used over 500°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	750	1000	1500	2250	3750	6250
300	230	730	970	1455	2185	3640	6070
400	200	705	940	1410	2115	3530	5880
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	505	670	1010	1510	2520	4200
800	80	410	550	825	1235	2060	3430
850	65	270	355	535	805	1340	2230
900	50	170	230	345	515	860	1430
950	35	105	140	205	310	515	860
1000	20	50	70	105	155	260	430

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.3 RATINGS FOR GROUP 1.3 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C-Si		A 352 Gr. LCB (3)	A 515 Gr. 65 (1)
C-Mn-Si			A 516 Gr. 65 (1)(2)
2½Ni			A 203 Gr. A (1)
3½Ni			A 203 Gr. D (1)

NOTES:

- (1) Upon prolonged exposure to temperatures above 800°F, the carbide phase of steel may be converted to graphite. Permissible, but not recommended for prolonged use above 800°F.
 (2) Not to be used over 850°F.
 (3) Not to be used over 650°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	265	695	925	1390	2085	3470	5785
200	250	655	875	1315	1970	3280	5470
300	230	640	850	1275	1915	3190	5315
400	200	620	825	1235	1850	3085	5145
500	170	585	775	1165	1745	2910	4850
600	140	535	710	1065	1600	2665	4440
650	125	525	695	1045	1570	2615	4355
700	110	520	690	1035	1555	2590	4320
750	95	475	630	945	1420	2365	3945
800	80	390	520	780	1175	1955	3260
850	65	270	355	535	805	1340	2230
900	50	170	230	345	515	860	1430
950	35	105	140	205	310	515	860
1000	20	50	70	105	155	260	430

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.4 RATINGS FOR GROUP 1.4 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C-Si			A 515 Gr. 60 (1)
C-Mn-Si	A 350 Gr. LF1, Cl. 1 (1)		A 516 Gr. 60 (1)(2)

NOTES:

(1) Upon prolonged exposure to temperatures above 800°F, the carbide phase of steel may be converted to graphite. Permissible, but not recommended for prolonged use above 800°F.

(2) Not to be used over 850°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	235	620	825	1235	1850	3085	5145
200	215	560	750	1125	1685	2810	4680
300	210	550	730	1095	1640	2735	4560
400	200	530	705	1060	1585	2645	4405
500	170	500	665	995	1495	2490	4150
600	140	455	610	915	1370	2285	3805
650	125	450	600	895	1345	2245	3740
700	110	450	600	895	1345	2245	3740
750	95	445	590	885	1325	2210	3685
800	80	370	495	740	1110	1850	3085
850	65	270	355	535	805	1340	2230
900	50	170	230	345	515	860	1430
950	35	105	140	205	310	515	860
1000	20	50	70	105	155	260	430

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.5 RATINGS FOR GROUP 1.5 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C-½Mo	A 182 Gr. F1 (1)	A 217 Gr. WC1 (1)(2) A 352 Gr. LC1 (3)	A 204 Gr. A (1) A 204 Gr. B (1)

NOTES:

- (1) Upon prolonged exposure to temperatures above 875°F, the carbide phase of carbon-molybdenum steel may be converted to graphite. Permissible, but not recommended for prolonged use above 875°F.
- (2) Use normalized and tempered material only.
- (3) Not to be used over 650°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	265	695	925	1390	2085	3470	5785
200	260	680	905	1360	2035	3395	5660
300	230	655	870	1305	1955	3260	5435
400	200	640	855	1280	1920	3200	5330
500	170	620	830	1245	1865	3105	5180
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	710	1065	1595	2660	4430
800	80	510	675	1015	1525	2540	4230
850	65	485	650	975	1460	2435	4060
900	50	450	600	900	1350	2245	3745
950	35	280	375	560	845	1405	2345
1000	20	165	220	330	495	825	1370

APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.7 RATINGS FOR GROUP 1.7 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C- $\frac{1}{2}$ Mo	A 182 Gr. F2 (3)	A 217 Gr. WC4 (2)(3) A 217 Gr. WC5 (2)	A 204 Gr. C (1)
$\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo			
Ni- $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo			
$\frac{3}{4}$ Ni- $\frac{3}{4}$ Cr-1Mo			

NOTES:

- (1) Upon prolonged exposure to temperatures above 875°F, the carbide phase of carbon-molybdenum steel may be converted to graphite. Permissible, but not recommended for prolonged use above 875°F.
- (2) Use normalized and tempered material only.
- (3) Not to be used over 1000°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	750	1000	1500	2250	3750	6250
300	230	720	965	1445	2165	3610	6015
400	200	695	925	1385	2080	3465	5775
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	710	1065	1595	2660	4430
800	80	510	675	1015	1525	2540	4230
850	65	485	650	975	1460	2435	4060
900	50	450	600	900	1350	2245	3745
950	35	315	420	630	945	1575	2630
1000	20	200	270	405	605	1010	1685
1050	...	160	210	315	475	790	1315

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.9 RATINGS FOR GROUP 1.9 MATERIALS

Nominal Designation	Forgings	Castings	Plates
1Cr- $\frac{1}{2}$ Mo	A 182 Gr. F12 Cl. 2 (1)(2)	A 217 Gr. WC6 (1)(3)	
1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo			
1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo	A 182 Gr. F11 Cl. 2 (1)(2)		A 387 Gr. 11 Cl. 2 (2)

NOTES:

(1) Use normalized and tempered material only.

(2) Permissible, but not recommended for prolonged use above 1100°F.

(3) Not to be used over 1100°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	750	1000	1500	2250	3750	6250
300	230	720	965	1445	2165	3610	6015
400	200	695	925	1385	2080	3465	5775
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	710	1065	1595	2660	4430
800	80	510	675	1015	1525	2540	4230
850	65	485	650	975	1460	2435	4060
900	50	450	600	900	1350	2245	3745
950	35	320	425	640	955	1595	2655
1000	20	215	290	430	650	1080	1800
1050	...	145	190	290	430	720	1200
1100	...	95	130	190	290	480	800
1150	...	60	80	125	185	310	515
1200	...	40	50	75	115	190	315

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.10 RATINGS FOR GROUP 1.10 MATERIALS

Nominal Designation	Forgings	Castings	Plates
2½Cr-1Mo	A 182 Gr. F22 Cl. 3 (2)	A 217 Gr. WC9 (1)(3)	A 387 Gr. 22 Cl. 2 (2)

NOTES:

- (1) Use normalized and tempered material only.
 (2) Permissible, but not recommended for prolonged use above 1100°F.
 (3) Not to be used over 1100°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	750	1000	1500	2250	3750	6250
300	230	730	970	1455	2185	3640	6070
400	200	705	940	1410	2115	3530	5880
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	710	1065	1595	2660	4430
800	80	510	675	1015	1525	2540	4230
850	65	485	650	975	1460	2435	4060
900	50	450	600	900	1350	2245	3745
950	35	375	505	755	1130	1885	3145
1000	20	260	345	520	780	1305	2170
1050	...	175	235	350	525	875	1455
1100	...	110	145	220	330	550	915
1150	...	70	90	135	205	345	570
1200	...	40	55	80	125	205	345

APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.13 RATINGS FOR GROUP 1.13 MATERIALS

Nominal Designation	Forgings	Castings	Plates
5Cr- $\frac{1}{2}$ Mo	A 182 Gr. F5 A 182 Gr. F5a	A 217 Gr. C5 (1)	

NOTE:

(1) Use normalized and tempered material only.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	745	995	1490	2235	3725	6205
300	230	715	955	1430	2150	3580	5965
400	200	705	940	1410	2115	3530	5880
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	705	1055	1585	2640	4400
800	80	510	675	1015	1525	2540	4230
850	65	485	645	965	1450	2415	4030
900	50	370	495	740	1110	1850	3085
950	35	275	365	550	825	1370	2285
1000	20	200	265	400	595	995	1655
1050	...	145	190	290	430	720	1200
1100	...	100	135	200	300	495	830
1150	...	60	80	125	185	310	515
1200	...	35	45	70	105	170	285

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.14 RATINGS FOR GROUP 1.14 MATERIALS

Nominal Designation	Forgings	Castings	Plates
9Cr-1Mo	A 182 Gr. F9	A 217 Gr. C12 (1)	

NOTE:

(1) Use normalized and tempered material only.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	750	1000	1500	2250	3750	6250
300	230	730	970	1455	2185	3640	6070
400	200	705	940	1410	2115	3530	5880
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	710	1065	1595	2660	4430
800	80	510	675	1015	1525	2540	4230
850	65	485	650	975	1460	2435	4060
900	50	450	600	900	1350	2245	3745
950	35	375	505	755	1130	1885	3145
1000	20	255	340	505	760	1270	2115
1050	...	170	230	345	515	855	1430
1100	...	115	150	225	340	565	945
1150	...	75	100	150	225	375	630
1200	...	50	70	105	155	255	430

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-1.15 RATINGS FOR GROUP 1.15 MATERIALS

Nominal Designation	Forgings	Castings	Plates
9Cr-1Mo-V	A 182 Gr. F91	A 217 Gr. C12A	A 387 Gr. 91 Cl. 2

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	290	750	1000	1500	2250	3750	6250
200	260	750	1000	1500	2250	3750	6250
300	230	730	970	1455	2185	3640	6070
400	200	705	940	1410	2115	3530	5880
500	170	665	885	1330	1995	3325	5540
600	140	605	805	1210	1815	3025	5040
650	125	590	785	1175	1765	2940	4905
700	110	570	755	1135	1705	2840	4730
750	95	530	710	1065	1595	2660	4430
800	80	510	675	1015	1525	2540	4230
850	65	485	650	975	1460	2435	4060
900	50	450	600	900	1350	2245	3745
950	35	385	515	775	1160	1930	3220
1000	20	365	485	725	1090	1820	3030
1050	...	360	480	720	1080	1800	3000
1100	...	300	400	605	905	1510	2515
1150	...	225	295	445	670	1115	1855
1200	...	145	190	290	430	720	1200

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-2.1 RATINGS FOR GROUP 2.1 MATERIALS

Nominal Designation	Forgings	Castings	Plates
18Cr-8Ni	A 182 Gr. F304 (1)	A 351 Gr. CF3 (2)	A 240 Gr. 304 (1)
	A 182 Gr. F304H	A 351 Gr. CF8 (1)	A 240 Gr. 304H

NOTES:

(1) At temperatures over 1000°F, use only when the carbon content is 0.04% or higher.

(2) Not to be used over 800°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	275	720	960	1440	2160	3600	6000
200	230	600	800	1200	1800	3000	5000
300	205	540	720	1080	1620	2700	4500
400	190	495	660	995	1490	2485	4140
500	170	465	620	930	1395	2330	3880
600	140	435	580	875	1310	2185	3640
650	125	430	575	860	1290	2150	3580
700	110	425	565	850	1275	2125	3540
750	95	415	555	830	1245	2075	3460
800	80	405	540	805	1210	2015	3360
850	65	395	530	790	1190	1980	3300
900	50	390	520	780	1165	1945	3240
950	35	380	510	765	1145	1910	3180
1000	20	320	430	640	965	1605	2675
1050	...	310	410	615	925	1545	2570
1100	...	255	345	515	770	1285	2145
1150	...	200	265	400	595	995	1655
1200	...	155	205	310	465	770	1285
1250	...	115	150	225	340	565	945
1300	...	85	115	170	255	430	715
1350	...	60	80	125	185	310	515
1400	...	50	65	90	145	240	400
1450	...	35	45	70	105	170	285
1500	...	25	35	55	80	135	230

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-2.2 RATINGS FOR GROUP 2.2 MATERIALS

Nominal Designation	Forgings	Castings	Plates
16Cr-12Ni-2Mo	A 182 Gr. F316 (1) A 182 Gr. F316H	A 351 Gr. CF3M (2) A 351 Gr. CF8M (1)	A 240 Gr. 316 (1) A 240 Gr. 316H
18Cr-13Ni-3Mo			A 240 Gr. 317 (1)
19Cr-10Ni-3Mo		A 351 Gr. CG8M (3)	

NOTES:

(1) At temperatures over 1000°F, use only when the carbon content is 0.04% or higher.

(2) Not to be used over 850°F.

(3) Not to be used over 1000°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	275	720	960	1440	2160	3600	6000
200	235	620	825	1240	1860	3095	5160
300	215	560	745	1120	1680	2795	4660
400	195	515	685	1025	1540	2570	4280
500	170	480	635	955	1435	2390	3980
600	140	450	600	900	1355	2255	3760
650	125	445	590	890	1330	2220	3700
700	110	430	580	870	1305	2170	3620
750	95	425	570	855	1280	2135	3560
800	80	420	565	845	1265	2110	3520
850	65	420	555	835	1255	2090	3480
900	50	415	555	830	1245	2075	3460
950	35	385	515	775	1160	1930	3220
1000	20	350	465	700	1050	1750	2915
1050	...	345	460	685	1030	1720	2865
1100	...	305	405	610	915	1525	2545
1150	...	235	315	475	710	1185	1970
1200	...	185	245	370	555	925	1545
1250	...	145	195	295	440	735	1230
1300	...	115	155	235	350	585	970
1350	...	95	130	190	290	480	800
1400	...	75	100	150	225	380	630
1450	...	60	80	115	175	290	485
1500	...	40	55	85	125	205	345

APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-2.3 RATINGS FOR GROUP 2.3 MATERIALS

Nominal Designation	Forgings	Castings	Plates
16Cr-12Ni-2Mo	A 182 Gr. F316L		A 240 Gr. 316L
18Cr-8Ni	A 182 Gr. F304L (1)		A 240 Gr. 304L (1)

NOTE:

(1) Not to be used over 800°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	230	600	800	1200	1800	3000	5000
200	195	505	675	1015	1520	2530	4220
300	175	455	605	910	1360	2270	3780
400	160	415	550	825	1240	2065	3440
500	145	380	510	765	1145	1910	3180
600	140	360	480	720	1080	1800	3000
650	125	350	470	700	1050	1750	2920
700	110	345	460	685	1030	1715	2860
750	95	335	450	670	1010	1680	2800
800	80	330	440	660	985	1645	2740
850	65	320	430	645	965	1610	2680

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APPENDIX E (cont'd)

PIPE FLANGES AND FLANGED FITTINGS

TABLE 2-2.4 RATINGS FOR GROUP 2.4 MATERIALS

Nominal Designation	Forgings	Castings	Plates
18Cr-10Ni-Ti	A 182 Gr. F321 (2) A 182 Gr. F321H (1)		A 240 Gr. 321 (2) A 240 Gr. 321H (1)

NOTES:

(1) At temperatures over 1000°F, use only if the material is heat treated by heating to a minimum temperature of 2000°F.

(2) Not to be used over 1000°F.

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
-20 to 100	275	720	960	1440	2160	3600	6000
200	245	645	860	1290	1935	3230	5380
300	230	595	795	1190	1785	2975	4960
400	200	550	735	1105	1655	2760	4600
500	170	515	685	1030	1545	2570	4285
600	140	485	650	975	1460	2435	4060
650	125	480	635	955	1435	2390	3980
700	110	465	620	930	1395	2330	3880
750	95	460	610	915	1375	2290	3820
800	80	450	600	900	1355	2255	3760
850	65	445	595	895	1340	2230	3720
900	50	440	590	885	1325	2210	3680
950	35	385	515	775	1160	1930	3220
1000	20	355	475	715	1070	1785	2970
1050	...	315	415	625	940	1565	2605
1100	...	270	360	545	815	1360	2265
1150	...	235	315	475	710	1185	1970
1200	...	185	245	370	555	925	1545
1250	...	140	185	280	420	705	1170
1300	...	110	145	220	330	550	915
1350	...	85	115	170	255	430	715
1400	...	65	85	130	195	325	545
1450	...	50	70	105	155	255	430
1500	...	40	50	75	115	190	315

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For a complete list of pressure-temperature ratings for flanges not listed, refer to ASME B16.5a.

APPENDIX F EQUIVALENTS OF PRESSURE

Pressure	lb/in. ²	Bar	Atmos- pheres	kg/cm ²	KPa	in. water (68 F)	ft. water (68 F)	in. mercury (32 F)	mm mercury (32 F)
lb/in. ²	1	0.068947	0.068046	0.070307	6.89476	27.707	2.3039	2.03601	51.7148
Bar	14.5037	1	0.98692	1.0192	100	402.156	33.513	29.5300	750.062
Atmospheres	14.696	1.01325	1	1.0332	101.325	407.17	33.931	29.921	760.
kg/cm ²	14.2234	0.980675	0.96784	1	98.0669	394.08	32.840	28.959	735.559
KPa	0.145038	0.010	0.009869	0.010197	1	4.02156	0.33513	0.295300	7.5006
in. water	0.036092	0.002466	0.002456	0.00253	0.248846	1	0.08333	0.073483	1.8665
ft. water	0.433103	0.029839	0.029471	0.03045	2.98639	12.	1	0.88180	22.3980
in. mercury	0.491157	0.033864	0.033421	0.03453	3.38641	13.608	1.1340	1	25.40005
mm mercury	0.0193368	0.00133	0.0013158	0.0013595	0.133323	0.535764	0.044647	0.03937	1

1000 mmHg = 1Micron (μ)1000 N/m² = 1KPa

Sample Problem:

How many inches of mercury are equivalent to 10 inches of water?

Solution:

1 inch of water is equal to 0.073483 inch mercury.

Then, $10 \times 0.073483 = 0.73483$ inch mercury.

APPENDIX G ALTITUDE PRESSURE TABLE

Feet Altitude	Temp F	Pressure In. Hg.		Feet Altitude	Temp F	Pressure In. Hg.
0	59.00	29.92		55,000	-69.7	2.712
50				60,000	-69.7	2.135
100	58.64	29.81		65,000	-69.7	1.682
200	58.28	29.71		70,000	-67.42	1.325
300	57.93	29.60		75,000	-64.7	1.046
400	57.57	29.49		80,000	-61.98	8.273-1
500	57.21	29.38		85,000	-59.26	6.553-1
600	56.86	29.28		90,000	-56.53	5.200-1
700	56.50	29.17		95,000	-53.82	4.133-1
800	56.15	29.07		100,000	-51.10	3.290-1
900	55.79	28.96		110,000	-41.29	2.098-1
1,000	55.43	28.86		120,000	-26.09	1.358-1
1,500	53.65	28.33		130,000	-10.91	8.921-2
2,000	51.87	27.82		140,000	4.253	5.947-2
2,500	50.09	27.32		150,000	19.40	4.018-2
3,000	48.30	26.82		160,000	27.50	2.746-2
3,500	46.52	26.33		170,000	27.50	1.880-2
4,000	44.74	25.84		180,000	18.88	1.2843-2
4,500	42.96	25.37		190,000	8.099	8.7026-3
5,000	41.17	24.90		200,000	-2.671	5.8457-3
7,500	32.26	22.66		210,000	-21.96	3.8790-3
10,000	23.36	20.58		220,000	-43.46	2.5229-3
15,000	5.55	16.89		230,000	-64.94	1.6046-3
20,000	-12.26	13.76		240,000	-86.40	9.9546-4
25,000	-30.05	11.12		250,000	-107.84	6.0065-4
30,000	-47.83	8.903		260,000	-129.26	3.5127-4
35,000	-65.61	7.060		270,000	-134.50	2.0046-4
40,000	-69.70	5.558		280,000	-134.50	1.1433-4
45,000	-69.70	4.375		290,000	-134.50	6.5244-5
50,000	-69.70	3.444		300,000	-126.77	3.7368-5

Note: A number (preceded by a plus or minus sign) following the entry in each block indicates the power of ten by which that entry should be multiplied.

Source of Data: NASA, U.S. Standard Atmosphere, 1962

APPENDIX H **ABSOLUTE PRESSURE AND VOLUME RELATIONS FOR DRY AIR**

ABSOLUTE PRESSURE					VACUUM Inches Hg ²	SP VOL cu ft per lb	FLOW RATE OF 1 LB PER HOUR DRY AIR	
Microns Hg	MM Hg	Inches Hg	Psi	KG/CM ²			CFM	Liters/ Second
1	.001	.....	.....	.....	.....	9,933,000	165,530	78,280
2	.002	.....	.....	.....	.....	4,966,000	82,765	39,044
3	.003	.....	.....	.....	.....	3,312,000	55,176	26,052
4	.004	.....	.....	.....	.....	2,483,000	41,363	19,532
5	.005	.....	.....	.....	.....	1,986,000	33,104	15,621
6	.006	.....	.....	.....	.....	1,656,000	27,588	13,031
7	.007	.....	.....	.....	.....	1,419,000	23,647	11,161
8	.008	.....	.....	.....	.....	1,242,000	20,691	9,766
9	.009	.....	.....	.....	.....	1,104,000	18,402	8,681
10	.010	.....	.....	.....	.....	993,300	16,553	7,828.0
20	.020	.....	.....	.....	.....	496,600	8,276	3,904.4
30	.030	.....	.....	.....	.....	331,200	5,520	2,605.2
40	.040	.....	.....	.....	.....	248,300	4,136	1,953.2
50	.050	.....	.....	.....	.....	198,600	3,310	1,562.6
60	.060	.....	.....	.....	.....	165,600	2,760	1,303.1
70	.070	.....	.....	.....	.....	141,900	2,365	1,116.1
80	.080	.....	.....	.....	.....	124,200	2,069	976.6
90	.090	.....	.....	.....	.....	110,400	1,840	868.1
100	.100	.0039	.....	.....	.....	99,330	1,655.3	782.8
200	.200	.0079	.....	.....	.....	49,660	827.6	390.4
300	.300	.0118	.....	.....	.....	33,120	552.0	260.5
400	.400	.0158	.....	.....	.....	24,830	413.6	195.3
500	.500	.0197	.....	.....	.....	19,860	331.0	156.2
600	.600	.0236	.....	.....	.....	16,560	276.0	130.3
700	.700	.0276	.....	.....	.....	14,190	236.5	111.61
800	.800	.0315	.....	.....	.....	12,420	206.9	97.66
900	.900	.0354	.....	.....	.....	11,040	184.0	86.81
1000	1.00	.0394	.0193	.00136	29.96	9,933	165.53	78.28
....	2.00	.0787	.0387	.00272	29.92	4,966	82.76	39.04
....	2.54	.100	.0491	.00345	29.90	3,912	65.20	30.77
....	3.00	.1181	.0580	.00408	29.88	3,312	55.20	26.05
....	4.00	.158	.0774	.00544	29.84	2,482	41.36	19.53
....	5.00	.197	.0967	.00680	29.80	1,986	33.10	15.62
....	5.08	.200	.0982	.00691	29.80	1,956	32.60	15.39
....	6.00	.236	.1160	.00815	29.76	1,656	27.60	13.03
....	7.00	.276	.1354	.00951	29.72	1,419	23.65	11.16
....	7.62	.300	.1474	.01036	29.70	1,304	21.733	10.26
....	8.00	.315	.1547	.01088	29.68	1,242	20.69	9.77
....	9.00	.354	.1741	.01224	29.65	1,104	18.40	8.68
....	10.00	.394	.1934	.01359	29.61	993.3	16.55	7.83
....	10.16	.400	.1965	.01381	29.60	977.5	16.29	7.69
....	11.00	.433	.2127	.01496	29.57	903.0	15.05	7.10
....	12.00	.472	.2321	.01632	29.53	827.9	13.79	6.51
....	12.70	.500	.2456	.01727	29.50	782.1	13.03	6.15
....	13.00	.512	.2514	.01768	29.49	764.10	12.73	6.01
....	14.00	.551	.2708	.01903	29.45	709.6	11.82	5.58
....	15.00	.591	.2900	.02039	29.41	662.3	11.04	5.21
....	15.24	.600	.2947	.02071	29.40	651.8	10.86	5.13
....	16.00	.630	.3094	.02176	29.37	621.6	10.36	4.885
....	17.00	.670	.3288	.0231	29.33	583.8	9.73	4.597

APPENDIX H (cont'd)
ABSOLUTE PRESSURE AND VOLUME RELATIONS FOR DRY AIR

ABSOLUTE PRESSURE					VACUUM Inches Hg*	SP VOL cu ft per lb	FLOW RATE OF 1 LB PER HOUR DRY AIR	
Microns Hg	MM Hg	Inches Hg	Psi	KG/CM ²			CFM	Liters/ Second
....	17.78	.700	.34386	.0242	29.30	558.7	9.31	4.394
....	18.00	.709	.3481	.0245	29.29	551.8	9.20	4.342
....	19.00	.748	.3675	.0258	29.25	522.66	8.72	4.111
....	20.00	.787	.3868	.0272	29.21	496.6	8.28	3.904
....	20.32	.800	.393	.0276	29.20	488.7	8.15	3.846
....	21.00	.827	.406	.0285	29.17	473.1	7.89	3.724
....	22.00	.866	.425	.0299	29.13	451.9	7.53	3.554
....	22.86	.900	.442	.0311	29.10	434.6	7.24	3.417
....	23.00	.906	.445	.0313	29.09	431.6	7.19	3.393
....	24.00	.945	.464	.0326	29.05	414.0	6.90	3.257
....	25.00	.984	.484	.0340	29.02	396.85	6.61	3.120
....	25.40	1.00	.491	.0345	29.00	391.19	6.52	3.077
....	25.86	1.018	.500	.0352	28.98	384.15	6.40	3.021
....	26.00	1.024	.503	.0353	28.97	381.86	6.36	3.002
....	27.00	1.063	.522	.0367	28.94	367.96	6.13	2.893
....	27.94	1.10	.540	.03797	28.90	355.70	5.93	2.799
....	28.00	1.102	.542	.0380	28.90	354.38	5.91	2.789
....	29.00	1.142	.561	.0394	28.86	342.38	5.71	2.695
....	30.00	1.181	.580	.0408	28.82	331.17	5.520	2.605
....	30.58	1.20	.591	.0416	28.80	325.00	5.417	2.558
....	33.12	1.30	.641	.0450	28.70	299.65	4.994	2.357
....	35.00	1.38	.677	.0476	28.62	283.72	4.792	2.232
....	35.66	1.40	.690	.0485	28.60	278.37	4.640	2.190
....	38.20	1.50	.739	.0519	28.50	259.91	4.332	2.045
....	40.00	1.57	.774	.0544	28.43	248.16	4.136	1.953
....	40.74	1.60	.788	.0554	28.40	243.75	4.063	1.916
....	43.28	1.70	.837	.0588	28.30	229.48	3.825	1.803
....	45.00	1.77	.870	.0612	28.23	220.78	3.680	1.737
....	45.82	1.80	.886	.0623	28.20	216.79	3.613	1.705
....	48.36	1.90	.935	.0657	28.10	205.43	3.424	1.614
....	50.00	1.97	.967	.0680	28.03	198.63	3.310	1.562
....	50.80	2.00	.982	.0690	28.00	195.59	3.260	1.539
....	51.72	2.04	1.000	.0703	27.96	192.08	3.201	1.511
....	53.34	2.10	1.032	.0725	27.90	186.12	3.102	1.463
....	55.88	2.20	1.081	.0760	27.80	177.68	2.961	1.397
....	58.42	2.30	1.130	.0794	27.70	169.98	2.833	1.336
....	60.00	2.36	1.160	.0815	27.64	165.58	2.760	1.303
....	60.96	2.40	1.179	.0828	27.60	162.91	2.715	1.284
....	63.50	2.50	1.228	.0863	27.50	156.41	2.607	1.230
....	66.04	2.60	1.277	.0898	27.40	150.41	2.507	1.185
....	68.58	2.70	1.326	.0932	27.30	144.85	2.414	1.137
....	70.00	2.76	1.354	.0951	27.26	141.90	2.365	1.116
....	71.12	2.80	1.375	.0967	27.20	139.70	2.328	1.099
....	73.66	2.90	1.425	.1001	27.10	134.79	2.247	1.060
....	76.20	3.00	1.474	.1036	27.00	130.31	2.172	1.025
....	77.57	3.06	1.500	.1054	26.94	128.05	2.134	1.007
....	80.00	3.15	1.547	.1087	26.85	124.16	2.069	.977
....	81.28	3.20	1.572	.1105	26.80	122.19	2.037	.961
....	86.36	3.40	1.670	.1174	26.60	115.02	1.917	.905
....	90.00	3.54	1.741	.1223	26.46	110.39	1.840	.868

APPENDIX H (cont'd)
ABSOLUTE PRESSURE AND VOLUME RELATIONS FOR DRY AIR

ABSOLUTE PRESSURE					VACUUM Inches Hg ^a	SP VOL cu ft per lb	FLOW RATE OF 1 LB PER HOUR DRY AIR	
Microns Hg	MM Hg	Inches Hg	Psi	KG/CM ²			CFM	Liters/ Second
....	91.44	3.60	1.768	.1243	26.40	108.64	1.811	.855
....	96.52	3.80	1.867	.1312	26.20	102.88	1.715	.809
....	100.00	3.94	1.934	.1359	26.06	99.33	1.655	.783
....	101.60	4.00	1.965	.1381	26.00	97.75	1.629	.769
....	103.43	4.07	2.000	.1406	25.93	96.04	1.601	.756
....	110.00	4.33	2.13	.1496	25.67	90.30	1.505	.710
....	114.30	4.50	2.21	.1554	25.50	86.91	1.449	.684
....	120.00	4.72	2.32	.1632	25.28	82.78	1.379	.651
....	127.00	5.00	2.46	.1726	25.00	78.08	1.301	.614
....	129.29	5.09	2.500	.1757	24.91	76.83	1.281	.605
....	130.00	5.12	2.51	.1768	24.88	76.41	1.273	.601
....	139.7	5.50	2.70	.1899	24.50	71.14	1.186	.560
....	140.00	5.51	2.71	.1903	24.49	70.96	1.182	.558
....	150.00	5.91	2.90	.2039	24.09	66.23	1.104	.521
....	152.4	6.00	2.95	.2072	24.00	65.11	1.085	.512
....	155.15	6.11	3.000	.2109	23.89	64.02	1.067	.504
....	160.00	6.30	3.09	.217	23.70	62.16	1.036	.489
....	165.1	6.50	3.19	.224	23.50	60.21	1.004	.474
....	170.0	6.69	3.29	.231	23.31	58.38	.973	.460
....	177.8	7.00	3.44	.242	23.00	55.84	.931	.439
....	180.0	7.09	3.48	.245	22.91	55.18	.920	.434
....	181.0	7.13	3.50	.246	22.87	54.88	.915	.432
....	190.0	7.48	3.67	.258	22.52	52.27	.872	.411
....	190.5	7.50	3.68	.259	22.50	52.19	.870	.411
....	200.0	7.87	3.87	.272	22.13	49.66	.828	.3904
....	203.2	8.00	3.93	.276	22.00	48.87	.815	.3846
....	206.9	8.15	4.00	.281	21.85	48.02	.800	.3776
....	210.0	8.27	4.06	.285	21.73	47.31	.789	.3724
....	215.9	8.50	4.18	.294	21.50	45.95	.766	.3615
....	220.0	8.66	4.25	.299	21.34	45.19	.753	.3554
....	228.6	9.00	4.42	.311	21.00	43.46	.724	.3417
....	230.0	9.06	4.45	.313	20.94	43.16	.719	.3393
....	232.7	9.16	4.50	.316	20.84	42.68	.711	.3356
....	240.0	9.45	4.64	.326	20.55	41.40	.690	.3257
....	241.3	9.50	4.67	.328	20.50	41.13	.686	.3238
....	250.0	9.84	4.84	.340	20.16	39.68	.661	.3120
....	254.0	10.00	4.91	.345	20.00	39.12	.652	.3077
....	258.6	10.18	5.00	.352	19.82	38.42	.640	.3021
....	275.0	10.83	5.32	.374	19.17	36.10	.602	.2841
....	279.4	11.00	5.40	.380	19.00	35.57	.593	.2799
....	300.0	11.81	5.80	.408	18.19	33.12	.552	.2605
....	304.8	12.00	5.89	.414	18.00	32.61	.544	.2567
....	310.3	12.22	6.00	.422	17.78	32.01	.534	.2520
....	325.0	12.80	6.29	.442	17.20	30.54	.509	.2402
....	330.2	13.00	6.39	.449	17.00	30.06	.501	.2365
....	350.0	13.78	6.77	.476	16.22	28.37	.473	.2232
....	355.6	14.00	6.88	.483	16.00	27.92	.465	.2195
....	362.0	14.25	7.00	.492	15.75	27.44	.457	.2157
....	375.0	14.76	7.25	.510	15.24	26.49	.442	.2086
....	381.0	15.00	7.37	.518	15.00	26.06	.434	.2048

APPENDIX H (cont'd)
ABSOLUTE PRESSURE AND VOLUME RELATIONS FOR DRY AIR

ABSOLUTE PRESSURE					VACUUM Inches Hg*	SP VOL cu ft per lb	FLOW RATE OF 1 LB PER HOUR DRY AIR	
Microns Hg	MM Hg	Inches Hg	Psi	KG/CM ²			CFM	Liters/ Second
....	400.0	15.75	7.74	.544	14.25	24.82	.413	.1953
....	406.4	16.00	7.86	.553	14.00	24.44	.4073	.1922
....	413.7	16.29	8.00	.562	13.71	24.01	.4002	.1889
....	425.0	16.73	8.22	.578	13.27	23.37	.3895	.1838
....	431.8	17.00	8.35	.587	13.00	23.00	.3833	.1809
....	450.0	17.72	8.70	.612	12.28	22.08	.3680	.1737
....	457.2	18.00	8.84	.621	12.00	21.73	.3622	.1709
....	465.4	18.32	9.00	.633	11.68	21.34	.3557	.1679
....	475.0	18.70	9.19	.646	11.30	20.90	.3483	.1644
....	482.6	19.00	9.33	.656	11.00	20.59	.3432	.1620
....	500.0	19.68	9.67	.680	10.32	19.86	.3310	.1562
....	508.0	20.00	9.82	.691	10.00	19.56	.3260	.1539
....	517.2	20.36	10.00	.703	9.64	19.21	.3202	.1511
....	525.0	20.67	10.15	.714	9.33	18.92	.3153	.1488
....	533.4	21.00	10.32	.725	9.00	18.61	.3102	.1464
....	550.0	21.65	10.64	.748	8.35	18.05	.3008	.1420
....	558.8	22.00	10.81	.760	8.00	17.77	.2962	.1398
....	568.9	22.40	11.00	.773	7.60	17.46	.2910	.1373
....	575.0	22.64	11.12	.782	7.36	17.27	.2878	.1358
....	584.2	23.00	11.30	.794	7.00	17.00	.2833	.1337
....	600.0	23.62	11.60	.815	6.38	16.56	.2760	.1303
....	609.6	24.00	11.79	.829	6.00	16.29	.2715	.1281
....	620.6	24.43	12.00	.844	5.57	16.01	.2668	.1259
....	625.0	24.61	12.09	.850	5.39	15.89	.2648	.1250
....	635.0	25.00	12.28	.863	5.00	15.64	.2607	.1230
....	650.0	25.59	12.57	.884	4.41	15.28	.2547	.1202
....	660.4	26.00	12.77	.898	4.00	15.04	.2507	.1183
....	672.3	26.47	13.00	.914	3.53	14.77	.2462	.1162
....	675.0	26.57	13.05	.917	3.43	14.72	.2453	.1158
....	685.8	27.00	13.26	.932	3.00	14.48	.2413	.1139
....	700.0	27.56	13.54	.951	2.44	14.19	.2365	.1116
....	711.2	28.00	13.75	.967	2.00	13.97	.2328	.1099
....	724.0	28.50	14.00	.984	1.50	13.72	.2287	.1079
....	725.0	28.54	14.02	.986	1.46	13.70	.2283	.1077
....	736.6	29.00	14.25	1.001	1.00	13.48	.2247	.1060
....	750.0	29.53	14.50	1.020	.47	13.25	.2208	.1042
....	760.0	29.92	14.696	1.0332	.08	13.07	.2178	.1028
....	762.0	30.00	14.74	1.036	....	13.03	.2172	.1025

Tables for Air Based on Standard Atmosphere. From NACA Report No. 218 and No. 538, Sea Level Conditions: 29.921 inches of mercury, 59°F., .07651 lb per cu ft, 14.696 psig. 1 lb per hr dry air equals .217836 CFM; 1 lb per hr dry air equals .10281 liters per second. Expanded volumes proportional to the reciprocal of the absolute pressure (Based on perfect gas).

*Referred to 30 inch Barometer.

APPENDIX I **PROPERTIES OF SATURATED WATER VAPOR**

Temp F	ABSOLUTE PRESSURE			Sp Vol cu ft per lb	Temp F	ABSOLUTE PRESSURE			Sp Vol cu ft per lb
	MM Hg	Inches Hg	Psi x 10 ³			MM Hg	Inches Hg	Psi x 10 ³	
- 102	.00100	....	.01929	11,040,000	- 57	.03160	....	.6112	392,500
- 101	.00109	....	.02103	10,160,000	- 56	.03383	....	.6543	367,500
- 100	.00118	....	.02281	9,352,000	- 55	.03622	....	.7001	344,300
- 99	.00129	....	.02494	8,613,000	- 54	.03874	.00152	.7489	322,600
- 98	.00140	....	.02715	7,936,000	- 53	.04140	.00163	.8009	302,400
- 97	.00153	....	.02954	7,314,000	- 52	.04428	.00174	.8562	283,600
- 96	.00166	....	.03212	6,745,000	- 51	.04732	.00186	.9151	266,000
- 95	.00181	....	.03491	6,223,000	- 50	.05055	.00199	.9776	249,600
- 94	.00196	....	.03793	5,743,000	- 49	.05399	.00213	1.044	234,300
- 93	.00213	....	.04118	5,303,000	- 48	.05766	.00227	1.115	220,000
- 92	.00231	....	.04470	4,899,000	- 47	.06152	.00242	1.190	206,600
- 91	.00251	....	.04850	4,528,000	- 46	.06566	.00258	1.270	194,100
- 90	.00272	....	.05260	4,186,000	- 45	.07003	.00276	1.354	182,400
- 89	.00295	....	.05702	3,872,000	- 44	.07468	.00294	1.444	171,500
- 88	.00320	....	.06179	3,583,000	- 43	.07959	.00313	1.539	161,200
- 87	.00346	....	.06692	3,317,000	- 42	.08484	.00334	1.641	151,600
- 86	.00375	....	.07245	3,072,000	- 41	.09040	.00356	1.748	142,700
- 85	.00405	....	.07841	2,846,000	- 40	.09627	.00379	1.861	134,300
- 84	.00439	....	.08482	2,638,000	- 39	.1025	.00404	1.982	126,400
- 83	.00474	....	.09171	2,446,000	- 38	.1091	.00429	2.110	119,100
- 82	.00513	....	.09913	2,270,000	- 37	.1161	.00457	2.245	112,200
- 81	.00554	....	.1071	2,106,000	- 36	.1235	.00486	2.388	105,700
- 80	.00598	....	.1157	1,955,000	- 35	.1314	.00517	2.540	99,610
- 79	.00646	....	.1249	1,816,000	- 34	.1396	.00550	2.700	93,910
- 78	.00697	....	.1347	1,687,000	- 33	.1484	.00584	2.870	88,570
- 77	.00752	....	.1453	1,568,000	- 32	.1577	.00621	3.049	83,550
- 76	.00811	....	.1567	1,458,000	- 31	.1675	.00659	3.239	78,830
- 75	.00874	....	.1689	1,356,000	- 30	.1779	.00700	3.440	74,410
- 74	.00941	....	.1820	1,262,000	- 29	.1889	.00743	3.652	70,250
- 73	.01014	....	.1960	1,175,000	- 28	.2005	.00789	3.876	66,340
- 72	.01091	....	.2110	1,094,000	- 27	.2127	.00837	4.113	62,670
- 71	.01174	....	.2271	1,020,000	- 26	.2256	.00888	4.363	59,210
- 70	.01263	....	.2443	950,000	- 25	.2393	.00942	4.627	55,960
- 69	.01359	....	.2627	885,800	- 24	.2537	.00999	4.905	52,900
- 68	.01461	....	.2824	826,100	- 23	.2689	.01059	5.199	50,030
- 67	.01570	....	.3035	770,700	- 22	.2849	.01122	5.509	47,320
- 66	.01686	....	.3260	719,300	- 21	.3018	.01188	5.836	44,770
- 65	.01811	....	.3501	671,500	- 20	.3198	.01259	6.181	42,370
- 64	.01944	....	.3758	627,200	- 19	.3386	.01333	6.545	40,110
- 63	.02086	....	.4033	585,900	- 18	.3581	.01410	6.928	37,970
- 62	.02237	....	.4326	547,600	- 17	.3792	.01493	7.332	35,960
- 61	.02399	....	.4639	512,000	- 16	.4011	.01579	7.757	34,070
- 60	.02571	....	.4972	478,800	- 15	.4242	.01670	8.204	32,280
- 59	.02756	....	.5328	447,900	- 14	.4487	.01766	8.676	30,600
- 58	.02952	....	.5708	419,200	- 13	.4742	.01867	9.172	29,010

APPENDIX I (cont'd) **PROPERTIES OF SATURATED WATER VAPOR**

Temp F	ABSOLUTE PRESSURE			Sp Vol cu ft per lb	Temp F	ABSOLUTE PRESSURE			Sp Vol cu ft per lb
	MM Hg	Inches Hg	Psi x 10 ³			MM Hg	Inches Hg	Psi	
-12	.5014	.01974	9.694	27,600	33	4.769	.1878	.09223	3,180
-11	.5298	.02086	10.24	26,090	34	4.965	.1955	.09600	3,062
-10	.5596	.02203	10.82	24,750	35	5.166	.2034	.09991	2,948
-9	.5911	.0233	11.43	23,490	36	5.337	.2117	.1040	2,839
-8	.6241	.0246	12.07	22,290	37	5.593	.2202	.1081	2,734
-7	.6588	.0259	12.74	21,160	38	5.817	.2290	.1125	2,634
-6	.6952	.0274	13.44	20,100	39	6.052	.2382	.1170	2,538
-5	.7336	.0289	14.19	19,090	40	6.292	.2477	.1216	2,445
-4	.7739	.0305	14.96	18,140	41	6.541	.2575	.1265	2,357
-3	.8161	.0321	15.78	17,230	42	6.797	.2676	.1314	2,272
-2	.8606	.0339	16.64	16,380	43	7.064	.2781	.1366	2,190
-1	.9073	.0357	17.54	15,570	44	7.341	.2890	.1419	2,112
0	.9561	.0376	18.49	14,810	45	7.652	.3002	.1475	2,037
1	1.0074	.0397	19.48	14,080	46	7.920	.3118	.1532	1,965
2	1.061	.0418	20.52	13,400	47	8.227	.3239	.1591	1,896
3	1.118	.0440	21.61	12,750	48	8.542	.3363	.1652	1,829
4	1.177	.0463	22.76	12,140	49	8.867	.3491	.1715	1,766
5	1.239	.0488	23.96	11,550	50	9.205	.3624	.1780	1,704
6	1.304	.0513	25.21	11,000	51	9.553	.3761	.1847	1,645
7	1.372	.0540	26.53	10,480	52	9.914	.3903	.1917	1,589
8	1.443	.0568	27.91	9,979	53	10.284	.4049	.1989	1,534
9	1.518	.0598	29.36	9,507	54	10.67	.4200	.2063	1,482
10	1.597	.0629	30.87	9,060	55	11.06	.4356	.2140	1,431
11	1.678	.0661	32.46	8,636	56	11.48	.4518	.2219	1,383
12	1.764	.0695	34.12	8,234	57	11.90	.4684	.2301	1,336
13	1.854	.0730	35.85	7,851	58	12.33	.4856	.2385	1,292
14	1.948	.0767	37.67	7,489	59	12.78	.5033	.2472	1,249
15	2.046	.0806	39.57	7,144	60	13.25	.5216	.2562	1,207
16	2.149	.0846	41.56	6,817	61	13.73	.5405	.2654	1,167
17	2.256	.0888	43.63	6,505	62	14.22	.5599	.2750	1,129
18	2.369	.0933	45.81	6,210	63	14.73	.5800	.2849	1,092
19	2.486	.0979	48.08	5,929	64	15.26	.6007	.2950	1,056
20	2.609	.1027	50.45	5,662	65	15.80	.6221	.3055	1,022
21	2.738	.1078	52.93	5,408	66	16.36	.6441	.3164	988.6
22	2.870	.1130	55.52	5,166	67	16.94	.6668	.3275	956.8
23	3.012	.1186	58.23	4,936	68	17.53	.6902	.3390	926.1
24	3.157	.1243	61.05	4,717	69	18.14	.7143	.3508	896.5
25	3.310	.1303	64.00	4,509	70	18.78	.7392	.3630	868.0
26	3.469	.1366	67.08	4,311	71	19.43	.7648	.3756	840.5
27	3.635	.1431	70.30	4,122	72	20.09	.7911	.3886	814.0
28	3.810	.1500	73.65	3,943	73	20.78	.8183	.4019	788.4
29	3.990	.1571	77.15	3,771	74	21.50	.8463	.4156	763.7
30	4.178	.1645	80.80	3,608	75	22.23	.8751	.4298	740.0
31	4.376	.1723	84.61	3,453	76	22.98	.9047	.4443	717.0
32	4.581	.1804	88.59	3,305	77	23.75	.9352	.4593	694.9

APPENDIX I (cont'd)
PROPERTIES OF SATURATED WATER VAPOR

Temp F	ABSOLUTE PRESSURE			Sp Vol cu ft per lb	Temp F	ABSOLUTE PRESSURE			Sp Vol cu ft per lb
	MM Hg	Inches Hg	Psi			MM Hg	Inches Hg	Psi	
78	24.55	.9667	.4748	673.5	113	71.91	2.831	1.390	244.6
79	25.38	.9990	.4907	652.9	114	73.97	2.912	1.430	238.1
80	26.21	1.032	.5070	633.0	115	76.10	2.996	1.472	231.8
81	27.08	1.066	.5238	613.8	116	78.28	3.082	1.514	225.7
82	28.00	1.102	.5411	595.3	117	80.52	3.170	1.557	219.8
83	28.91	1.138	.5589	577.4	118	82.83	3.261	1.601	214.1
84	29.85	1.175	.5772	560.1	119	85.17	3.353	1.647	208.6
85	30.84	1.214	.5960	543.3	120	87.58	3.448	1.693	203.2
86	31.83	1.253	.6154	527.2	121	90.04	3.545	1.741	197.9
87	32.84	1.293	.6353	511.6	122	92.56	3.644	1.790	192.9
88	33.91	1.335	.6557	496.5	123	95.17	3.745	1.840	187.9
89	35.00	1.378	.6768	482.0	124	97.79	3.850	1.891	183.2
90	36.12	1.422	.6984	467.9	125	100.7	3.956	1.943	178.5
91	37.26	1.467	.7206	454.3	126	103.3	4.065	1.997	174.0
92	38.46	1.514	.7434	441.1	127	106.1	4.177	2.051	169.6
93	39.65	1.561	.7668	428.4	128	109.0	4.291	2.107	165.4
94	40.89	1.610	.7909	416.1	129	112.0	4.408	2.165	161.3
95	42.19	1.661	.8156	404.2	130	115.0	4.527	2.224	157.3
96	43.49	1.712	.8410	392.7	135	131.3	5.168	2.538	138.9
97	44.83	1.765	.8671	381.5	140	149.5	5.884	2.890	123.0
98	46.23	1.820	.8939	370.7	145	169.8	6.683	3.282	109.1
99	47.65	1.876	.9214	360.3	150	192.4	7.573	3.719	97.04
100	49.10	1.933	.9496	350.2	155	217.5	8.561	4.205	86.50
101	50.60	1.992	.9785	340.4	160	245.3	9.656	4.742	77.27
102	52.15	2.053	1.008	331.0	165	276.1	10.87	5.337	69.17
103	53.72	2.115	1.039	321.8	170	309.9	12.20	5.994	62.04
104	55.35	2.179	1.070	312.9	175	347.5	13.68	6.717	55.77
105	57.00	2.244	1.102	304.4	180	388.4	15.29	7.512	50.22
106	58.70	2.311	1.135	296.0	185	433.6	17.07	8.384	45.31
107	60.45	2.380	1.169	288.0	190	483.1	19.02	9.340	40.96
108	62.23	2.450	1.203	280.2	195	537.0	21.14	10.39	37.09
109	64.08	2.523	1.239	272.6	200	596.1	23.47	11.53	33.64
110	65.96	2.597	1.275	265.3	205	660.4	26.00	12.77	30.57
111	67.89	2.673	1.313	258.2	210	730.3	28.75	14.12	27.82
112	69.88	2.751	1.351	251.3	212	759.99	29.92	14.690	26.80

Taken from - Handbook of American Society Heating & Ventilating Engineers, 1951 Edition, Table 3, page 43.
 Compiled by J. Goff and S. Gratch

APPENDIX J

STEAM JET VACUUM SYSTEM USER SPECIFICATION FORM

1	Company				Date		
2	Address						
3	Name			Title		Tel.	
4	Inq. No.			Project Ref.			
5	SUCTION CONDITIONS						
6	Mass Flow and Properties of Each Component (100% Flow)						
7	No.	Name	Flow (#/hr)	M.W.	Vap. Pres./Temp. Pairs (mm HgA & °F)	Lat. Ht. (BTU/#)	Vap. Cp/Liq. Cp (BTU/#/°F)
8	1.	Air		29		Gas	
9	2.						
10	3.						
11	4.						
12	Miscibility of condensibles in water (%)						
13	Suction Pres. (mm or in. HgA)						
14	Suction Temp. (°F)						
15	Evacuation: Initial Pres. (mm or in. HgA)				Initial Temp. (°F)		
16	Volume to be evacuated (cu ft)				Final Pres. (mm or in. HgA)		
17	Time for Evacuation (mins.)				Air-in Leakage (#/hr)		
18	DISCHARGE CONDITIONS						
19	Max Vent Pres. (in. HgA)						
20	Max Allowable Vent Temp. (°F)						
21	Normal Barometric Pres. (in. HgA)						
22	UTILITY CONDITIONS						
23	Steam						
24	Min Maintainable Supply Pres. (psig)				Total Temp. (°F)		
25	Max Supply Pres. (psig)				Total Temp. (°F)		
26	Cooling Water						
27	Max Supply Temp. (°F)				Max Δ T Allowed (°F)		
28	Supply Pres. (psig)				Max Δ P Allowed (psi)		
29	Min/Max Flow Available (gpm)						
30	CONSTRUCTION (Materials unless otherwise noted.)						
31	Ejectors: Nozzle(s)			Steam Chest			
32	Diffuser			Suction Chamber			
33	Steam Chest Design Pres. (psig)				Temp. (°F)		
34	Body Design Pres. (psig)				Temp. (°F)		
35	Condensers: ☐ Shell & Tube, or, ☐ Barometric (Direct Contact)						
36	Shell		Internals		Channel(s)		
37	Tube Sheet(s)			Tubes			
38	TEMA	☐ C	☐ B	or	☐ R	TEMA Type	
39	ASME Code Construction		☐ Yes	☐ No	Stamp ☐ Yes ☐ No		
40	Design Pres./Temp (psig/°F)		Shell Side		/	Tube Side /	
41	Fouling Factors		Shell Side		Tube Side		
42	Condensing in		☐ Shell or	☐ Tubes,	☐ Horizontal or		☐ Vertical
43	ACCESORIES AND OTHER REQUIREMENTS						
44							
45							

NOTE: See Section 3.0 for assistance in specifying steam jet vacuum systems.

HEAT EXCHANGE INSTITUTE

Ejector Test Report – Field Test Form

EQUIPMENT DESCRIPTION _____ SERIAL NUMBER _____ TEST NUMBER: _____

AMBIENT DATA

Barometric Pressure _____ In. HgA

Ambient Temp. _____ °F.

Water Temp. _____ °F

Design Suction Pressure _____ mm or Inches HgA

[illegible]

CERTIFIED BY: Signature _____ Title _____ Date _____

APPENDIX L FLOW OF WATER THROUGH SCHEDULE 40 STEEL PIPE

Discharge		Pressure Drop per 100 feet and Velocity in Schedule 40 Pipe for Water at 60°F															
Gallons per Minute	Cubic Ft. per Second	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.
		1/8"		1/4"		3/8"		1/2"		3/4"		1"		1 1/4"		1 1/2"	
.2	0.000446	1.13	1.86	0.616	0.359												
.3	0.000668	1.69	4.22	0.924	0.903	0.504	0.159	0.317	0.061	3/4"							
.4	0.000891	2.26	6.98	1.23	1.61	0.672	0.345	0.422	0.086								
.5	0.00111	2.82	10.5	1.54	2.39	0.840	0.539	0.528	0.167	0.301	0.033						
.6	0.00134	3.39	14.7	1.85	3.29	1.01	0.751	0.633	0.240	0.361	0.041						
.8	0.00178	4.52	25.0	2.46	5.44	1.34	1.25	0.844	0.408	0.481	0.102	1"		1 1/4"			
1	0.00223	5.65	37.2	3.08	8.28	1.68	1.85	1.06	0.600	0.602	0.155	0.371	0.048			1 1/2"	
2	0.00446	11.29	134.4	6.16	30.1	3.36	6.58	2.11	2.10	1.20	0.526	0.743	0.164	0.429	0.044		
3	0.00668			9.25	64.1	5.04	13.9	3.17	4.33	1.81	1.09	1.114	0.336	0.644	0.090	0.473	0.043
4	0.00891			12.33	111.2	6.72	23.9	4.22	7.42	2.41	1.83	1.49	0.565	0.858	0.150	0.630	0.071
5	0.01114	2"				8.40	36.7	5.28	11.2	3.01	2.75	1.86	0.835	1.073	0.223	0.788	0.104
6	0.01337	0.574	0.044	2 1/2"		10.08	51.9	6.33	15.8	3.61	3.84	2.23	1.17	1.29	0.309	0.946	0.145
8	0.01782	0.765	0.073			13.44	91.1	8.45	27.7	4.81	6.60	2.97	1.99	1.72	0.518	1.26	0.241
10	0.02228	0.956	0.108	0.670	0.046	3"		10.56	42.4	6.02	9.99	3.71	2.99	2.15	0.774	1.58	0.361
15	0.03342	1.43	0.224	1.01	0.094			9.03	21.6	5.57	6.36	3.22	1.63	3.22	1.63	2.37	0.755
20	0.04456	1.91	0.375	1.34	0.158	0.868	0.056	3 1/2"		12.03	37.8	7.43	10.9	4.29	2.78	3.16	1.28
25	0.05570	2.39	0.561	1.68	0.234	1.09	0.083	0.812	0.041	4"		9.28	16.7	5.37	4.22	3.94	1.93
30	0.06684	2.87	0.786	2.01	0.327	1.30	0.114	0.974	0.056	11.14	23.8	6.44	5.92	6.44	5.92	4.73	2.72
35	0.07798	3.35	1.05	2.35	0.436	1.52	0.151	1.14	0.704	0.882	0.041	12.99	32.2	7.51	7.90	5.52	3.64
40	0.08912	3.83	1.35	2.68	0.556	1.74	0.192	1.30	0.095	1.01	0.052	14.85	41.5	8.59	10.24	6.30	4.65
45	0.1003	4.30	1.67	3.02	0.668	1.95	0.239	1.46	0.117	1.13	0.064			9.67	12.80	7.09	5.85
50	0.1114	4.78	2.03	3.35	0.839	2.17	0.288	1.62	0.142	1.26	0.076	5"		10.74	15.66	7.88	7.15
60	0.1337	5.74	2.87	4.02	1.18	2.60	0.406	1.95	0.204	1.61	0.107			12.89	22.2	9.47	10.21
70	0.1560	6.70	3.84	4.69	1.59	3.04	0.540	2.27	0.261	1.76	0.143	1.12	0.047			11.05	13.71
80	0.1782	7.65	4.97	5.36	2.03	3.47	0.687	2.60	0.334	2.02	0.180	1.28	0.060			12.62	17.59
90	0.2005	8.60	6.20	6.03	2.53	3.91	0.861	2.92	0.416	2.27	0.224	1.44	0.074	6"		14.20	22.0
100	0.2228	9.56	7.59	6.70	3.09	4.34	1.05	3.25	0.509	2.52	0.272	1.60	0.090	1.11	0.036	15.78	26.9
125	0.2785	11.97	11.76	8.38	4.71	5.43	1.61	4.06	0.769	3.15	0.415	2.01	0.135	1.39	0.055	19.72	41.4
150	0.3342	14.36	16.70	10.05	6.69	6.51	2.24	4.87	1.08	3.78	0.580	2.41	0.190	1.67	0.077		
175	0.3899	16.75	22.3	11.73	8.97	7.60	3.00	5.68	1.44	4.41	0.774	2.81	0.253	1.94	0.102		
200	0.4456	19.14	28.8	13.42	11.68	8.68	3.87	6.49	1.85	5.04	0.985	3.21	0.323	2.22	0.130	8"	
225	0.5013	...	...	15.09	14.63	9.77	4.83	7.30	2.32	5.67	1.23	3.61	0.401	2.50	0.162	1.44	0.043
250	0.557	...	...	...	...	10.85	5.93	8.12	2.84	6.30	1.46	4.01	0.495	2.78	0.195	1.60	0.051
275	0.6127	...	...	...	...	11.94	7.14	8.93	3.40	6.93	1.79	4.41	0.583	3.05	0.234	1.76	0.061
300	0.6684	...	...	...	...	13.00	8.36	9.74	4.02	7.66	2.11	4.81	0.683	3.33	0.275	1.92	0.072
325	0.7241	...	...	...	...	14.12	9.89	10.53	4.09	8.19	2.47	5.21	0.797	3.61	0.320	2.08	0.083
350	0.7798	...	...	...	...	...	...	11.36	5.41	8.82	2.84	5.82	0.919	3.89	0.367	2.24	0.095
375	0.8355	...	...	...	...	...	...	12.17	6.18	9.45	3.25	6.02	1.05	4.16	0.416	2.40	0.108
400	0.8912	...	...	...	...	...	...	12.98	7.03	10.08	3.68	6.42	1.19	4.44	0.471	2.56	0.121
425	0.9469	...	...	...	...	...	...	13.80	7.89	10.71	4.12	6.82	1.33	4.72	0.529	2.73	0.136
450	1.003	10"		...	...	...	...	14.61	8.80	11.34	4.60	7.22	1.48	5.00	0.590	2.89	0.151
475	1.059	1.93	0.054	...	...	...	...	...	...	11.97	5.12	7.62	1.64	5.27	0.653	3.04	0.166
500	1.114	2.03	0.059	...	...	...	...	...	...	12.60	5.65	8.02	1.81	5.55	0.720	3.21	0.182
550	1.225	2.24	0.071	...	...	...	...	...	...	13.85	6.79	8.82	2.17	6.11	0.861	3.53	0.219
600	1.337	2.44	0.083	...	...	...	...	...	...	15.12	8.04	9.63	2.55	6.66	1.02	3.85	0.258
650	1.448	2.64	0.097	12"		...	...	...	...	...	...	10.43	2.98	7.22	1.18	4.17	0.301
700	1.560	2.85	0.112	2.01	0.047	...	...	...	...	...	...	11.23	3.43	7.78	1.35	4.49	0.343
750	1.671	3.05	0.127	2.15	0.054	14"		...	...	...	...	12.03	3.92	8.33	1.55	4.81	0.392
800	1.782	3.25	0.143	2.29	0.061	...	...	...	...	...	...	12.83	4.43	8.88	1.75	5.13	0.443
850	1.894	3.46	0.160	2.44	0.068	2.02	0.042	...	...	...	...	13.64	5.00	9.44	1.96	5.45	0.497
900	2.005	3.66	0.179	2.58	0.075	2.13	0.047	...	...	...	...	14.44	5.68	9.99	2.18	5.77	0.554
950	2.117	3.86	0.198	2.72	0.083	2.25	0.052	...	...	...	...	15.24	6.21	10.55	2.42	6.09	0.613
1 000	2.228	4.07	0.218	2.87	0.091	2.37	0.057	16"		...	...	16.04	6.84	11.10	2.68	6.41	0.675
1 100	2.451	4.48	0.260	3.15	0.110	2.61	0.068	...	...	...	...	17.65	8.23	12.22	3.22	7.05	0.807
1 200	2.674	4.88	0.306	3.44	0.128	2.85	0.080	2.18	0.042	...	...	...	...	13.33	3.81	7.70	0.948
1 300	2.896	5.29	0.355	3.73	0.150	3.08	0.093	2.36	0.048	...	...	...	...	14.43	4.45	8.33	1.11
1 400	3.119	5.70	0.409	4.01	0.171	3.32	0.107	2.54	0.055	...	...	...	...	15.55	5.13	8.98	1.28
1 500	3.342	6.10	0.466	4.30	0.195	3.56	0.122	2.72	0.063	18"		...	...	16.66	5.85	9.62	1.46
1 600	3.565	6.51	0.527	4.59	0.219	3.79	0.138	2.90	0.071	...	...	...	...	17.77	6.61	10.26	1.65
1 800	4.010	7.32	0.663	5.16	0.276	4.27	0.172	3.27	0.088	2.58	0.050	...	...	19.99	8.37	11.54	2.08
2 000	4.456	8.14	0.808	5.73	0.339	4.74	0.209	3.63	0.107	2.87	0.060	20"		22.21	10.3	12.82	2.55
2 500	5.570	10.17	1.24	7.17	0.515	5.93	0.321	4.54	0.163	3.59	0.091	...	...	...	...	16.03	3.94
3 000	6.684	12.20	1.76	8.60	0.731	7.11	0.451	5.45	0.232	4.30	0.129	3.46	0.075	24"		19.24	5.59
3 500	7.798	14.24	2.38	10.03	0.982	8.30	0.607	6.35	0.312	5.02	0.173	4.04	0.101	...	...	22.44	7.56
4 000	8.912	16.27	3.08	11.47	1.27	9.48	0.787	7.26	0.401	5.74	0.222	4.62	0.129	...	...	25.65	9.80
4 500	10.03	18.31	3.87	12.90	1.60	10.67	0.990	8.17	0.503	6.46	0.280	5.20	0.162	3.19	0.052	28.87	12.2
5 000	11.14	20.35	4.71	14.33	1.95	11.85	1.21	9.08	0.617	7.17	0.340	5.77	0.199	3.99	0.079	...	...
6 000	13.37	24.41	6.74	17.20	2.77	14.23	1.71	10.89	0.877	8.61	0.483	6.93	0.280	4.79	0.111	...	...
7 000	15.60	28.49	9.11	20.07	3.74	16.60	2.31	12.71	1.18	10.04	0.652	8.08	0.376	5.59	0.150	...	...
8 000	17.82	...	...	22.93	4.84	18.96	2.99	14.52	1.51	11.47	0.839	9.23	0.488	6.38	0.192	...	...
9 000	20.05	...	...	25.79	6.09	21.34	3.76	16.34	1.90	12.91	1.05	10.39	0.608	7.18	0.242	...	...
10 000	22.28	...	...	28.66	7.46	23.71	4.61	18.15	2.34	14.34	1.28	11.54	0.739	7.98	0.294	...	...
12 000	26.74	...	...	34.40	10.7	28.45	6.59	21.79	3.33	17.21	1.83	13.85	1.06	9.58	0.416	...	...
14 000	31.19	...	...	...	...	33.19	8.89	25.42	4.49	20.08	2.45	16.16	1.43	11.17	0.562	...	...
16 000	35.65	...	...	...	...	...	...	29.05	5.83	22.95	3.18	18.47	1.85	12.77	0.723	...	...
18 000	40.10	...	...	...	...	...	...	32.68	7.31	25.82	4.03	20.77	2.32	14.36	0.907	...	...
20 000	44.56	...	...	...	...	...	...	36.31	9.03	28.69	4.93	23.08	2.86	15.96	1.12	...	...</

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