

HEAT EXCHANGE INSTITUTE, INC.

STANDARDS and TYPICAL SPECIFICATIONS for **DEAERATORS**

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DEAERATORS

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FOREWORD

The fifth edition of this standard has been developed by Kansas City Heater Co., The Permutit Co., Inc., and Stickle Steam Specialties Co., members of the Deaerator Section of the Heat Exchange Institute. This standard provides practical information on the design of deaerators and serves as a guide to individuals who design, purchase, and specify deaerators.

It is intended that these standards be periodically reviewed and updated. Comments and suggestions for improvements by users of deaerators are welcomed and should be directed to the Deaerator Section at the Institute's address. This edition represents the first revision after a long hiatus and was necessitated by

changes in the Industry. Future revisions will be made during scheduled meetings by the deaerator technical committee.

In the writing of this standard, consideration has been given to the work done by National Association of Corrosion Engineers (NACE) and Technical Association of The Pulp and Paper Industry (TAPPI) on deaerator cracking. Credit is hereby given to those organizations for the extensive work done by them on this problem. In particular, reference is made to NACE Standard RP0590-90, adherence to which is strongly recommended.

1.0 SCOPE AND PURPOSE

1.1 Scope

The 5th edition of the HEI Standards for Deaerators is intended to apply to open type heaters where water is contacted with steam, condensing the steam, and where non-condensable gases are removed from the incoming water. While commonly referred to as a deaerator, the terms deaerating feedwater heater and deaerating heater are also widely used.

1.2 Purpose

This standard has been completely revised and developed to give guidance to persons specifying deaerators as well as to deaerator purchasers and manufacturers. It is intended to delineate some of the

critical areas of the design features of this type of heater. The equipment covered by this standard should also conform to the appropriate part of the ASME Boiler and Pressure Vessel Code, commonly Section VIII, Division 1, although other sections and divisions can be utilized. While this standard is intended to apply to all deaerators, some specialized types may require additional specifications. In particular, those used in Heat Recovery Steam Generator (HRSG) applications will be reviewed and elaborated on in future additions of these standards. The present HEI requirements will be required as a minimum standard for Section 1 HRSG Integral Deaerators.

2.0 DEFINITIONS

2.1 Deaerator

A deaerator is defined as a mechanical device for removal of dissolved gases, primarily oxygen and carbon dioxide from water. For the purposes of this standard, we will consider only thermal or hot water deaerators which deaerate by contacting water with steam and elevating the temperature. Vacuum deaerators remove dissolved gases by reducing the pressure over the liquid without heating and will not be considered in this standard at this time. Also, in cases where the storage section is a separate vessel, the term deaerator is used to describe what might better be called the deaerator vessel or deaerator section.

2.2 Tray Deaerator

This is a common industry term for a type of deaerator also known as a spray-tray deaerator. Inlet water is sprayed into a steam atmosphere and falls onto a bank of trays through which the steam passes. Steam flow may be co-current, cross-current, or counter-current to the water flow.

2.3 Spray Deaerator

This is the common industry term for a unit which might more properly be called a spray-scrubber or a spray atomizing deaerator. Inlet water is sprayed into a steam atmosphere and falls onto a spray deck or catchment from which it flows into the scrubber/atomizer where it is mixed with incoming steam.

2.4 Storage Section

The storage section is an area in a deaerator which contains a specified volume of water. This may be contained in the lower portion of an integral unit or may be a separate tank located below the deaerator tank. The storage capacity is defined as the amount of water in the full storage vessel. HEI requires a minimum of 12 minutes of storage unless contrary to the specifications. See Section 7.3.

2.5 Vent Condenser

The vent condenser is an area in a deaerator where steam is cooled by the incoming water and caused to

condense. External shell and tube heat exchangers were historically used, but internal, direct-contact vent condensers are commonly used today.

2.6 Vent

A vent is an opening in the deaerator through which the non-condensable gases and some steam are released. This release is normally to the atmosphere although it is possible to vent to a vacuum for special applications.

2.7 Design Pressure

The pressure for which the shell and heads of the deaerator vessel and storage tank are mechanically designed.

2.8 Operating Pressure

The operating pressure is the pressure inside the deaerator when operating. This pressure is important as it determines what the temperature of the deaerator outlet will be. The deaerator outlet temperature will be the saturated temperature at the operating pressure.

2.9 Corrosion Allowance

An additional thickness of steel added to the shell, heads, and nozzles in addition to that required to meet the structural requirements for pressure vessel design at a given pressure.

2.10 Rated Capacity

The total quantity of hot water leaving the deaerator, including condensed inlet steam and high pressure returns, normally expressed in pounds per hour.

2.11 Effective Storage

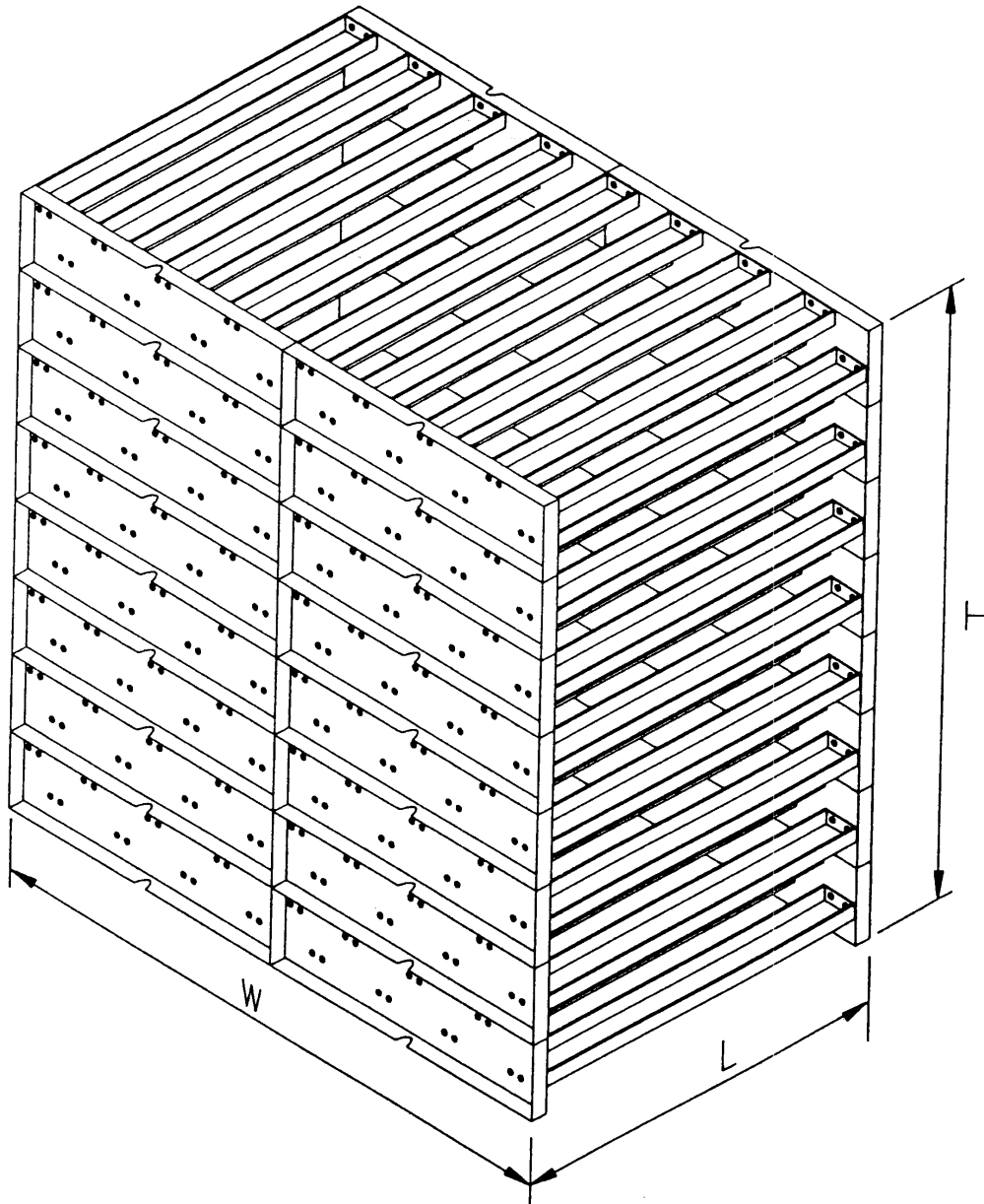
The volume of water deemed to be usable, normally between the overflow level and the top of the pump suction nozzle. It is a nominal figure calculated by disregarding the thickness of the vessel steel and thermal expansion of the steel.

2.12 Trap Returns

A trap return is water from a steam trap in a high pressure steam line. This will usually be at a temperature substantially above the operating temperature of the deaerator and will therefore flash upon entering the deaerator.

2.13 Total Tray Stack Volume

Total tray stack volume is the total volume of all of the tray bundles, i.e. height X length X width of total trays. See Figure 1.



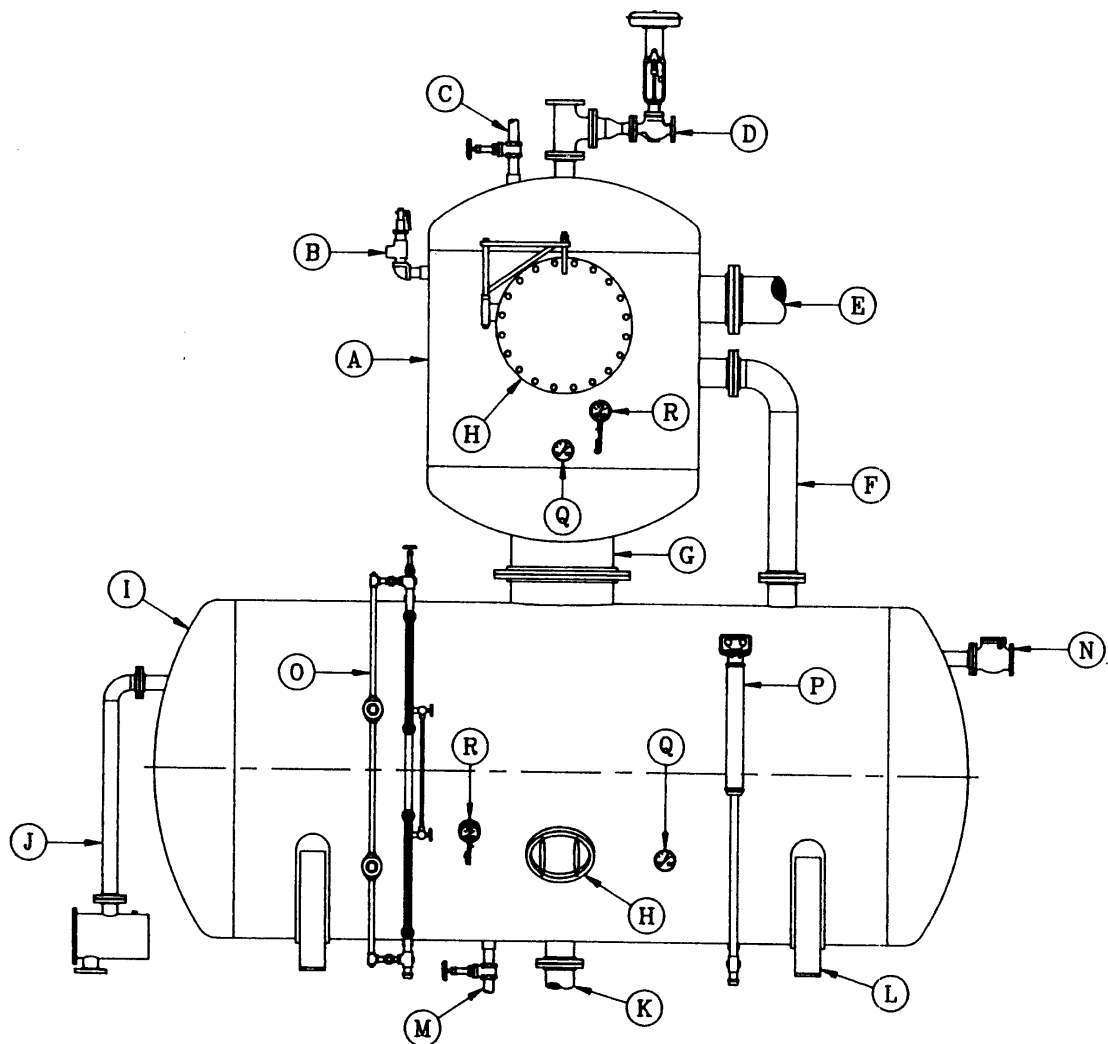
$$\text{TOTAL TRAY STACK VOLUME} = (L \times W \times H) \text{ in}^3$$

Fig. No. 1

3.0 NOMENCLATURE

With the view of establishing standard terminology, the following diagram is shown. The sketch itself

is merely illustrative for the purpose of indicating names of parts.



- | | |
|---------------------|----------------------------|
| A Deaerator Section | J Overflow |
| B Relief Valve | K Outlet |
| C Vent | L Support Saddle |
| D Inlet | M Drain |
| E Steam Inlet | N Vacuum Breaker |
| F Equalizer | O Level Gauge/Alarm Column |
| G Downcomer | P Level Controller |
| H Access Manway | Q Thermometer |
| I Storage Section | R Pressure Gauge |

Fig. No. 2

4.0 ILLUSTRATIONS OF TYPICAL ARRANGEMENTS

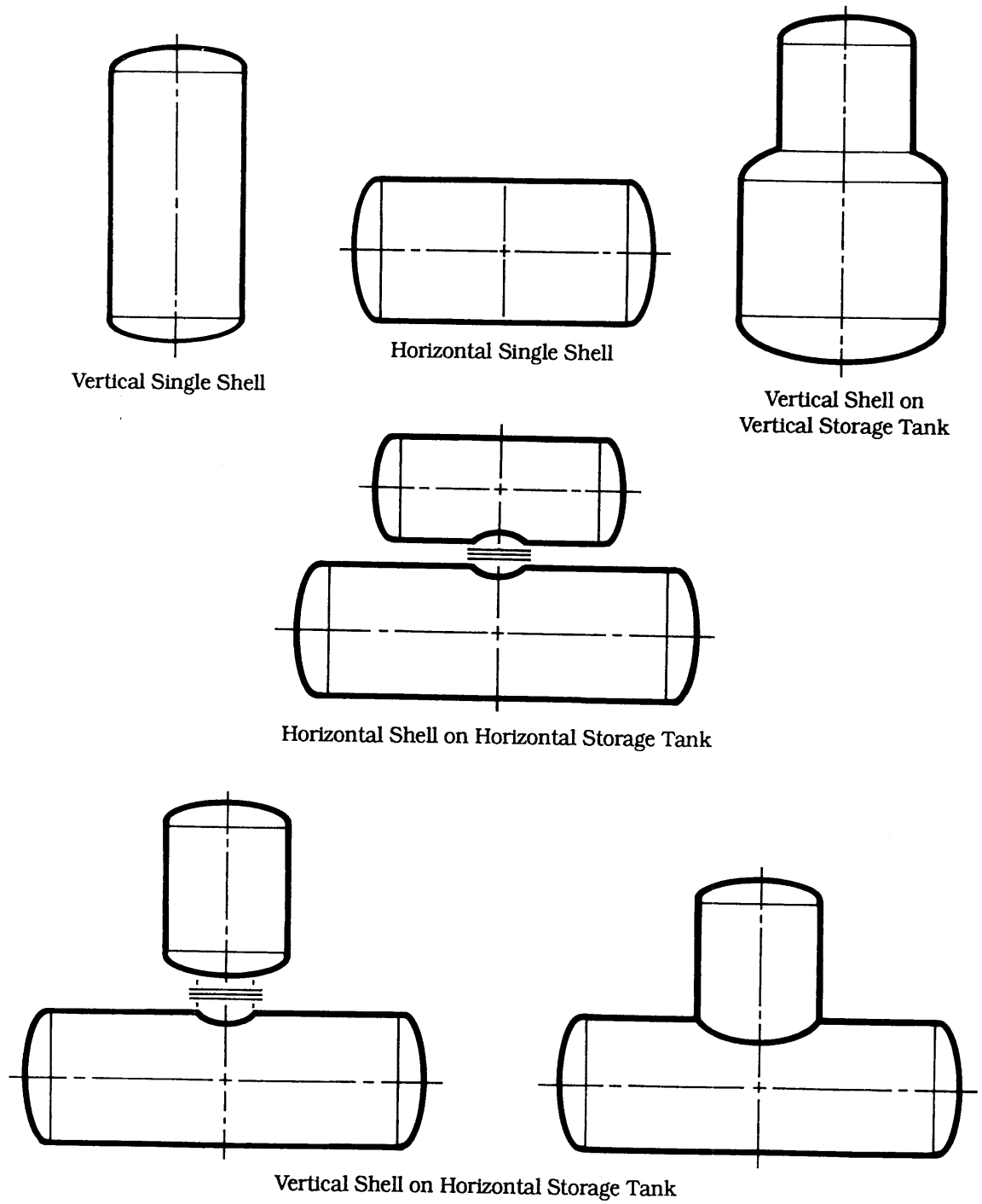


Fig. No. 3

5.0 STANDARDS OF CONSTRUCTION

5.1 Code Requirements

A deaerator shall be constructed in accordance with the applicable portion of the ASME Code, normally Section VIII, Division 1, and the appropriate state and local requirements for pressure vessel construction, seismic design, wind loads, etc.

5.2 Operating Conditions

In order for the deaerator manufacturer to properly design the unit, the buyer must make available all known operating conditions and circumstances (heat/mass balances), including especially, start-up, minimum flow, maximum flow, and others. Simply providing a design condition may not provide sufficient information to adequately design the unit.

5.3 Special Design Requirements

Studies have indicated that strict adherence to the ASME Code may not be adequate for deaerator design. Many of these units operate at conditions which require more stringent design standards. Deaerator design should therefore incorporate the following, in addition to the ASME Code:

- (1) A corrosion allowance of 1/8" is required for shell and heads. When the unit is designed for vacuum 1/16" of the 1/8" corrosion allowance may be used in the vacuum calculation.
- (2) The vessels shall be Post Weld Heat Treated (PWHT). Treatment shall be as described in the ASME Code.
- (3) Internal weld seams shall be ground smooth.
- (4) Wet Fluorescent Magnetic Particle Testing (WFMPT) shall be performed for nozzles.
- (5) All vessel shell and head seams, longitudinal and circumferential, shall be 100% x-rayed.

5.4 Pressure/Vacuum Design

The vessels shall be designed for the proper internal pressure and temperature as determined by user/engineer. Minimum internal design pressure shall be 30 psig. Minimum design temperature shall be 400 degrees F. The vessels shall be designed for vacuum or shall be provided with a vacuum relief device by owner.

5.5 Deaerator Outlet Design

The pump suction outlet nozzle shall extend a minimum of 3" into the storage section. A vortex breaker shall be provided.

5.6 Relief Valve

A sentinel relief valve shall be provided. Purchaser shall provide a relief valve in his steam line capable of passing the full capacity of the pressure control valve in the failed open condition. Additionally, this valve should protect the system from overpressure buildup that would exceed the design pressure of the deaerator.

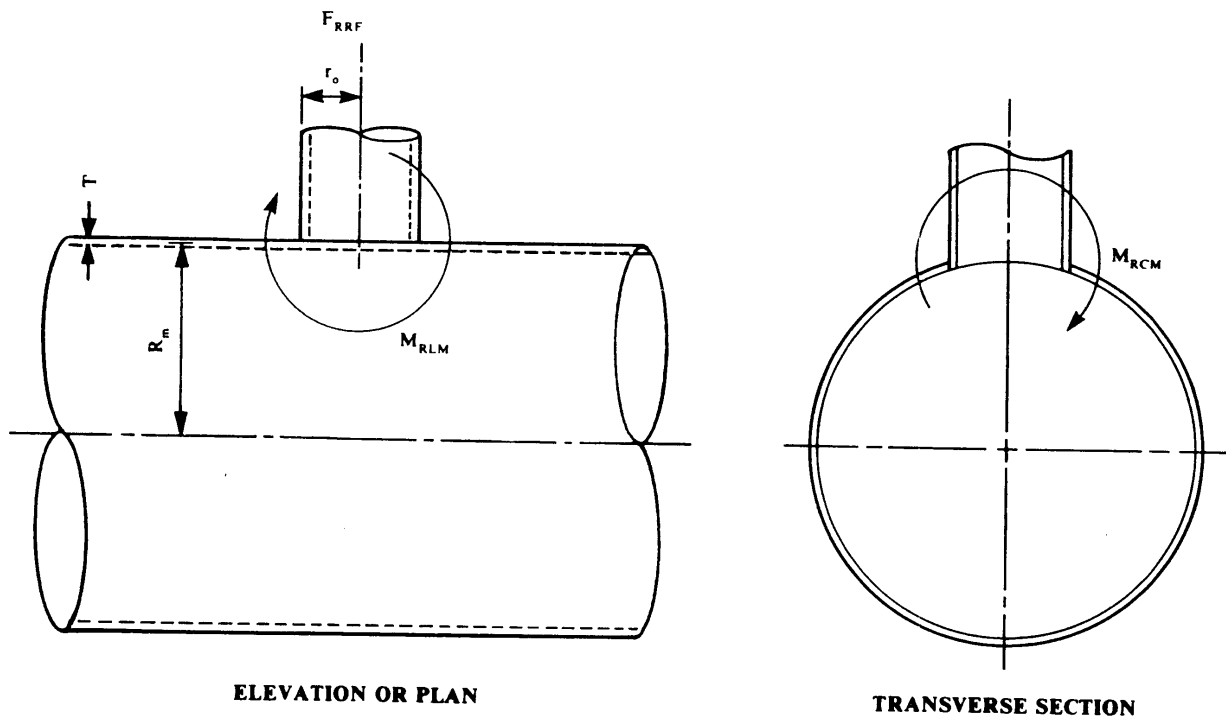
5.7 Nozzle Loads

The determination of acceptable nozzle loads is a complex problem involving the interaction of external forces and moments applied at the vessel wall. These loads are functions of the mechanical and thermal piping design. Frequently, the piping designer has a need to know the allowable loads at the nozzle in order to determine the piping configuration and generate the actual loads. The procedure below permits estimating nozzle loads for cylindrical shells. The procedure is based in part on the design data included in Welding Research Council Bulletin 107.¹ The allowable loads have been linearized to show the interaction between the maximum permitted external radial load and the maximum permitted applied moment vector.

The procedure represents a simplification of the method of WRC 107 and users of the procedure included in this standard are cautioned that more exact analysis is required to verify the adequacy of final designs. The stresses considered in developing the procedure have been defined as secondary stresses with stress limits established according to the definition. Although the effect of internal pressure has been included in the combined stresses, the effect of pressure on nozzle thrust has not been included and requires combination with other radial loads.

Loads exceeding those calculated by this method usually require additional reinforcement. The user is cautioned that the higher allowable loads obtained through design modification may require strengthening other parts such as supports, supporting structure and floors. It should be understood by the user that the deaerators are not intended to serve as anchor points for the piping.

¹ Local Stresses in Spherical and Cylindrical Shells Due to External Loadings, K. R. Wichman, A. G. Hopper and J. L. Mershon - Welding Research Council. Bulletin 107/August 1965 - Revised Printing - December 1968.



PROCEDURE FOR CALCULATING NOZZLE EXTERNAL FORCES AND MOMENTS IN CYLINDRICAL VESSELS

Fig. No. 4

5.7.1 Nomenclature

P	= Design Pressure, pounds per square inch
r_o	= Nozzle Outside Radius, inches
R_m	= Mean Radius of Shell, inches
T	= Shell Thickness, inches
S_y	= Yield Strength of Material at Design Temperature, pounds per square inch
σ	= Stress Due to Design Pressure, pounds per square inch
S_a	= ASME Section VIII, Division 1 Code Allowable Stress, pounds per square inch
β	= Dimensionless Numbers
γ	= Dimensionless Numbers
α	= Dimensionless Numbers
Σ	= Dimensionless Numbers
Δ	= Dimensionless Numbers

F_{RRF}	= Maximum Resultant Radial Force, pounds*
M_{RCM}	= Maximum Resultant Circumferential Moment, inch-pounds*
M_{RLM}	= Maximum Resultant Longitudinal Moment, inch-pounds*
F_{RF}	= Maximum Resultant Force, pounds*
M_{RM}	= Maximum Resultant Moment, inch-pounds*

*Use absolute values.

5.7.2 External Forces and Moments

To calculate the maximum force and moment, first evaluate β and γ . Then determine α , Σ and Δ from Figures 4, 5 and 6 for the specified β and γ , substitute into the equations below and calculate F_{RRF} , M_{RCM} and M_{RLM} .

$$\beta = .875 \left(\frac{r_o}{R_m} \right) \quad \gamma = \frac{R_m}{T}$$

Determine α , Σ and Δ from Figures 7, 8 and 9.
Calculate Pressure Stress (σ).

$$\sigma = \frac{2P}{T} \left(R_m - \frac{T}{2} \right)$$

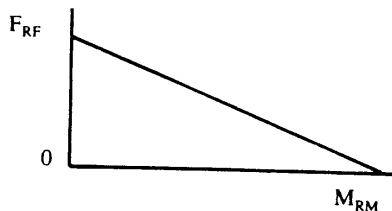
If σ is greater than S_u , then use S_u as the stress due to design pressure:

$$F_{RRF} = \frac{R_m^2}{\alpha} (S_y - \sigma)$$

$$M_{RCM} = \frac{R_m^2 r_o S_y}{\Sigma}$$

$$M_{RLM} = \frac{R_m^2 r_o}{\Delta} (S_y - \sigma)$$

Plot the value of F_{RRF} as F_{RF} and the smaller of M_{RCM} and M_{RLM} as M_{RM} . The allowable nozzle loads are bounded by the area F_{RF} , 0, M_{RM} .



3.14.3 Sample Problem

Determine Resultant Force and Moment

$$R_m = 37.5 \quad S_y = 31,500 \text{ psi @ } 460^\circ$$

$$r_o = 15'' \quad S_u = 17,500 \text{ psi}$$

$$T = .75''$$

$$P = 150 \text{ psi}$$

$$\beta = .875 \left(\frac{r_o}{R_m} \right) = .875 \left(\frac{15}{37.5} \right) = .35$$

$$\gamma = \left(\frac{R_m}{T} \right) = \frac{37.5}{.75} = 50$$

$$\text{From Figure 5, } \alpha = 440$$

$$\text{From Figure 6, } \Sigma = 1,070$$

$$\text{From Figure 7, } \Delta = 340$$

Calculate Pressure Stress

$$\sigma = \frac{2P}{T} \left(R_m - \frac{T}{2} \right) = \frac{2(150)}{.75} \left(37.5 - \frac{.75}{2} \right) =$$

$$14,850 \text{ psi} < S_u = 17,500 \text{ psi}$$

Use $\sigma = 14,850$ in the equations for calculating F_{RRF} and M_{RLM} .

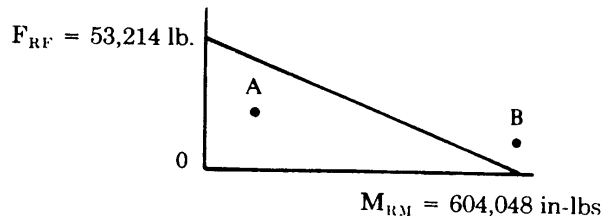
Calculate Allowable Forces and Moments

$$F_{RRF} = \frac{R_m^2}{\alpha} (S_y - \sigma) = \frac{(37.5)^2}{440} (31,500 - 14,850) = 53,214 \text{ lb}$$

$$M_{RCM} = \frac{R_m^2 r_o S_y}{\Sigma} = \frac{(37.5)^2 (15) (31,500)}{1,100} = 604,048 \text{ in-lb}$$

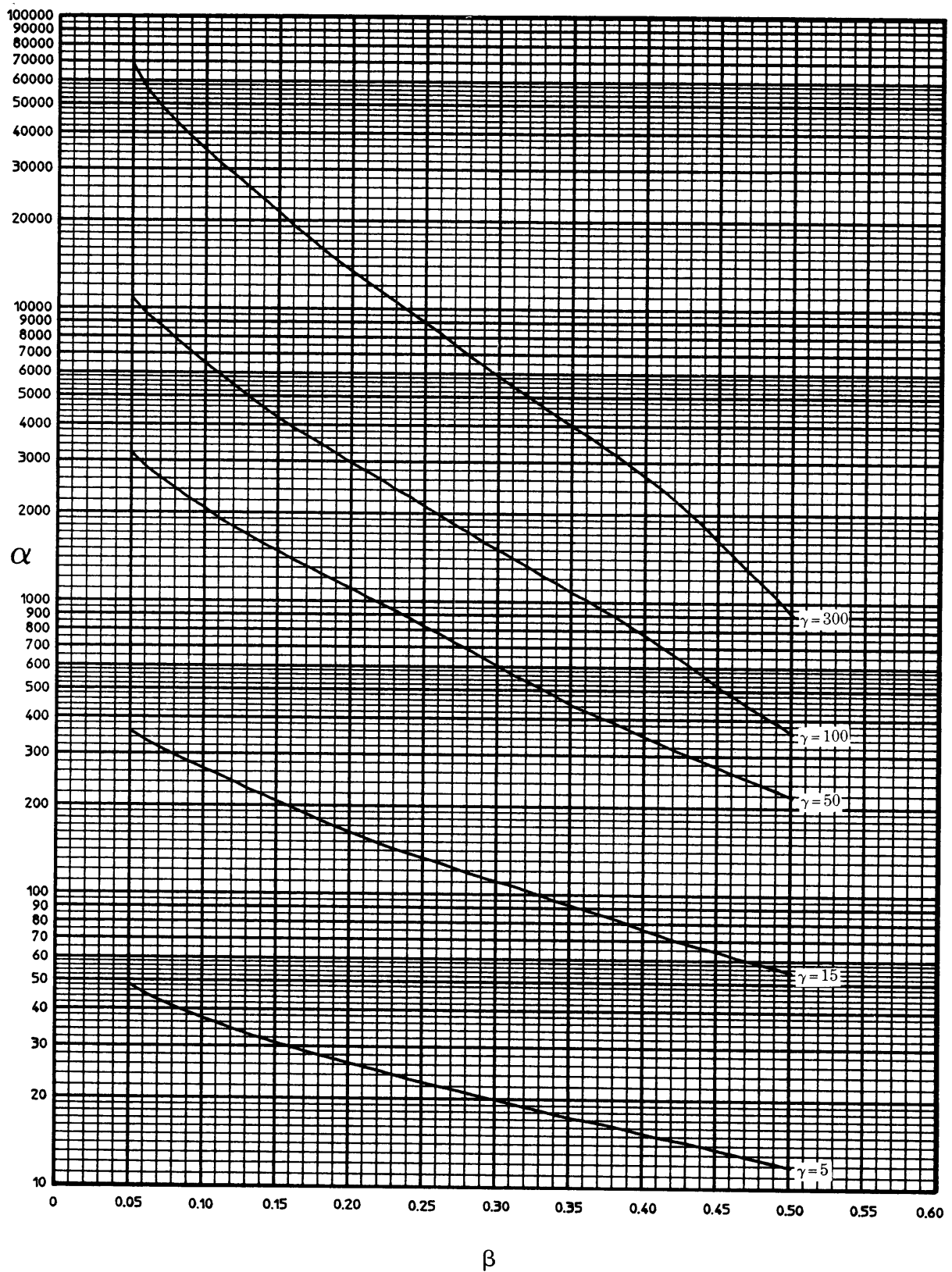
$$M_{RLM} = \frac{R_m^2 r_o}{\Delta} (S_y - \sigma) = \frac{(37.5)^2 (15) (31,500 - 14,850)}{340} = 1,032,973 \text{ in-lb}$$

Plot the value of F_{RRF} as F_{RF} and the smaller of M_{RCM} and M_{RLM} as M_{RM} . The allowable nozzle loads are bounded by the area of F_{RF} , 0, M_{RM} .



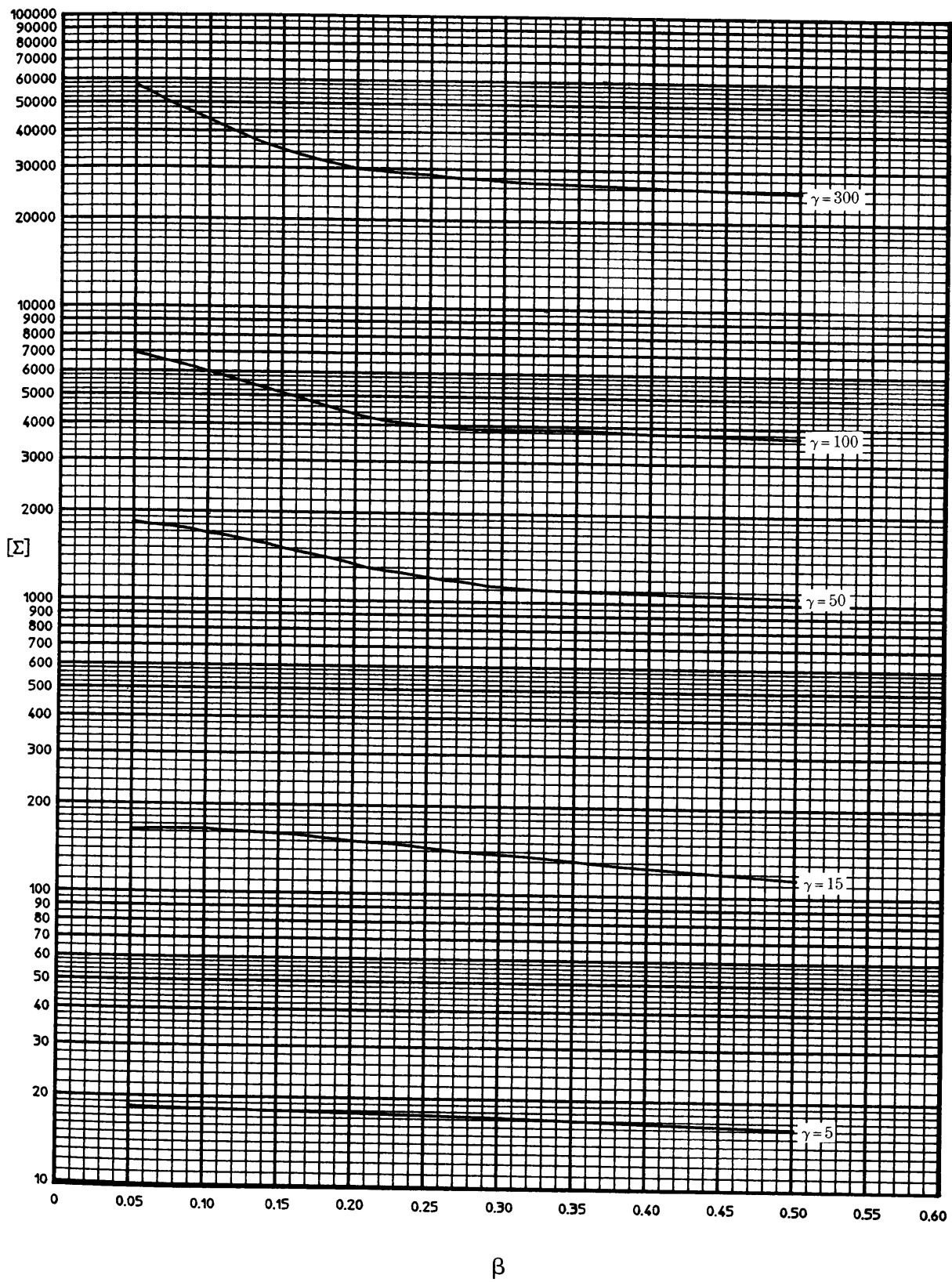
Therefore, a nozzle reaction of $F = 20,000$ lbs. and $M = 100,000$ in-lbs would be allowable (point A) but a nozzle reaction of $F = 5,000$ lbs. and $M = 604,000^*$ in-lbs would not be allowable (point B).

*Note: Use absolute values in the graph.



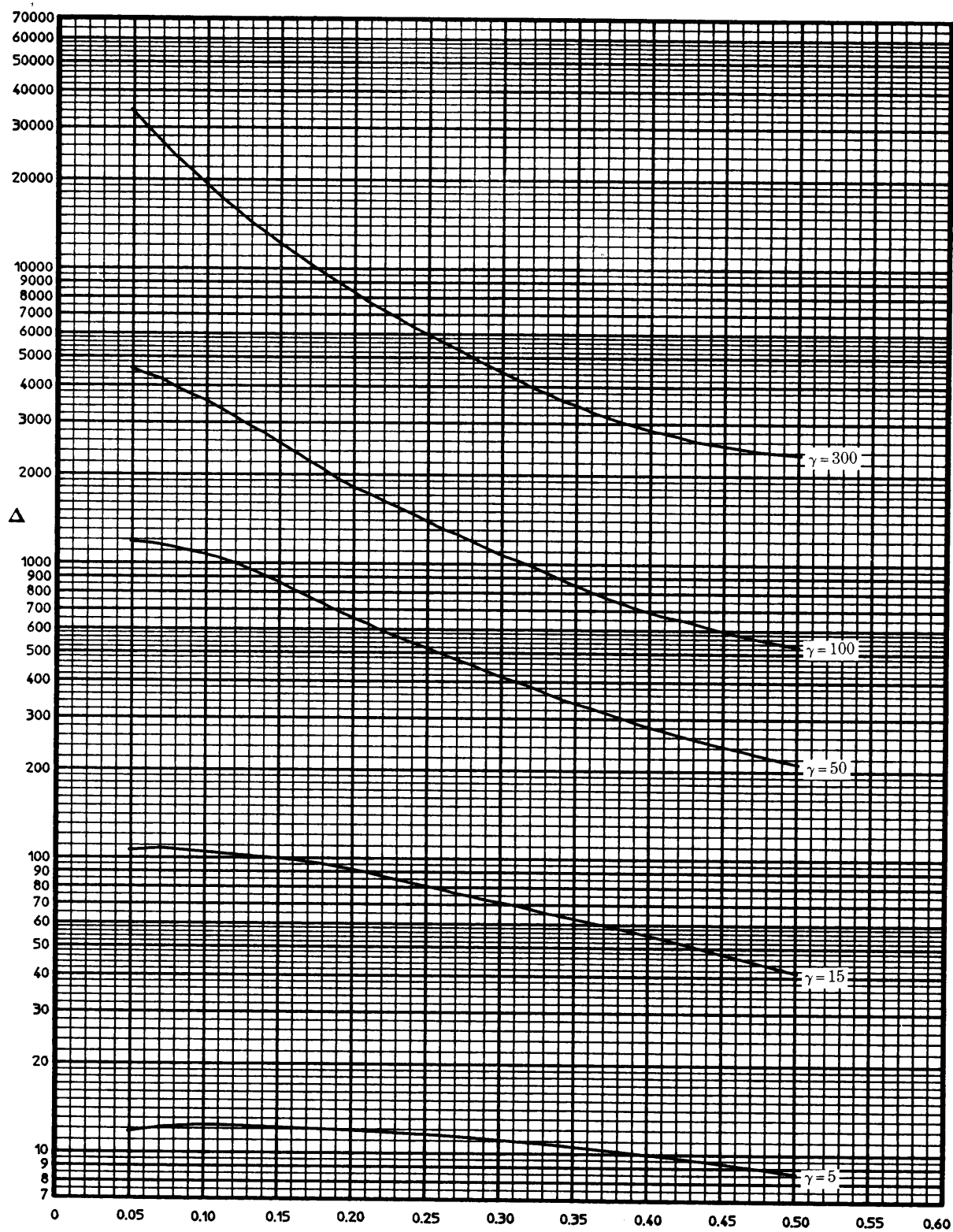
ALLOWABLE NOZZLE LOADS

Fig. No. 5



ALLOWABLE NOZZLE LOADS

Fig. No. 6



β

ALLOWABLE NOZZLE LOADS

Fig. No. 7

5.8 Nozzle Sizes

The deaerator shall be provided with steam inlet, water inlet, pump suction, overflow, drain, vent, relief valve, sample, pressure gauge, and thermometer connections. Other connections as required for particular installation may be provided. All openings for connections 2-1/2" diameter and larger shall have standard ASA flanges. All others shall be threaded IPS. Alternately, weld-end or socket weld connections may be used. Suitable openings shall be provided for inspection and removal of parts.

Sizing of openings should consider velocities within the ranges specified:

Connection	Velocity
Water Inlet	6-8 fps
Steam Inlet	125-175 fps
Pump Suction	3-5 fps
Overflow	3-5 fps
Drain	10-14 fps

Manways – Minimum elliptical manway size shall be 12" x 16" on the storage vessel. Tray deaerators shall employ a minimum of 18" hinged or davited manway on the deaerator section.

Mixing high temperature and low temperature flows internal to the deaerator can cause thermal stresses, potentially damaging to the deaerator internals. Make-up and low pressure condensate shall be mixed prior to introduction into the deaerator to eliminate possible damage to the internals. Make-up and low pressure condensate, including all flows lower than the outlet deaerator temperature shall be mixed in a tee external to the deaerator in the external piping scope. Flows with temperatures higher than the operating temperature (flashing returns) shall be introduced elsewhere.

5.9 ACCESSORIES

5.9.1 Sizes of Accessories

The sizes of some accessories suitable for use with deaerating units of various capacities are tabulated in Table 1. Selection of sizes should be based on maximum operating conditions specified. Accessories shall be provided when specifically requested by the owner.

TABLE 1
Standard Relief Valve and Vacuum Breaker
Selection Table

Rated Capacity	Relief Valve	Vacuum Breaker
Lbs./Hr.	Size Inches	Size Inches
10,000	1-1/2	1
20,000	2	1-1/2
45,000	2-1/2	2
100,000	3	2-1/2
200,000	4	3
600,000	6	4
1,200,000 and over	2-6	6

Note 1: This table lists the minimum sizes of suitable accessories for operating pressures up to 50 psig.

Note 2: Use the higher capacity rating in selecting accessories.

Note 3: These relief valve sizes are intended to protect the deaerator from overpressure which may be caused by trap discharges. These safety relief valves may not be adequate to protect the equipment from overpressure from other causes. Since possible overpressure in a deaerator is a function of the steam system, it is the responsibility of the purchaser to provide adequate relieving capacity for all components in the system.

5.9.2 Water Inlet Regulating Valves and Controls

It may be desirable to control the water flow from one or more sources. The valve size depends on the required flow rate and the pressure at the valve inlet. Direct linkage operated valves are controlled by floats in the storage space of the equipment or located in external float cages. Air operated valves are actuated through pilots controlled by ball floats, displacement floats, or differential level devices usually externally mounted on the deaerator. External control equipment shall be complete with equalizing lines and shut-off valves to connect to the storage space.

5.9.3 Overflow Control

This control is a device to protect against high water level in the deaerator and shall be a trap or externally float controlled valve.

5.9.4 Safety Relief Valve

This valve is intended to protect the deaerator from excessive pressure generated from trap discharges. Since possible overpressure in a deaerator is a function of the steam system, it is the responsibility of the purchaser to provide adequate relieving capacity for all components in the system.

5.9.5 Gauge Glasses

Gauge glasses to show water level in the storage compartment should be included.

5.9.6 Thermometers

Thermometers, properly located, give a visual indication of deaerator performance. Probable locations are the steam space of the deaerator, and storage compartment of the deaerator.

Thermometers may be mercury, dial, remote reading, or recording type.

5.9.7 High and/or Low Water Alarm Switches

Switches may be desirable for warning of high or low water levels. Audible or visible alarms may be specified if desired.

5.9.8 Pressure Gauge

A pressure gauge shall be provided for the steam space. Range shall cover the entire operating pressure of the unit.

5.9.9 Vent Valve

A properly sized vent valve or vent orifice shall be provided.

5.9.10 Steam Pressure Reducing Valve

Units operating at pressures lower than the available steam pressure shall be provided with a steam pressure reducing valve. Supplier of the pressure reducing valve shall provide an adequately sized relief valve.

5.10 OTHER DESIGN CONSIDERATIONS

In many plants today, it is necessary to save energy in every way possible. One of the ways this is done is to heat the inlet water to the deaerator, usually using a shell and tube heat exchanger. It should be recognized that this practice may be detrimental to proper deaerator operation and may also shorten deaerator life, often by many years. Preheating the cold make-up water to the deaerator reduces steam demand in the deaerator, but more importantly, if the inlet water is saturated with or near saturation with oxygen, preheating it may cause liberation of this oxygen which the deaerator can no longer remove. This should be taken into consideration in the original design concept of the plant and in subsequent modifications.

Deaerators operate best when operated as steady-state heat exchangers. It must be recognized that frequent cooldown and reheat of a deaerator can cause cracking. It is suggested that deaerators operated

intermittently be provided with an auxiliary means of warming the stored water prior to start-up, such as a sparger pipe or other method.

When operated properly, deaerators can and do produce water with very low levels of dissolved oxygen. In order to determine what oxygen level the deaerator is producing, it is necessary that the analysis be very carefully conducted. Atmospheric oxygen which enters a water sample can result in a completely erroneous reading. The analyst must be extremely careful to prevent oxygen from entering his sample. Oxygen can be introduced into pressurized piping systems through leaking pump seals and by other mechanical means. Sample points should therefore be located as close as possible to the deaerator, preferably on the storage tank itself. Failing this, they should be located prior to the boiler feed pumps. Sample lines themselves must be carefully checked for tightness and test instruments calibrated.

6.0 MATERIALS OF CONSTRUCTION

6.1 General

The materials used for pressure parts and for external supports, where applicable, shall be in accordance with the ASME Code, as necessitated by the Design Specifications.

Some materials which are permitted for use in Section VIII deaerators may not be permitted by the ASME Code for use in the construction of Section I deaerators. Furthermore, the required tests and inspections differ depending on the applicable section of the ASME Code.

In general on tray units all materials in contact with undeaerated or partially deaerated water shall be a minimum of 1/8" thick stainless steel including from the inlet nozzle, water box, water box lining, vent condenser valve plate, vent, and spray valves. Tray enclosures shall be a minimum of 1/8" thick stainless steel or 1/4" thick carbon steel. Trays shall be a minimum of 20 gauge stainless steel.

All materials including heads and shells in contact with steam which has previously been in contact with undeaerated water or partially deaerated water shall be stainless steel or stainless steel lined.

It would be impractical to list all the materials that may be used in Code constructed units; however, some of the more commonly used materials and the parts for which they are used are given in Table 2. It should be noted that the specification number indicated may not be acceptable for use in all ASME Code Sections. It is recommended that the materials in Table 2 be utilized as minimum requirements for materials of construction. It is recommended that SA-515 not be utilized.

6.2 Gaskets

The choice of suitable gasket material depends upon the condition of service and, unless otherwise specified by the Purchaser, will be in accordance with the standards of the deaerator manufacturer.

6.3 Make-Up Inlet Nozzle

The make-up inlet nozzle for deaerators shall be stainless steel, or stainless steel lined.

6.4 Water Box/and Water Box Liner

The water box shall be stainless steel with a stainless steel liner so as to prohibit all undeaerated water from coming in contact with any carbon steel.

6.5 Valve Plate/Vent Condenser

The valve plate and vent condenser is where concentrated oxygen collects and shall be constructed with stainless steel.

6.6 Tray Enclosure

The tray enclosure contains the trays that remove the final traces of oxygen and should be either 1/8" thick stainless steel, or 1/4" thick carbon steel.

6.7 Trays

Trays shall be stainless steel and shall be stamped or riveted. Welding of trays shall not be utilized for tray construction.

6.8 Corrosion Allowance & Minimum Thickness

The vessel head and shells shall be fabricated in accordance with the ASME Code and shall be a minimum of 1/8" thick plus 1/8" corrosion allowance totaling 1/4". Nozzles, reinforcing pads, nozzle necks, and manway covers shall include a minimum of 1/16" corrosion allowance.

Additional minimum thickness of materials are required for deaerator internals.

TABLE 2

For deaerator internals:	
Water Box	1/4" S.S.
Tray Enclosure	1/8" S.S. or 1/4" C.S.
Vent Condenser/Hood	1/8" S.S.
Trays	20 Gauge S.S.
Baffles	1/4" S.S.
Drip Shields/Vortex Breakers	1/4" C.S.

7.0 DEAERATOR PERFORMANCE

7.1 Thermal Capacity

The deaerator shall be guaranteed to heat the influent water to the temperature corresponding to the saturation temperature of the deaerator at the operating pressure. The user shall provide the minimum inlet water temperature, percentage make-up and operating pressure at that condition. (Reference Deaerating Feedwater Heater Data Sheet attached).

7.2 Performance Guarantee

The deaerator shall be guaranteed to remove oxygen in the effluent from 10% to 100% of design point to .005 ml/liter (7PPB) when tested by the ASTM D888 Method A (Colormetric Indigo Carmine).

The deaerator shall remove all carbon dioxide from loads of 10% to 100% when tested by the APHA method.

A sample connection is to be provided in the storage section. Length of sample lines should be at a mini-

mum between storage section and sample cooler with as few fittings as possible.

7.3 Storage Capacity

For deaerators with separate storage and deaerating vessels, it is recommended that a twelve minute storage be supplied as a minimum unless the engineer feels that less storage capacity is acceptable. The storage capability shall be that volume of water in the storage vessel when completely full. The overflow level shall not be closer to the top of the vessel than 85% of the tank diameter.

For a single tank deaerator with integral storage, the storage capacity shall be 10 minutes to overflow as determined by the manufacturer's design criteria.

The storage capacity shall be calculated using the density of water at the effluent temperature.

Refer to Table 2 for approximate storage requirements for different rated capacities.

3

10 MINUTES				12 MINUTES			
Flow PPH	Lbs	Cu Ft	Gallons	Lbs	Cu Ft	Gallons	Flow PPH
10,000	1,667	28	208	2,000	33	249	10,000
20,000	3,334	56	416	4,000	67	499	20,000
30,000	5,000	83	623	6,000	100	748	30,000
40,000	6,667	111	831	8,000	133	997	40,000
50,000	8,334	139	1,039	10,000	167	1,247	50,000
60,000	10,000	167	1,247	12,000	200	1,496	60,000
75,000	12,500	208	1,558	15,000	250	1,870	75,000
100,000	16,667	278	2,078	20,000	333	2,493	100,000
150,000	25,000	417	3,117	30,000	500	3,740	150,000
200,000	33,334	556	4,156	40,000	667	4,987	200,000
250,000	41,667	694	5,195	50,000	833	6,233	250,000
300,000	50,000	833	6,233	60,000	1,000	7,480	300,000
400,000	66,667	1,111	8,311	80,000	1,333	9,973	400,000
500,000	83,334	1,389	10,389	100,000	1,667	12,467	500,000
600,000	100,000	1,667	12,467	120,000	2,000	14,960	600,000
700,000	116,667	1,944	14,545	140,000	2,333	17,453	700,000
800,000	133,334	2,222	16,622	160,000	2,667	19,947	800,000
900,000	150,000	2,500	18,700	180,000	3,000	22,440	900,000
1,000,000	166,667	2,778	20,778	200,000	3,333	24,933	1,000,000

Above table is based on a water density of 60 lb/ft³.

Ten and Twelve Minute Storage Requirements

Table No. 3

APPENDIX A

UNITS OF MEASURE AND 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	$m \cdot kg/s^2$
degree Fahrenheit		°F	
kelvin	(SI)	K	
degree Celsius		°C	
British thermal unit (International Table)		Btu	
kilocalorie (International Table)		kcal	
joule	(SI)	J	$N \cdot m, m^2 \cdot kg/s^2$
kilojoule		kJ	
second (customary)		sec	
second	(SI)	s	
minute		min	
hour (customary)		hr	
hour (metric)		h	
watt	(SI)	W	$J/s, N \cdot m/s, m^2 \cdot kg/s^3$
pound force/square inch		psi	lbf/in^2
inches of mercury		inHg	
feet of water		ftH ₂ O	
pascal	(SI)	Pa	$N/m^2, kg/m \cdot s^2$
kilopascal		kPa	

APPENDIX A (cont'd) **UNITS OF MEASURE AND CONVERSION FACTORS**

NAME	NOMENCLATURE SYMBOL	OTHER UNITS
bar (metric)	bar	
millimeter of mercury	mmHg	
torr	torr	
centipoise	cp	

Notes:

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

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)

APPENDIX A (cont'd) **UNITS OF MEASURE AND CONVERSION FACTORS**

TEMPERATURE

$$\begin{aligned} K &= (^\circ F + 459.67) / 1.8 & (SI) \\ ^\circ C &= (^\circ F - 32) / 1.8 \\ ^\circ F &= 1.8K - 459.67 \\ ^\circ F &= 1.8^\circ C + 32 \end{aligned}$$

ENERGY, WORK OR QUANTITY OF HEAT

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

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)

APPENDIX A (cont'd)

UNITS OF MEASURE AND CONVERSION FACTORS

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	

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	

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	

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 B
HEAT EXCHANGE INSTITUTE INC.
DEAERATOR SPECIFICATION SHEET

[illegible]

Heat Exchange Institute, Inc.

PUBLICATION LIST

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2nd Edition, 1963

**Performance Standards for Liquid Ring
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1st Edition, 1987

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5th Edition, 1970

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4th Edition, 1988

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