

STANDARDS OF THE TUBULAR EXCHANGER MANUFACTURERS ASSOCIATION



ELEVENTH EDITION

TUBULAR EXCHANGER MANUFACTURERS ASSOCIATION, INC.
www.tema.org

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PREFACE

Eleventh Edition – 2023

The Eleventh Edition of the TEMA Standards was prepared by the Technical Committee of the Tubular Exchanger Manufacturers Association. Sections have been added to provide direction concerning the design of one pass floating heads and Type-D high pressure channel closures. The Eleventh Edition introduces an Exchanger Type Selection Guide which discusses the benefits and disadvantages of various types of exchangers and a section on Inspection which has information concerning non-destructive examination techniques and recommendations for their use for shell and tube heat exchangers. This edition includes new appendices for Repairs and Alterations of Heat Exchangers; for Clad and Overlay Construction; and for Installation, Operation, and Maintenance of Shell and Tube Heat Exchangers. TEMA has modified the Heat Exchanger Specification Sheet to better define the design requirements necessary to specify a heat exchanger. This Standard has been revised to include weld calculations for vertical support lugs, a clarification to the mitigation of erosion of the tube ends due to certain tube side flows, and a more detailed discussion concerning tube to tubesheet joints.

One of the main goals of the Eleventh Edition is to better present the TEMA Standards to all users. To do this, content has been expanded to include separate tables and graphics with metric units for more clarity and to provide units that make practical sense for manufacturers. The editor acknowledges the contributions of Raj Chhatrapati, M. Venkatesh, Sarath Kumar, and Parikshit Padture in this effort. Their insight and help are very much appreciated.

The editor acknowledges with appreciation the many years of service and contributions of Sam Davis and Cris Smelley to the TEMA Technical Committee.

Miles Duvall, Editor

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NOTES TO USERS OF THE TEMA STANDARDS

Three classes of Mechanical Standards, R, C, and B, reflecting acceptable designs for various service applications, are presented. The user should refer to the definition of each class and choose the one that best fits the specific need.

Corresponding subject matter in the three classes of Mechanical Standards is covered by paragraphs identically numbered except for the class prefix letter. Paragraph numbers preceded by RCB indicates that all three classes are identical. Any reference to a specific paragraph must be preceded by the class designation.

The Recommended Good Practice section has been prepared to assist the designer in areas outside the scope of the basic Standards. Paragraphs in the Standards having additional information in the RGP section are marked with an asterisk (*). The reference paragraph in the RGP section has the identical paragraph number, but with an "RGP" prefix.

It is the intention of the Tubular Exchanger Manufacturers Association that this edition of its Standards may be used beginning with the date of issuance, and that its requirements supersede those of the previous edition six months from such date of issuance, except for heat exchangers contracted for prior to the end of the six month period. For this purpose, the date of issuance is July 1, 2024.

This Standard has both US Customary (USC) and SI units. A single system of units shall be used for all aspects of design and fabrication except where otherwise permitted by this Standard. Where not specified, and unless otherwise indicated, dimensions in USC tables are in inches, and dimensions in SI tables are in millimeters. When presented together in tables, figures, and text, SI values are presented in parentheses following the USC values and do not always indicate direct conversions. Tables with an M suffix use SI units and immediately follow the corresponding USC table; they are not referenced separately in text. Examples of this methodology may be found in Appendix GG of the [ASME Boiler and Pressure Vessel Code](#), Section VIII.

Questions by registered users on interpretation of the TEMA Standards should be submitted online at www.tema.org. Questions requiring development of new or revised technical information will only be answered through an addendum or a new edition of the Standards.

Upon agreement between purchaser and fabricator, exceptions to TEMA requirements are acceptable. An exchanger may still be considered as meeting TEMA requirements as long as the exception is documented.

N-1 SIZE NUMBERING AND TYPE DESIGNATION - RECOMMENDED PRACTICE

It is recommended that heat exchanger size and type be designated by numbers and letters as described below.

N-1.1 SIZE

Sizes of shells (and tube bundles) shall be designated by numbers describing shell (and tube bundle) diameters and tube lengths, as follows:

N-1.1.1 NOMINAL DIAMETER

The nominal diameter shall be the inside diameter of the shell in inches (mm), rounded to the nearest inch (10 mm). For kettle reboilers the nominal diameter shall be the port diameter followed by the shell diameter, rounded to the nearest inch (10 mm).

N-1.1.2 NOMINAL LENGTH

The nominal length shall be the tube length in inches (mm). Tube length for straight tubes shall be taken as the actual overall length. For U-tubes the length shall be taken as the approximate straight length from end of tube to bend tangent.

N-1.2 TYPE

Figure N-1.2 shows some available exchanger component types. Type designation for complete assemblies shall be by letters describing each of the front-end stationary, shell, and rear-end types. Type designations shall also be used for partial heat exchanger assemblies.

N-1.3 TYPICAL EXAMPLES**N-1.3.1**

Split-ring floating head exchanger with removable channel and cover, single pass shell, 23 1/4" (591 mm) inside diameter with tubes 16' (4877 mm) long. SIZE 23-192 (590-4877) TYPE AES.

N-1.3.2

U-tube exchanger with bonnet type stationary head, split flow shell, 19" (483 mm) inside diameter with tubes 7' (2134 mm) straight length. SIZE 19-84 (480-2134) TYPE BGU.

N-1.3.3

Pull-through floating head kettle type reboiler having stationary head integral with tubesheet, 23" (584 mm) port diameter and 37" (940 mm) inside shell diameter with tubes 16' (4877 mm) long. SIZE 23/37-192 (580/940-4877) TYPE CKT.

N-1.3.4

Fixed tubesheet exchanger with removable channel and cover, bonnet type rear head, two pass shell, 33 1/8" (841 mm) inside diameter with tubes 8' (2438 mm) long. SIZE 33-96 (840-2438) TYPE AFM.

N-1.3.5

Fixed tubesheet exchanger having stationary and rear heads integral with tubesheets, single pass shell, 17" (432 mm) inside diameter with tubes 16' (4877 mm) long. SIZE 17-192 (430-4877) TYPE NEN.

N-1.4 SPECIAL DESIGNS

Special designs are not covered and may be described as best suits the manufacturer. For example, a single tube pass, fixed tubesheet exchanger with conical heads may be described as "TYPE BEM with Conical Heads". A pull-through floating head exchanger with an integral shell cover may be described as "TYPE AET with Integral Shell Cover".

N-1.5 EXCHANGER TYPE SELECTION GUIDE

Many different configurations of shell and tube heat exchangers are available. Each type has advantages and disadvantages, depending on such factors as process and thermal requirements, available space, financial budget, fouling and cleaning considerations, etc. This section provides information on several of the most widely used configurations and briefly discusses some of the issues to consider when planning for and selecting a heat exchanger configuration.

N-1.5.1 STRAIGHT TUBE, FIXED TUBESHEET TYPE HEAT EXCHANGERS

Straight tube, fixed tubesheet types are generally the least expensive shell and tube exchanger designs. Examples include BEM, AEL, and NEN types. Advantages include low cost and access to the tube side for cleaning. However, because the tube bundle is not removable, the shell side cannot be mechanically cleaned. This could be an issue if the shell side fluid causes fouling or sediment buildup. Another disadvantage is that due to the fixed tubesheets, differential thermal expansion between the tubes and shell causes stress in those components. An expansion joint may be required to relieve this stress, adding cost and a potential failure point to the unit.

Since NEN and AEL types have bolted end covers, they have the advantage of providing access to the tubes for cleaning without removal of the bonnets or disconnecting inlet and outlet piping. This can save time if frequent cleaning of the tube side is required.

N-1.5.2 EXPANSION JOINT CONSIDERATIONS

In any shell and tube heat exchanger, operating fluid temperatures result in differing metal temperature for the shell and tubes, which will vary along the length of the unit. While the tube material is in contact with fluids on both sides of the exchanger, the shell material is only in contact with the shell side fluid. Because the shell and tubes reach different temperatures while operating (and may be of different metallurgies), the thermal growth of these components will be different. In any fixed tubesheet type exchanger, this differential thermal expansion between the shell and tubes causes stresses in the shell, tubes, and tubesheets that must be considered by the designer. An expansion joint may be required to relieve this stress. This is often the case when there is a large difference in the operating temperatures of the shell and tube sides. For this reason, it is important for the designer to know the expected operating temperatures of the fluids on each side for any expected operating case, even temporary cases (see E-3). Examples of operating cases that should be considered are start-up, shutdown, steady-state operation, external piping loads, and any special events such as upset conditions or steam cleaning operations. An existing fixed-tubesheet exchanger should be evaluated before placing it into any new thermal operating condition.

There are two main types of expansion joints: flexible shell elements (FSE) and bellows. The FSE type is a thick-wall expansion joint design (see RCB-8). Although it is less flexible than a thin-wall bellows type, it is much more durable and unlikely to fail. Multiple FSEs can be connected in series to relieve additional thermal stress and allow more expansion.

Straight tube, fixed tubesheet type exchangers with larger amounts of expected differential thermal expansion often require a bellows type expansion joint. This type is thinner, with one or more convolutions that allow expansion. Due to the thin wall, any minor mechanical damage can cause a leak that may be expensive or difficult to repair. Bellows-type joints are usually supplied with a protective shroud to prevent accidental damage.

N-1.5.3 REMOVABLE U-TUBE BUNDLE TYPES

Types BEU, BKU, and AEU are examples of heat exchangers with removable U-tube bundles. These configurations are economical and allow better access to the shell side for inspection and cleaning than fixed type exchangers. Another advantage is that U-tube configurations allow the tube bundle to freely expand and contract with temperature differences without causing additional stress in the shell. Individual tubes or part of the bundle can expand at different rates without any detrimental effects. Expansion joints are not needed in these types. Another advantage is that the tube bundles can easily be replaced if necessary.

A disadvantage of U-tube bundles is the difficulty of cleaning the inside of the bent portion of the tubes. Also, individual tubes inside the bundle cannot be replaced if they become damaged.

N-1.5.4 REMOVABLE BUNDLE, FLOATING TUBESHEET TYPES

Exchangers with rear end types P, S, T, and W all feature a floating tubesheet (see RCB-5). The floating tubesheet allows bundle thermal expansion and bundle removal like a U-type but maintains the advantages of having straight tubes. Expansion joints are not usually needed with floating tubesheets since the bundle can freely expand and contract with thermal changes, except in one-pass S and T types (see RCB-5.4). Because both shell and tube sides can be accessed more easily for cleaning purposes, floating tubesheet designs are commonly used in dirty services such as refinery applications. Bundle replacements are also easily performed. However, while each of the floating types offers a slightly different design, any floating tubesheet design will be generally more costly to fabricate than the fixed tubesheet or U-tube options. P and W type exchangers have the disadvantage that they require a packing seal, which can lead to reliability problems, as these seals can be less robust than gasket type seals; while S and T types include a submerged bolted connection that introduces the potential for shell side and tube side fluids to cross-contaminate if a gasket leak were to occur.

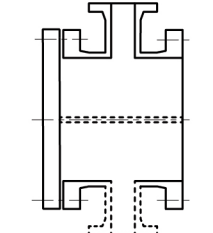
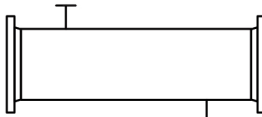
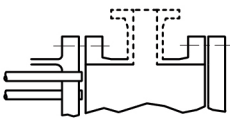
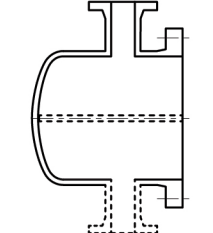
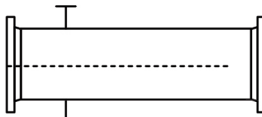
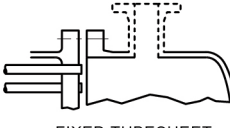
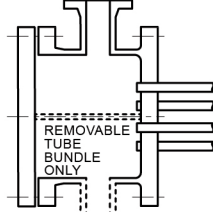
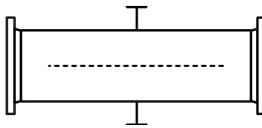
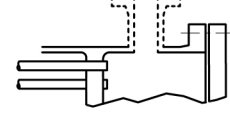
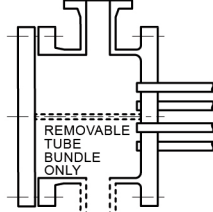
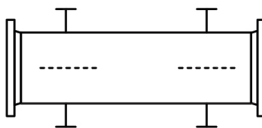
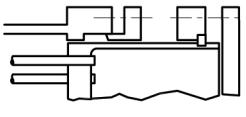
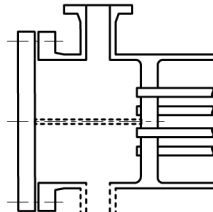
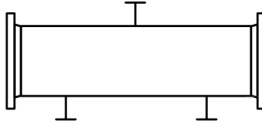
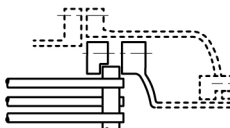
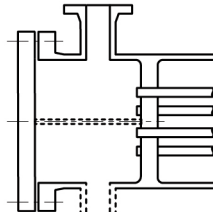
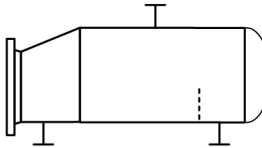
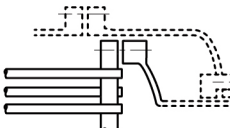
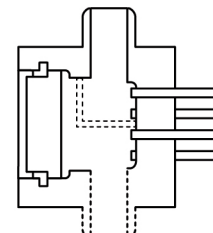
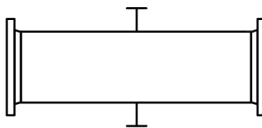
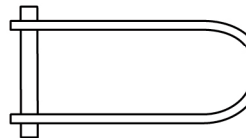
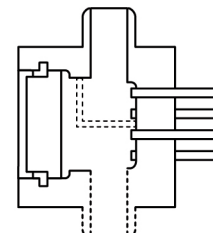
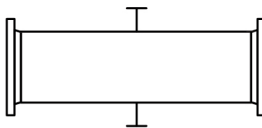
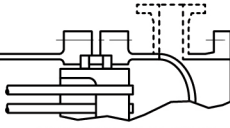
N-1.5.5 DOUBLE TUBESHEET DESIGNS

Most shell and tube configurations can be built with a double tubesheet (see RCB-7.1.2). This design adds a secondary tubesheet and seal to further separate the shell and tube sides of the exchanger. Any leaks at the primary tube-to-tubesheet joint are contained in a secondary chamber or vented before reaching the other side. This option can add significant cost to the unit price. However, double tubesheets minimize the risk of cross-contamination between shell and tube sides due to a failure at the tube to tubesheet joint. When a leak from one side to the other must be avoided for safety or process reasons, double tubesheets should be considered.

N-1.5.6 SHELL CONFIGURATIONS

The simplest, most common, and usually least expensive shell type is TEMA 'E' type, in which the shell side fluid flows in a single pass from one end to the other. The 'F' type uses a longitudinal baffle to create a two-pass shell, which can be used when the exchanger has a temperature cross (the cold stream leaves at a higher temperature than the outlet of the hot stream). Longitudinal baffles can be welded to the shell or installed in the bundle with a flexible seal at the shell. 'G' and 'H' type shells use central baffles to split the shell side flow and are often used for thermosyphon reboilers. Kettle shells (type 'K') include a larger diameter shell to create a vapor space above the tube bundle and are also used for reboilers. Types 'J' and 'X' provide other options for divided and cross flow on the shell side.

FIGURE N-1.2

FRONT END STATIONARY HEAD TYPES		SHELL TYPES		REAR END HEAD TYPES	
A		E		L	
	CHANNEL AND REMOVABLE COVER		ONE PASS SHELL		FIXED TUBESHEET LIKE "A" STATIONARY HEAD
					
	BONNET (INTEGRAL COVER)		TWO PASS SHELL WITH LONGITUDINAL BAFFLE		FIXED TUBESHEET LIKE "B" STATIONARY HEAD
					
	REMOVABLE TUBE BUNDLE ONLY		SPLIT FLOW		FIXED TUBESHEET LIKE "N" STATIONARY HEAD
C		H		P	
	CHANNEL INTEGRAL WITH TUBESHEET AND REMOVABLE COVER		DOUBLE SPLIT FLOW		OUTSIDE PACKED FLOATING HEAD
					
	CHANNEL INTEGRAL WITH TUBESHEET AND REMOVABLE COVER		DIVIDED FLOW		FLOATING HEAD WITH BACKING DEVICE
N		K		T	
	CHANNEL INTEGRAL WITH TUBESHEET AND REMOVABLE COVER		KETTLE TYPE		PULL THROUGH FLOATING HEAD
D		X		U	
	SPECIAL HIGH PRESSURE CLOSURE		CROSS FLOW		U-TUBE BUNDLE
D		X		W	
	SPECIAL HIGH PRESSURE CLOSURE		CROSS FLOW		EXTERNALLY SEALED FLOATING TUBESHEET

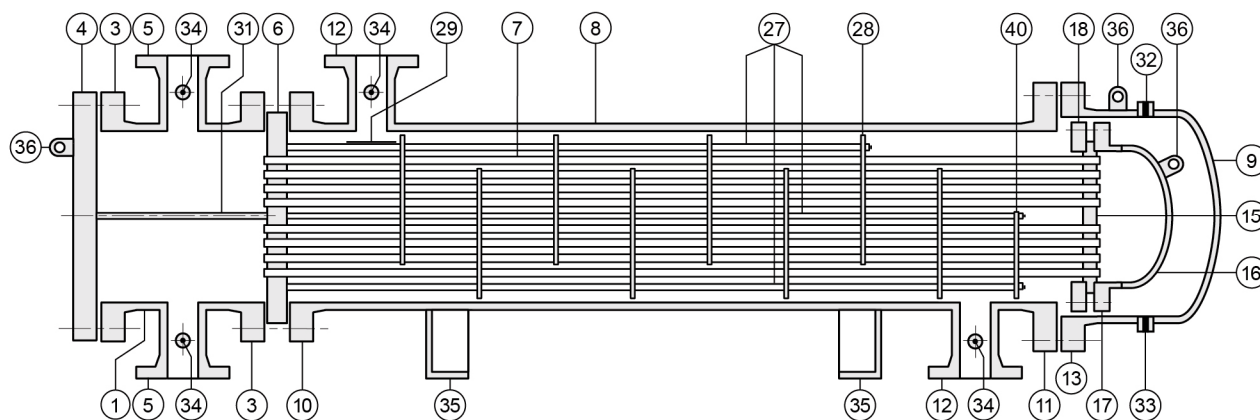
N-2 NOMENCLATURE OF HEAT EXCHANGER COMPONENTS

For the purpose of establishing standard terminology, Figure N-2 illustrates various types of heat exchangers. Typical parts and connections, for illustrative purposes only, are numbered for identification in Table N-2.

TABLE N-2

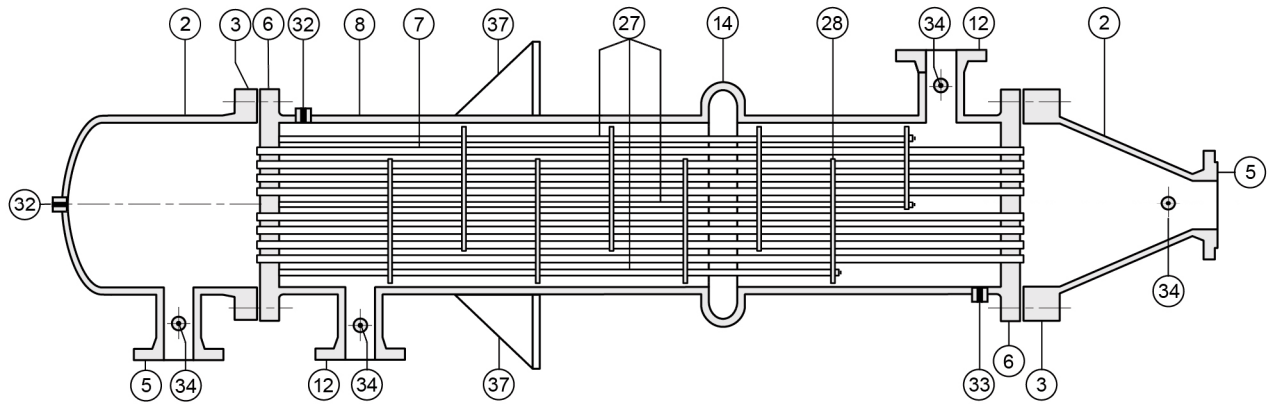
1. Stationary Head-Channel	21. Floating Head Cover-External
2. Stationary Head-Bonnet	22. Floating Tubesheet Skirt
3. Stationary Head Flange-Channel or Bonnet	23. Packing Box
4. Channel Cover	24. Packing
5. Stationary Head Nozzle	25. Packing Gland
6. Stationary Tubesheet	26. Lantern Ring
7. Tubes	27. Tierods and Spacers
8. Shell	28. Transverse Baffles or Support Plates
9. Shell Cover	29. Impingement Plate
10. Shell Flange-Stationary Head End	30. Longitudinal Baffle
11. Shell Flange-Rear Head End	31. Pass Partition
12. Shell Nozzle	32. Vent Connection
13. Shell Cover Flange	33. Drain Connection
14. Expansion Joint	34. Instrument Connection
15. Floating Tubesheet	35. Support Saddle
16. Floating Head Cover	36. Lifting Lug
17. Floating Head Cover Flange	37. Support Bracket
18. Floating Head Backing Device	38. Weir
19. Split Shear Ring	39. Liquid Level Connection
20. Slip-on Backing Flange	40. Floating Head Support

FIGURE N-2

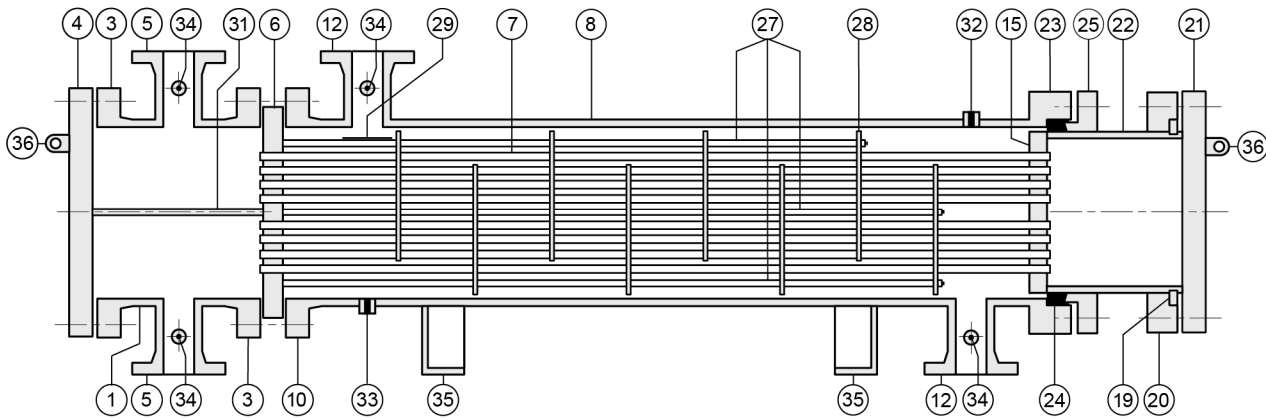


AES

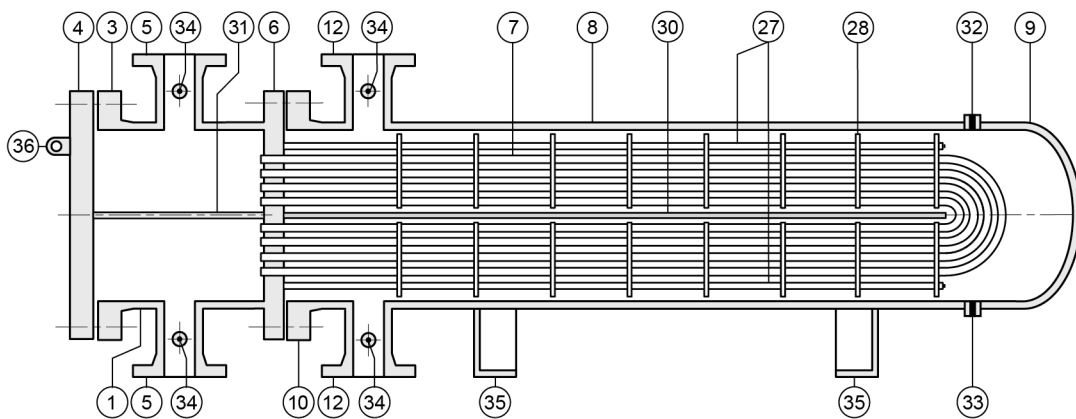
FIGURE N-2 (continued)



BEM

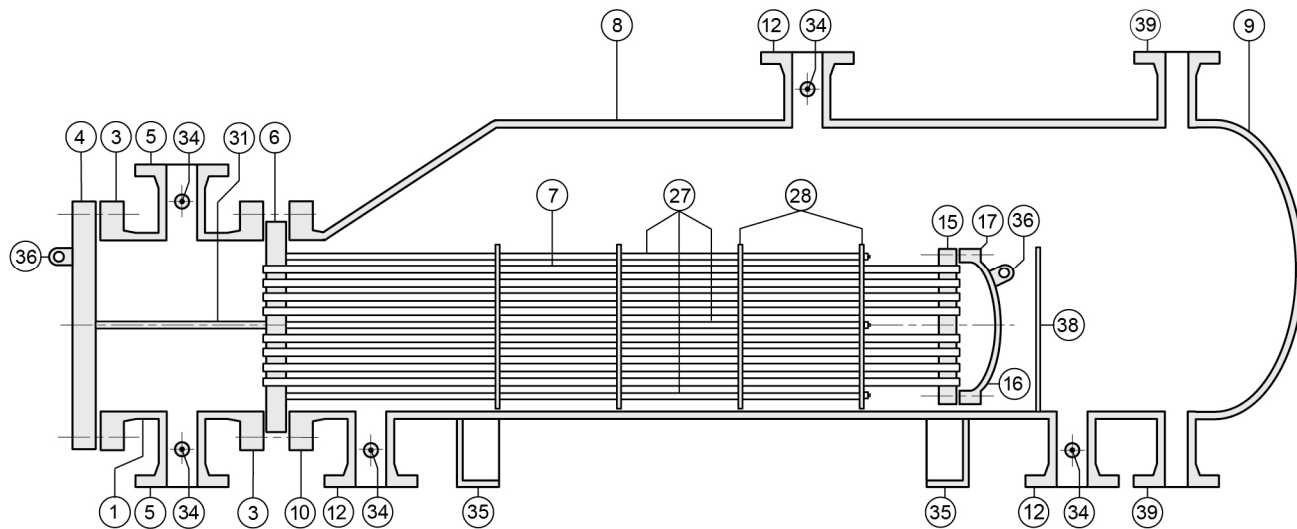


AEP

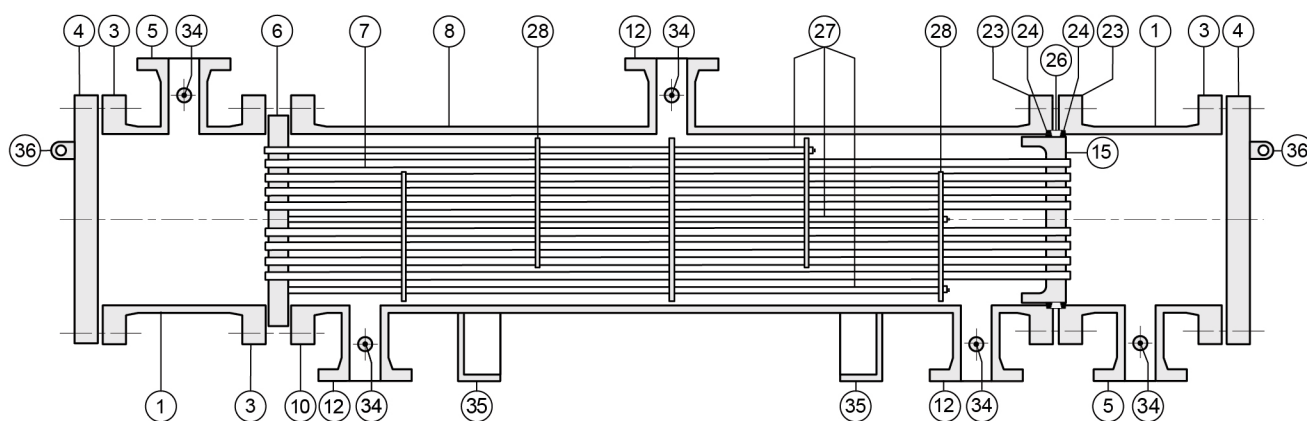


CFU

FIGURE N-2 (continued)



AKT



AJW

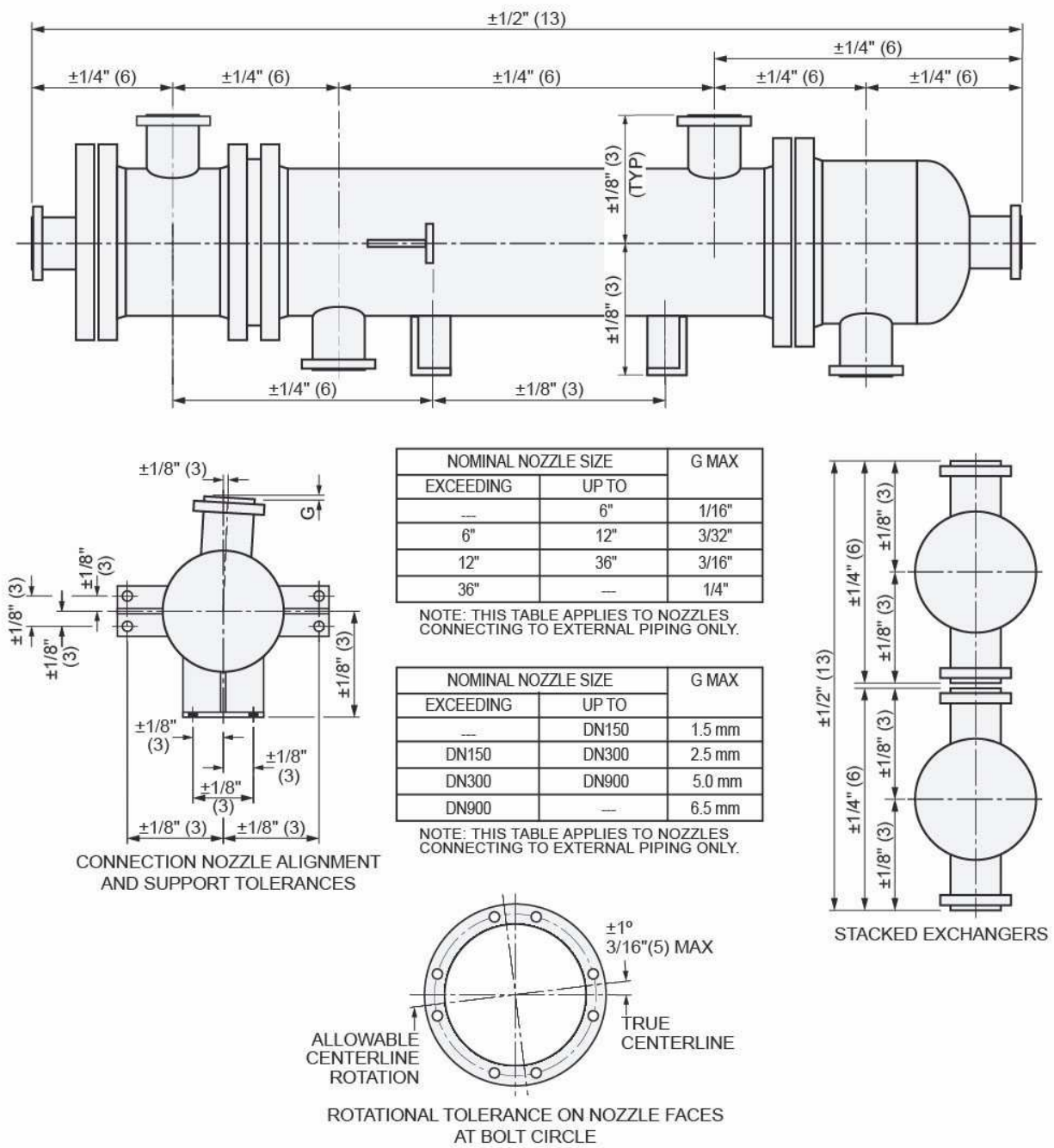
N-3 DEFINITIONS

1. Baffle is a device to direct the shell side fluid across the tubes for optimum heat transfer.
2. Double Tubesheet Construction is a type of construction in which two (2) spaced tubesheets or equivalent are employed in lieu of the single tubesheet at one or both ends of the heat exchanger.
3. Effective Shell and Tube Side Design Pressures are the resultant load values expressed as uniform pressures used in the determination of tubesheet thickness for fixed tubesheet heat exchangers and are functions of the shell side design pressure, the tube side design pressure, the equivalent differential expansion pressure and the equivalent bolting pressure.
4. Equivalent Bolting Pressure is the pressure equivalent resulting from the effects of bolting loads imposed on tubesheets in a fixed tubesheet heat exchanger when the tubesheets are extended for bolting as flanged connections.
5. Equivalent Differential Expansion Pressure is the pressure equivalent resulting from the effect of tubesheet loadings in a fixed tubesheet heat exchanger imposed by the restraint of differential thermal expansion between shell and tubes.
6. Expanded Tube Joint is the tube-to-tubesheet joint achieved by mechanical, hydraulic, or explosive expansion of the tube into the tube hole in the tubesheet.
7. Expansion Joint "J" Factor is the ratio of the spring rate of the expansion joint to the sum of the axial spring rate of the shell and the spring rate of the expansion joint. Refer to section A.1.5.1
8. Flange Load Concentration Factors are factors used to compensate for the uneven application of bolting moments due to large bolt spacing.
9. Minimum and Maximum Baffle and Support Spacings are design limitations for the spacing of baffles to provide for mechanical integrity and thermal and hydraulic effectiveness of the bundle. The possibility for induced vibration has not been considered in establishing these values.
10. Normal Operating Conditions of a shell and tube heat exchanger are the thermal and hydraulic performance requirements generally specified for sizing the heat exchanger.
11. Pulsating Fluid Conditions are conditions of flow generally characterized by rapid fluctuations in pressure and flow rate resulting from sources outside of the heat exchanger.
12. Seismic Loadings are forces and moments resulting in induced stresses on any member of a heat exchanger due to pulse mode or complex waveform accelerations to the heat exchanger, such as those resulting from earthquakes.
13. Shell and Tube Mean Metal Temperatures are the average metal temperatures through the shell and tube thicknesses integrated over the length of the heat exchanger for a given steady state operating condition.
14. Shut-Down is the condition of operation which exists from the time of steady state operating conditions to the time that flow of both process streams has ceased.
15. Start-Up is the condition of operation which exists from the time that flow of either or both process streams is initiated to the time that steady state operating conditions are achieved.
16. Support plate is a device to support the bundle or to reduce unsupported tube span without consideration for heat transfer.
17. Tubesheet Ligament is the shortest distance between edge of adjacent tube holes in the tube pattern.
18. Welded Tube Joint is a tube-to-tubesheet joint where the tube is welded to the tubesheet.

F-1 EXTERNAL DIMENSIONS, NOZZLE AND SUPPORT LOCATIONS

Standard tolerances for process flow nozzles and support locations and projections are shown in Figure F-1.

FIGURE F-1



F-2 RECOMMENDED FABRICATION TOLERANCES

Fabrication tolerances normally required to maintain process flow nozzle and support locations are shown in Figure F-2-1. These tolerances may be adjusted as necessary to meet the tolerances shown in Figure F-1.

FIGURE F-2-1
NOZZLE AND SUPPORT TOLERANCES

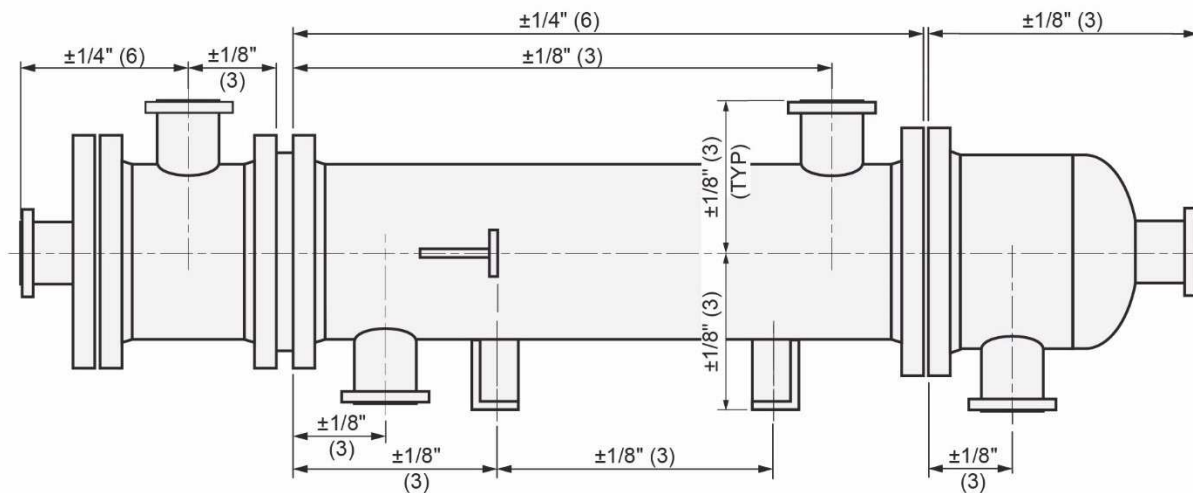
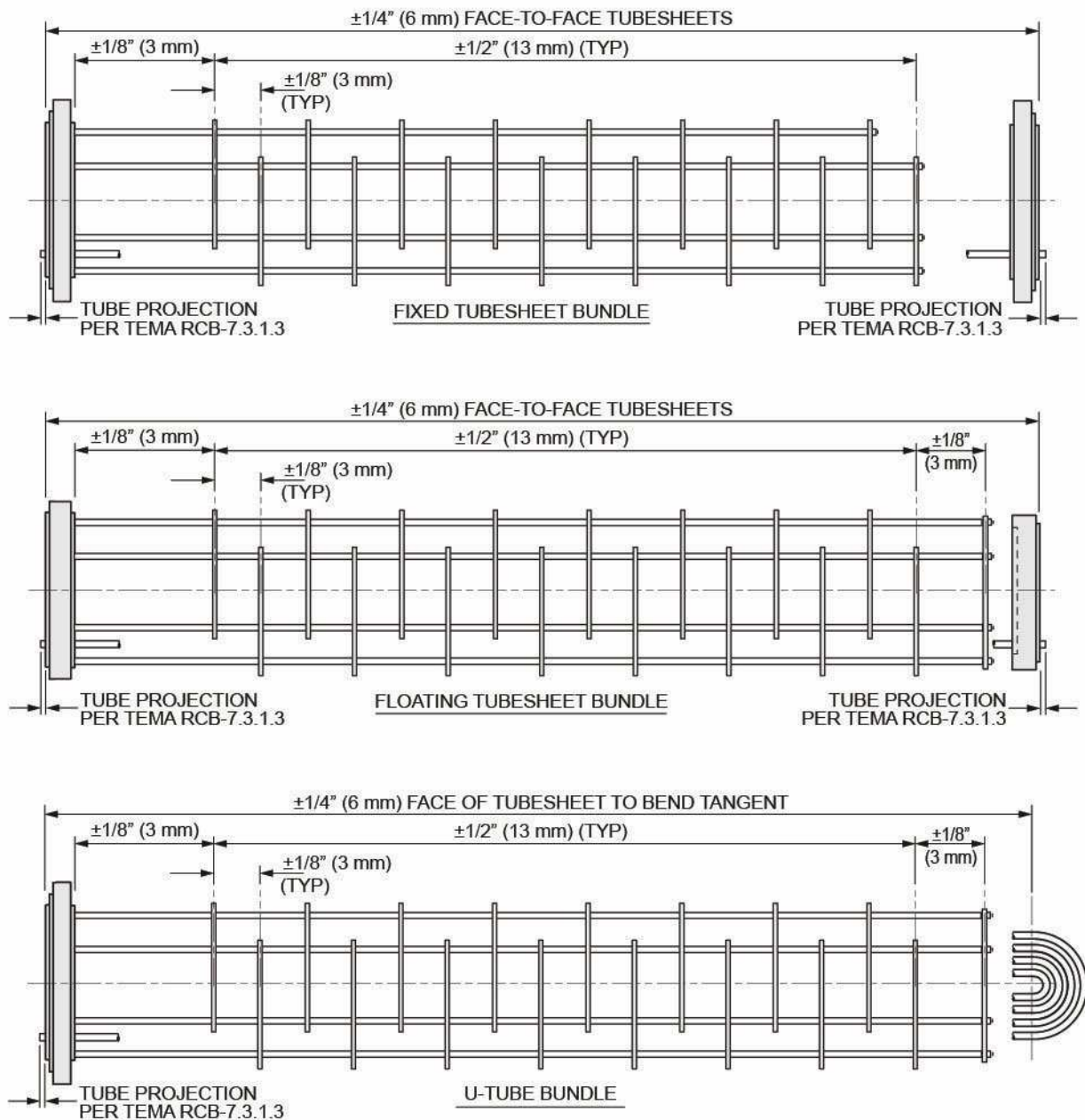


FIGURE F-2-2
BUNDLE TOLERANCES



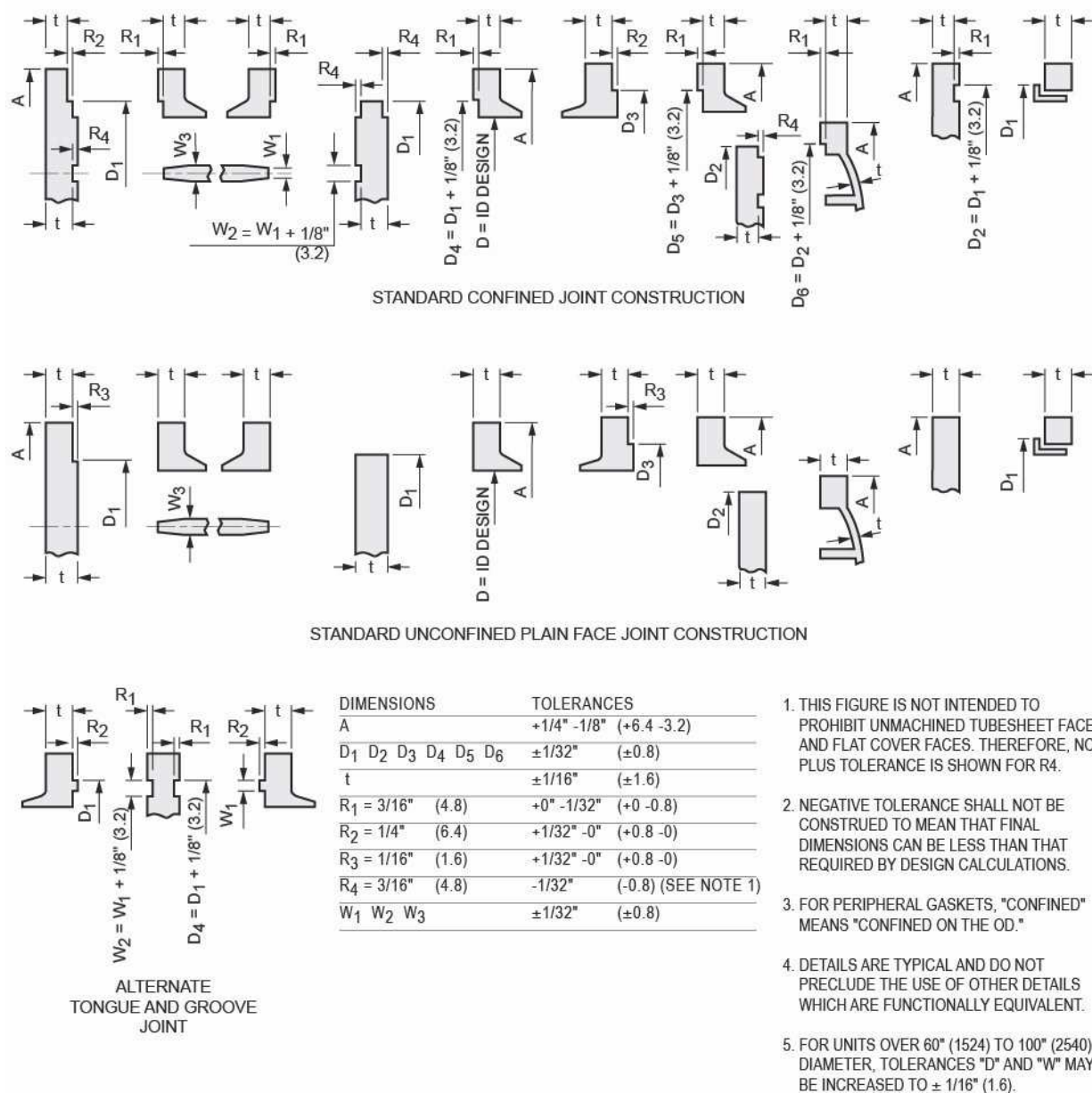
Notes:

- 1) First and last baffles shall be clear of the inside diameter of inlet and outlet nozzles. This requirement does not apply to tube supports or baffles used to split flow in TEMA shell types G, H, or X.
- 2) Tolerances shown are for segmental baffles only. Tube support tolerances are per agreement between manufacturer and purchaser.
- 3) Tolerances of skid/seal bars are as follows (also see Figure RCB-4.8):
 - A) slot/hole sizing 0" (0) to 1/8" (3) over skid bar/rod size.
 - B) skid bar projection outside baffle OD: 1/32" (1) to 1/16" (2)

F-3 TUBESHEETS, PARTITIONS, COVERS, AND FLANGES

The standard clearances and tolerances applying to tubesheets, partitions, covers and flanges are shown in Figure F-3. Dimensions in () are millimeters.

FIGURE F-3



F-4 FLANGE FACE PERMISSIBLE IMPERFECTIONS

Imperfections in the flange facing finish for ASME B16.5 flanges with ASME B16.20 gasket sizes, used either for nozzle or body flanges, shall not exceed the dimensions shown in Table F-4. For custom flanges, permissible imperfections should be per ASME PCC-1 Appendix D.

TABLE F-4
PERMISSIBLE IMPERFECTIONS IN FLANGE FACING FINISH
FOR RAISED FACE AND LARGE MALE AND FEMALE FLANGES ^{1,2}

NPS	Maximum Radial Projections of Imperfections Which Are No Deeper Than the Bottom of the Serrations, in.	Maximum Depth and Maximum Radial Projection of Imperfections Which Are Deeper Than the Bottom of the Serrations, in.
1/2	0.125	0.0625
3/4	0.125	0.0625
1	0.125	0.0625
1 1/4	0.125	0.0625
1 1/2	0.125	0.0625
2	0.125	0.0625
2 1/2	0.125	0.0625
3	0.1875	0.0625
3 1/2	0.25	0.125
4	0.25	0.125
5	0.25	0.125
6	0.25	0.125
8	0.3125	0.125
10	0.3125	0.1875
12	0.3125	0.1875
14	0.3125	0.1875
16	0.375	0.1875
18	0.50	0.25
20	0.50	0.25
24	0.50	0.25

NOTES:

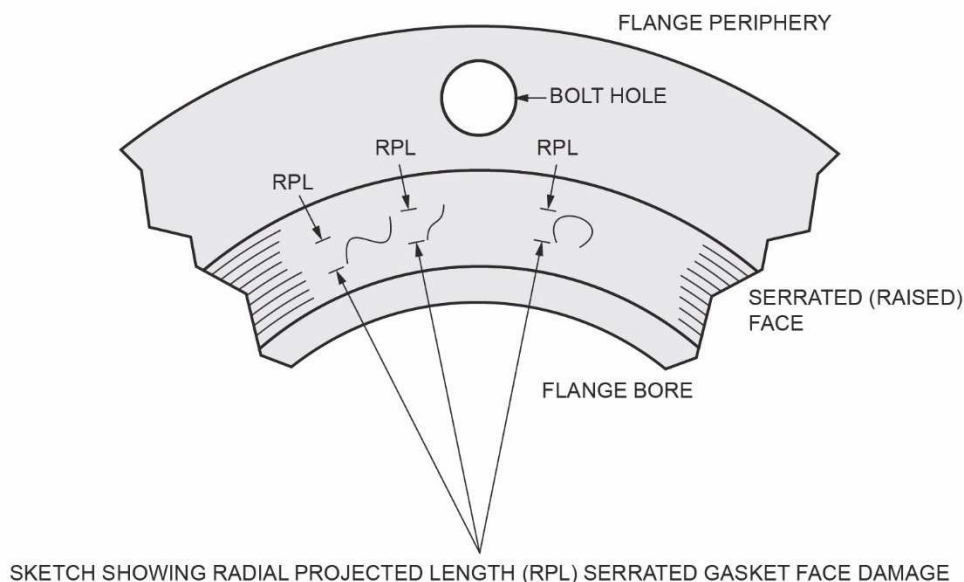
- (1) Imperfections must be separated by at least four times the permissible radial projection.
(2) Protrusions above the serrations are not permitted

TABLE F-4M
PERMISSIBLE IMPERFECTIONS IN FLANGE FACING FINISH
FOR RAISED FACE AND LARGE MALE AND FEMALE FLANGES ^{1,2}

DN	Maximum Radial Projections of Imperfections Which Are No Deeper Than the Bottom of the Serrations, mm	Maximum Depth and Maximum Radial Projection of Imperfections Which Are Deeper Than the Bottom of the Serrations, mm
10	3.2	1.6
15	3.2	1.6
20	3.2	1.6
25	3.2	1.6
32	3.2	1.6
40	3.2	1.6
50	3.2	1.6
65	4.8	1.6
80	6.4	3.2
100	6.4	3.2
125	6.4	3.2
150	6.4	3.2
200	7.9	3.2
250	7.9	4.8
300	7.9	4.8
350	7.9	4.8
400	9.5	4.8
450	12.7	6.4
500	12.7	6.4
600	12.7	6.4

NOTES:

- (1) Imperfections must be separated by at least four times the permissible radial projection.
(2) Protrusions above the serrations are not permitted

FIGURE F-4

F-5 PERIPHERAL GASKET SURFACE FLATNESS

Peripheral gasket contact surfaces shall have a flatness tolerance of $1/32$ " (0.8 mm) maximum deviation from any reference plane.

G-1 HEAT EXCHANGER SPECIFICATION SHEETS

The TEMA Heat Exchanger Specification Sheets in Figure G-1 are provided so that the purchaser or end user can clearly define and communicate the data necessary to design and fabricate a shell and tube heat exchanger. All design requirements and process information (if known) should be completed by the purchaser. Supplemental documents or data sheets may be used in addition to or instead of these specification sheets. The designer or manufacturer may also use these specification sheets to report results of thermal or mechanical exchanger designs to the purchaser. The specification sheets are available on the TEMA website www.tema.org.

In fixed tubesheet exchangers, thermal expansion differences between the shell and tubes must be considered by the designer to determine the need for an expansion joint. The purchaser shall specify all expected thermal conditions for the exchanger in the data sheet section "Design, Operating, and Upset Conditions." In addition to standard operating cases, these cases may include cleanout, loss of flow on one side, or other upset conditions (see E-3). If mean metal temperatures are not known, inlet and outlet fluid temperatures should be specified. If the exchanger is operated under thermal conditions outside of those specified, damage to the exchanger can occur (see G-5.2).

G-2 INSPECTION AND SHOP OPERATION

G-2.1 MANUFACTURER'S INSPECTION

Inspection and testing of units will be provided by the manufacturer unless otherwise specified. The manufacturer shall carry out the inspections required by the Code, customer specifications, and those required by state and local codes when the purchaser specifies the plant location.

G-2.2 PURCHASER'S INSPECTION

The purchaser shall have the right to make inspections during fabrication and to witness any tests when so requested. Advance notification shall be given as agreed between the manufacturer and the purchaser. Inspection by the purchaser does not relieve the manufacturer of any contractual responsibilities. Any additional tests required by the purchaser, above those already agreed to, will be to the purchaser's account. Cost for remedial work as a result of these additional tests will also be to the purchaser's account.

G-2.3 NON-DESTRUCTIVE TESTING TECHNIQUES

A variety of inspection methods can be performed on pressure equipment without causing any damage to the equipment. These inspection techniques are collectively known as non-destructive testing or non-destructive examination (NDT or NDE). This section provides a brief overview of several testing methods, as well as TEMA's recommendations for their use in exchanger fabrication.

G-2.3.1 RADIOGRAPHIC TESTING (RT)

This testing method is used to detect discontinuities such as porosity, cracks and inclusions in materials or welds. Radiographic testing (radiography) is accomplished by placing film or a digital detector on one side of a weld, and introducing a radiographic source, either an X-ray tube or a radioactive isotope, on the other side of the weld. Any radiation from the source that is not absorbed by the weld passes through and exposes the film (or detector). This leaves an image of the internal structure of the weld once the film is developed. The amount of energy absorbed by the weld depends upon its thickness and density. Cracks and porosity will appear as dark indications on the film. Low density inclusions will also appear as dark areas, while high density inclusions will appear as light areas.

The amount of radiography required is dependent upon the Code and end user specifications. Increasing the level of radiography will increase the efficiency factor used in the calculations, which determine the required thickness of the various components of the exchanger. This will increase the cost of the NDE but can decrease the material and labor costs, allowing the designer some flexibility. An experienced designer might consider different levels of radiography with respect to Code, contractual specifications, their shop practices, metallurgy, material availability, and overall cost of the equipment.

An advantage of this testing method is that it is a positive method for detecting porosity, inclusions, cracks, and voids in materials and welds. It can also provide a permanent record of the quality of the weld. Since this is a volumetric testing method, sub-surface weld defects can be found with radiography.

FIGURE G-1 TEMA HEAT EXCHANGER SPECIFICATION SHEET

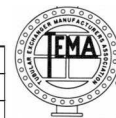
TEMA Heat Exchanger Specification Sheet



1			Job No.	
2	Customer:		PO No.	
3	Address:		Proposal No.	
4	Plant Location:		Date:	Rev.
5	Service of Unit:		Item No.	
6	Size:	/ in	TEMA Type:	Hor./Vert:
7	Surf/unit (eff.)	ft ²	Shells/unit	Surf/shell (eff.) ft ²
8	PERFORMANCE OF ONE UNIT			
9	Fluid Allocation		Shell Side	Tube Side
10			Inlet	Outlet
11	Fluid Name:			
12	Fluid Quantity, Total:	lb/hr		
13	Vapor:	lb/hr		
14	Liquid:	lb/hr		
15	Steam:	lb/hr		
16	Water:	lb/hr		
17	Noncondensable:	lb/hr		
18	Temperature:	°F		
19	Density (Vapor / Liquid):	lb/ft ³	/	/
20	Viscosity (Vapor / Liquid):	cP	/	/
21	Specific Heat (Vapor / Liquid):	BTU/(lb·°F)	/	/
22	Thermal Conductivity:	BTU/(ft·hr·°F)	/	/
23	Latent Heat:	BTU/lb @ °F	@	@
24	Inlet Pressure (abs):	psia		
25	Velocity:	ft/s		
26	Pressure Drop, allowable/calculated:	psi	/	/
27	Fouling Resistance (Min.):	(ft ² ·hr·°F)/BTU		
28	Average Film Coefficient:	BTU/(ft ² ·hr·°F)		
29	Heat exchanged:	BTU/hr	Mean Temperature Difference (MTD)	°F
30	Transfer Rate, Required:	Fouled:	Clean:	BTU/(ft ² ·hr·°F)
31	CONSTRUCTION OF ONE SHELL			
32			Shell Side	Tube Side
33	Design Internal/External/Test pressure:	psig	/	/
34	Design Temperature / MDMT:	°F	/	/
35	Number of passes:			
36	Corrosion allowance:	in		
37	Future Machining Allowance (Tubesheet, Flange, Cover):	in		
38	Minimum Radiography:			
39	Special Service (Lethal, Sour, etc.):			
40	Post-weld Heat Treatment (PWHT) required:			
41	Connections:	In		
42	Number/Size/Rating/	Out		
43	Type and Facing	Intermediate		
44		Vent		
45		Drain		
46		Other		
47				
48	EXCHANGER CONFIGURATION PER SHELL			
49	Number of Tubes:	Tube OD (in):	Tube thk. (in):	(BWG):
50	Tube type (plain/finned/other):	Tube Pitch (in):	Tube min. or avg. wall:	
51	Tube Length (in):	Tube Layout:	◀ 30 ▶ 60 ◻ 90 ◇ 45	
52	Tube to Tubesheet Joint:	Shell Diameter (in):	ID/OD:	Girth Flange Type:
53	Cross Baffle Type:	Number of Cross Baffles:		Baffle Spacing (in):
54	Baffle Cut (% of Dia.)	Vert. or Horiz. Cut:		Inlet Spacing (in):
55	Long. Baffle Seal Type:	Tube Support Type:		U-bend Support Type:
56	Expansion Joint Req. (Y/N):	Expansion Joint Type:		Bypass Seal Type:
57	Impingement Protection Req. (Y/N):	Impng. Protection Type:		Sets of Spare Gaskets req'd:
58	Support Type:	Number of Supports:		
59	ρV ² Inlet Nozzle (lb/(ft·s ²)):	ρV ² Bundle Ent. (lb/(ft·s ²)):		ρV ² Bundle Exit (lb/(ft·s ²)):
60	Total Weight/Shell Empty (lb):	Full of Water (lb):		Bundle Weight (lb):
61	Remarks:			
62				
63				
64				

FIGURE G-1 TEMA HEAT EXCHANGER SPECIFICATION SHEET (CONTINUED)

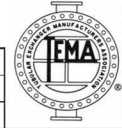
TEMA Heat Exchanger Specification Sheet



1			Job No.							
2	Customer		PO No.							
3	Address:		Proposal No.							
4	Plant Location:		Date:	Rev.						
5	Service of Unit:		Item No.							
6										
7	EXCHANGER SKETCH									
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24										
25										
26										
27										
28	DESIGN AND CODE REQUIREMENTS									
29	Design Code:		Code Stamp Required:	Calculate MAWP (Y/N):						
30	TEMA Class (R, C, B):		Customer Inspection (Y/N):	Cyclic Service (Y/N):						
31	Baseline UT (Y/N):		Baseline Eddy Current (Y/N):							
32										
33	DESIGN, OPERATING, AND UPSET CONDITIONS (if applicable)									
34		Shell Side		Shell	Tube Side		Tubes			
35		Design	Fluid Temperature	Pressure	Mean Metal	Fluid Temperature	Pressure	Mean Metal		
36	Condition/Case	Cycles	In (°F)	Out (°F)	(psig)	Temp. (°F)	In (°F)	Out (°F)	(psig)	Temp. (°F)
37										
38										
39										
40										
41										
42										
43										
44	MATERIALS									
45	Tubes:	Shell Side		Tube Side						
46	Stationary Tubesheet:	Shell:		Channel or Bonnet:						
47	Floating Tubesheet:	Shell Cover/Head:		Channel Cover/Head:						
48	Floating Head Cover:	Girth Flanges:		Girth Flanges:						
49	Cross Baffles:	Gaskets:		Gaskets:						
50	Long. Baffle:	Nozzle Flanges:		Nozzle Flanges:						
51	Tie Rods and Spacers:	Nozzle Necks:		Nozzle Necks:						
52	Supports:	Expansion Joint:								
53	Insulation Type/Thk:									
54	External Bolting:									
55	Internal Bolting:									
56	Paint Requirements:									
57										
58	Other Requirements and Applicable Specifications:									
59										
60										
61										
62										
63										
64										

FIGURE G-1M TEMA HEAT EXCHANGER SPECIFICATION SHEET

TEMA Heat Exchanger Specification Sheet



1			Job No.	
2	Customer:		PO No.	
3	Address:		Proposal No.	
4	Plant Location:		Date:	Rev.
5	Service of Unit:		Item No.	
6	Size:	/ mm	TEMA Type:	Hor./Vert: Connected in: parallel series
7	Surf/unit(eff.):	m ²	Shells/unit	Surf/shell (eff.) m ²
8	PERFORMANCE OF ONE UNIT			
9	Fluid Allocation:		Shell Side	Tube Side
10			Inlet	Outlet
11	Fluid Name:			
12	Fluid Quantity, Total:	kg/hr		
13	Vapor:	kg/hr		
14	Liquid:	kg/hr		
15	Steam:	kg/hr		
16	Water:	kg/hr		
17	Noncondensable:	kg/hr		
18	Temperature:	°C		
19	Density (Vapor / Liquid):	kg/m ³	/	/
20	Viscosity (Vapor / Liquid):	mPa·s	/	/
21	Specific Heat (Vapor / Liquid):	kJ/(kg·°C)	/	/
22	Thermal Conductivity:	W/(m·°C)	/	/
23	Latent Heat:	kJ/kg @ °C	@	@
24	Inlet Pressure (abs):	kPa(abs)		
25	Velocity:	m/s		
26	Pressure Drop, allowable/calculated:	kPa	/	/
27	Fouling Resistance (Min.):	(m ² ·°C)/kW		
28	Average Film Coefficient:	W/(m ² ·°C)		
29	Heat exchanged:	kW	Mean Temperature Difference (MTD)	°C
30	Transfer Rate, Required:	Fouled:	Clean:	W/(m ² ·°C)
31	CONSTRUCTION OF ONE SHELL			
32			Shell Side	Tube Side
33	Design Internal/External/Test pressure:	kPa(g)	/	/
34	Design Temperature / MDMT:	°C	/	/
35	Number of passes:			
36	Corrosion allowance:	mm		
37	Future Machining Allowance (Tubesheet, Flange, Cover):	mm		
38	Minimum Radiography:			
39	Special Service (Lethal, Sour, etc.):			
40	Post-weld Heat Treatment (PWHT) required:			
41	Connections:	In		
42	Number/Size/Rating	Out		
43	Type and Facing	Intermediate		
44		Vent		
45		Drain		
46		Other		
47				
48	EXCHANGER CONFIGURATION PER SHELL			
49	Number of Tubes:	Tube OD (mm):	Tube thk. (mm):	(BWG):
50	Tube type (plain/finned/other):	Tube Pitch (mm):	Tube min. or avg. wall:	
51	Tube Length (m):	Tube Layout:	◁ 30 ▷ 60 ▷ 90 ▷ 45	
52	Tube to Tubesheet Joint:	Shell Diameter (mm):	ID/OD:	Girth Flange Type:
53	Cross Baffle Type:	Number of Cross Baffles:		Baffle Spacing (mm):
54	Baffle Cut (% of Dia.)	Vert. or Horiz. Cut:		Inlet Spacing (mm):
55	Long. Baffle Seal Type:	Tube Support Type:		U-bend Support Type:
56	Expansion Joint Req. (Y/N):	Expansion Joint Type:		Bypass Seal Type:
57	Impingement Protection Req. (Y/N):	Impng. Protection Type:		Sets of Spare Gaskets req'd:
58	Support Type:	Number of Supports:		
59	ρV ² Inlet Nozzle (kg/(m·s ²)):	ρV ² Bundle Ent. (kg/(m·s ²)):		ρV ² Bundle Exit (kg/(m·s ²)):
60	Total Weight/Shell Empty (kg):	Full of Water (kg):		Bundle Weight (kg):
61	Remarks:			
62				
63				
64				

FIGURE G-1M TEMA HEAT EXCHANGER SPECIFICATION SHEET (CONTINUED)

TEMA Heat Exchanger Specification Sheet



1			Job No.							
2	Customer		PO No.							
3	Address:		Proposal No.							
4	Plant Location:		Date:	Rev.						
5	Service of Unit:		Item No.							
6										
7	EXCHANGER SKETCH									
8										
9										
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11										
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24										
25										
26										
27										
28	DESIGN AND CODE REQUIREMENTS									
29	Design Code:		Code Stamp Required:	Calculate MAWP (Y/N):						
30	TEMA Class (R, C, B):		Customer Inspection (Y/N):	Cyclic Service (Y/N):						
31	Baseline UT (Y/N):		Baseline Eddy Current (Y/N):							
32										
33	DESIGN, OPERATING, AND UPSET CONDITIONS (if applicable)									
34		Shell Side		Shell	Tube Side		Tubes			
35		Design	Fluid Temperature	Pressure	Mean Metal	Fluid Temperature	Pressure	Mean Metal		
36	Condition/Case	Cycles	In (°C)	Out (°C)	(kPa)	Temp. (°C)	In (°C)	Out (°C)	(kPa)	Temp. (°C)
37										
38										
39										
40										
41										
42										
43										
44	MATERIALS									
45	Tubes:		Shell Side		Tube Side					
46	Stationary Tubesheet:		Shell:		Channel or Bonnet:					
47	Floating Tubesheet:		Shell Cover/Head:		Channel Cover/Head:					
48	Floating Head Cover:		Girth Flanges:		Girth Flanges:					
49	Cross Baffles:		Gaskets:		Gaskets:					
50	Long. Baffle:		Nozzle Flanges:		Nozzle Flanges:					
51	Tie Rods and Spacers:		Nozzle Necks:		Nozzle Necks:					
52	Supports:		Expansion Joint:							
53	Insulation Type/Thk:									
54	External Bolting:									
55	Internal Bolting:									
56	Paint Requirements:									
57										
58	Other Requirements and Applicable Specifications:									
59										
60										
61										
62										
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A disadvantage of this method is that it generally requires access to both sides of the area to be examined. Radiography does not lend itself to inspection of some weld geometries such as the corner joints of nozzle attachment welds or certain cylinder to tubesheet welds. Radiography is also a relatively slow and expensive method. There are also inherent safety considerations with this method since it uses radioactive sources.

With specialized equipment, it is possible to radiograph tube-to-tubesheet welds. This technique is expensive and should only be used on the most critical tube end joints.

TEMA Recommendations:

A minimum of spot radiography should be performed on heat exchangers. Additional RT may be dictated by Code or contractual requirements.

G-2.3.2 ULTRASONIC TESTING (UT)

This method uses high frequency sound waves to evaluate materials and welds. A transducer is used which contains a crystal that vibrates when excited by high frequency voltage. The ultrasonic vibrations from the transducer are transmitted to the piece being tested through a coupling fluid (couplant). The ultrasonic waves travel through the test piece until they are reflected by either a boundary edge or by a discontinuity. The returning echoes are detected by the transducer and displayed on a screen indicating the time (distance) and amplitude of the signal. Since the velocity of the wave through the material is nearly constant, it is possible to determine the nature (detection, location, size and shape) of the discontinuity.

There are three types of ultrasonic waves: longitudinal (compression), shear (transverse), and surface (Rayleigh). Longitudinal waves travel the fastest with greater penetrating ability, but less resolution due to the longer wavelength. Thickness measurements and straight beam (0°) inspections use longitudinal waves. Shear waves are created by introducing the longitudinal wave at an angle to the surface of the part. For inspection purposes, the angle is chosen so the longitudinal wave is completely reflected, leaving an angled (refracted) shear wave inside the part. The speed is about half that of longitudinal waves, resulting in a shorter wavelength, thus the resolution and detectability of smaller discontinuities is improved. Shear waves are commonly used for weld inspection. Surface waves are less frequently used but can detect breaks in the surface such as cracks.

Traditional UT normally uses a single transducer that both sends and receives energy (known as pulse-echo) and is most often applied directly to the part. However, advances in technology have led to increased use of Phased Array Ultrasonic Testing (PAUT). PAUT uses multiple transducer elements contained within a single probe block. A computer controls the direction and focus of the sound and can scan larger sections of material at once. This method is more versatile and more accurate than traditional techniques. Data can be recorded and stored as a permanent record. These principals have been further expanded to produce high resolution and highly sensitive inspection techniques like Full Matrix Capture (FMC), also known as Total Focus Method (TFM). However, these techniques require greater computing power as well as increased data storage. Other multi-probe techniques utilizing through transmission (pitch-catch) such as Time of Flight Diffraction (TOFD) are used to increase efficiency and detectability. TOFD is often used in tandem with phased array for fast and accurate flaw sizing.

Ultrasonic testing offers several benefits in the construction of heat exchangers. Under certain conditions, the Code allows ultrasonic testing in lieu of radiography. Compared to radiography, ultrasonic testing offers similar full volumetric analysis of welds, but is safer and can be performed nearby other personnel. Ultrasonic testing can be performed on joints where radiography may not be possible, such as nozzle attachment welds and certain tubesheet-to-cylinder welds of fixed tubesheet exchangers. Closing seams that cannot be readily radiographed due to limited access for either the source or film are also good candidates for ultrasonic examination.

Ultrasonic testing can also be used to determine the as-built or baseline thickness of various components of a heat exchanger, which can be compared to future thickness measurements to determine erosion/corrosion rates and expected remaining life.

Ultrasonic flaw detection requires a highly skilled technician and can be limited by part surface conditions, temperatures, and geometry. Testing results are more subjective than other methods such as radiography.

TEMA Recommendations:

When specified by the purchaser, baseline ultrasonic thickness measurements shall be recorded for all shells, channels, heads, and nozzle cylinders. On shells and channels, measurements should be taken at the four cardinal points at each cylinder end and at every 60" (1524 mm) of length. For heads, measurements should be taken at four cardinal points, 6" (152.4 mm) from the center and in the knuckle area. Nozzle cylinders 4" NPS (DN 100) and greater should have one set of readings at the four cardinal points. Nozzles less than 4" NPS (DN 100) should have two readings recorded, 180° apart. All measurements should be provided to the end user in a report with test locations identified.

G-2.3.3 HARDNESS TESTING

Hardness testing is the determination of the resistance of a material to permanent deformation by the penetration of a harder material. This method can be used to measure the hardness of either base materials, welds, and/or heat affected zones around welds. This is useful in order to evaluate properties such as strength, ductility and wear resistance. Hardness can be an indicator of the effectiveness of material heat treatment and workability. It can also reveal susceptibility issues, including cracking, due to exposure to environmental factors. When performing a hardness test, a specifically dimensioned and loaded indenter is pressed into the surface of the material or weld being tested. The shape, size and load of the indenter is specific to the hardness test method being employed. The relative hardness is determined by measuring either the depth or the size of the impression left by the indenter. Typical hardness test methods are Rockwell (HRB or HRC), Vickers (HV), and Brinell (HB), among others.

Hardness testing is a relatively simple and inexpensive non-destructive test that can be performed on the surfaces of materials or welds. However, it does not find weld or base metal defects, and hardness information is of limited value for many common construction materials.

TEMA Recommendations:

TEMA does not recommend hardness testing unless otherwise specified by Code or contractual requirements.

G-2.3.4 MAGNETIC PARTICLE TESTING (MT)

This method is used to detect cracks or other indications at or near the surface of welds or base metals that would otherwise not be seen by visual inspection. In the most commonly used type of MT, a magnetic field is first applied to the part with a hand-held probe or yoke. The surface of the part is then covered with small iron particles in either a powder form or suspended in a solution. Any crack in the material will cause a disruption in the magnetic field, which will draw the particles to it and make it plainly visible. The dry powder technique is more suitable to be used outdoors or in brightly lit areas, to inspect less accessible parts, or to inspect high temperature parts. A technique using fine fluorescent particles suspended in a solution (wet fluorescent magnetic particle or WFMT) can increase detectability of smaller indications. The fluorescent particles glow when viewed under an ultraviolet light. The inspection area must be dark or shielded from bright light for this technique. The part surface must also be free of grease or other detergents that may be fluorescent.

Since the magnetic particle testing method uses magnetism, it cannot be performed on non-magnetic materials such as stainless steel. This method can only find flaws in the material that are open to the surface, therefore it is a surface inspection method only. Areas to be inspected must be cleaned and free of paint, insulation, or any other debris. Liquid penetrant testing is an acceptable substitution for this method.

TEMA Recommendations:

In addition to any Code and contractual requirements, magnetic particle testing shall be performed on all completed structural attachment welds, i.e., lifting devices, vertical lug supports, and associated reinforcement pads, as well as all locations of removed temporary attachments.

G-2.3.5 LIQUID PENETRANT TESTING (PT)

This method is used to detect surface imperfections such as cracks, surface porosity, seams, laps, etc. in both magnetic and non-magnetic materials and welds. A brightly colored liquid dye known as a penetrant is applied to the dry and clean surface that is being examined. The penetrant is generally applied by dipping, spraying, or brushing. The penetrant is left on the surface for a prerequisite amount of time (known as dwell time) to allow the penetrant to be absorbed into any imperfection by capillary action. Once sufficient time has passed, the excess penetrant is typically removed with a solvent or water spray, and a developer is applied to the surface. The developer then draws any penetrant out of the flaws so that the imperfection is revealed. This inspection is performed under either ultraviolet or white light depending upon what type of dye is used.

Liquid penetrant testing offers a quick low-cost method for the detection of surface imperfections in both non-magnetic and magnetic base metal and welds. The method is simple to learn, and results are very repeatable and reliable. A wide variety of part shapes and sizes can be tested. Liquid penetrant is a surface inspection and will not indicate imperfections that are below the surface. The irregular surface of welds may cause "false" indications. This method can be messy or require space for lighting control or drainage. It also cannot be used on high temperature parts.

TEMA Recommendations:

In addition to any Code and contractual requirements, liquid penetrant testing shall be performed on all tube end welds after expansion.

G-2.3.6 POSITIVE MATERIAL IDENTIFICATION (PMI)

Positive material identification is a program that helps to ensure that the specified material is being used in the construction of the exchanger. The program may make use of any combination of material test reports, metallographic analyzers, and laboratory testing. It is important for each manufacturer to verify that the alloying elements listed on the material test reports are verified against the contractual and code requirements for the specified materials.

Further verification on the alloying elements may be accomplished by using metallographic analyzers:

X-ray Fluorescence (XRF): This method uses an analyzer that contains a low radioactive source (isotope) or an x-ray tube. The tested material reflects the radiation from the analyzer which generates energy. Each alloying element has its own atomic structure and will generate a different energy level for each element. The analyzer detects and measures the reflected energy thus identifying the alloying elements. This method does not allow for the sampling of some elements such as carbon.

Optical Emission Spectrometry (OES): This method utilizes an analyzer with a probe which releases a spark that vaporizes a small sample of the material being analyzed. The vapor contains atoms and ions that produce a spectrum which can be optically measured to determine the alloying components of the material. This method can be used to determine elements such as carbon. Although the OES method is considered a non-destructive test in industry, the spark leaves a small burn mark that will need to be removed. This method is not recommended for tubes or final gasket surfaces.

Laser Induced Breakdown Spectroscopy (LIBS): This method uses an analyzer which emits a short laser pulse to create a micro-plasma on the tested surface. The atoms and ions in the plasma emit light with discrete spectral peaks as they cool. The emitted light from the plasma is collected and coupled with an ICCD/spectrograph detector module for LIBS spectral analysis. Since each element has a unique spectral peak, it is possible to determine the chemical makeup of the sampled material by analysis of each spectral peak.

Material verification can also be performed through chemical analysis of a sample of the material tested by a qualified laboratory. This method requires the removal of a material sample and repair of the part from which the sample is removed.

When required, positive material identification would typically be applied to alloy pressure components, fasteners, parts with alloy cladding, alloy weld consumables, and alloy welds. Some services may warrant alloy verification of carbon steel components.

TEMA Recommendations:

PMI testing should be considered for alloy material.

G-2.3.7 FERRITE TESTING

Some customers may find it desirable to measure the amount of ferrite in austenitic and duplex stainless steel welds and weld overlay in their equipment. Ferrite is one of the metallurgical phases found in the microstructures of stainless steels. The amount of ferrite present will greatly affect the mechanical properties, the weldability, and the corrosion resistance of these steels. The ferrite measurement may be accomplished by either a laboratory analysis or by the use of a magnetic instrument (ferritescope).

A laboratory analysis is a destructive test which involves the sectioning of a test specimen, and performing a point count of the ferrite structures on a grid placed on photomicrographs of the sectioned piece. This method would generally only be used for weld procedure qualifications.

The most common method for the determination of ferrite in materials and welds is by the use of a magnetic instrument. This method is non-destructive and can be performed on production welds (except for tube-to-tubesheet welds). During this testing a probe is placed in contact with the material or weld being tested which forms a closed loop. This allows the measurement of the magnetic permeability of the area being tested. This permeability is measured against standard percentages of other materials with known ferrite content. The magnetic permeability of the tested material relative to the known standards will indicate its ferrite percentage.

TEMA Recommendations:

When welding using procedures qualified per the code of construction, ferrite testing is not normally necessary nor recommended.

G-2.3.8 BUBBLE LEAK TEST

Bubble leak testing can be used to reveal leak paths in welded joints. Typically, this test is used for welded tube-to-tubesheet joints where the bundle is placed in either its shell or a temporary test shell so that the shell side of the bundle can be pressurized with air. A typical test pressure range is 10-15 psig. Once the shell side is pressurized, a soap water solution is applied to the tube side face of the tubesheet. A leak in a tube joint will be indicated by causing bubbles to form. This method can also be applied when testing the attachment welds for reinforcing pads that are equipped with weep holes. If pressurizing the part cannot be achieved, bubble leak testing can be performed by using various shaped vacuum boxes with similar results.

TEMA Recommendations:

Unless helium leak testing is performed, bubble leak testing shall be performed on tube end welds, prior to tube expansion. If the shell side cannot be pressurized or tube ends are not accessible for testing, this test is not required.

G-2.3.9 HELIUM LEAK TEST

A helium leak test may be used to determine if leak paths are present in tube-to-tubesheet welds. Like the bubble leak test above, this test works best when the bundle is installed in either a shell or test shell so that the shell side of the bundle may be pressurized with helium. A helium mass spectrometer is then used on the tube side face to detect helium amounts that are above normal background levels.

Due to the small size of the helium atom, very small leaks can be found with this method. Helium is also non-toxic and chemically inert. Helium leak testing is more costly than an air soap test due to the specialized equipment required. Some configurations may not be accessible to test with this method or may require a test ring such as 'S'-type floating tubesheets (see E-4.1.3 (3)).

TEMA Recommendations:

For critical applications, helium leak testing shall be performed on tube end welds, prior to tube expansion. If the shell side cannot be pressurized or tube ends are not accessible for testing, this test is not required.

G-2.3.10 EDDY CURRENT TESTING (ECT)

Eddy current testing is a procedure commonly used to inspect heat exchanger and boiler tubing, but it can be used in other applications. This method uses the principals of electromagnetic induction to detect flaws or wall loss in tubing, either before or after the tubes are installed in an exchanger. In the probe or bobbin-type testing method, the instrument is calibrated to a tube with known flaws. A probe is then passed through the inside of each exchanger tube, along its full length. Electric current in the probe creates a magnetic field in the tube or part to be tested. The

impedance of the coil within the probe changes as it interacts with the magnetic field of the part. Variations in the probe impedance are measured by the instrument and shown on the instrument's screen. A skilled technician interprets the signals to identify flaws or wall loss in the tubing. In the encircling coil method, tubes are passed through a stationary coil to produce similar results. This technique is often used at tubing mills to inspect new tubing.

Baseline probe-type eddy current testing is often performed on a new heat exchanger so that results can be compared to later in-service tests to determine if changes have occurred after some time in service. Eddy current testing is an efficient, accurate and economical method of finding weakened or damaged tubes before failure occurs. A disadvantage of this method is the specialized training needed to operate eddy current equipment and interpret testing results. Pin holes and some other tube discontinuities may not be detected by this method. Only non-magnetic tube materials can be tested, and fouled tubes cannot be inspected.

TEMA Recommendations:

If future in-service eddy current inspections will be performed, baseline eddy current testing should be considered for new units after tubes are installed in the bundle. This test is for information and should not be used for rejection. This requirement should be specified by the end user.

G-2.3.11 INTERNAL ROTARY INSPECTION SYSTEM (IRIS TESTING)

This test method also uses an internal probe to inspect tubes, but in this case the probe head uses a spinning mirror to perform ultrasonic inspection of the tube wall. As the probe is pulled through the tube, the rotating mirror results in a helical scan path. The tube is flooded with water while testing, to provide a couplant for the ultrasonic beam. This method accurately measures tube thickness or any wall loss at the ID or OD and can be used on any tubing material. Limitations include the high cost of equipment and operator training, and the requirements for clean tubes and constant supply of water. Circumferential cracks or pin holes may not be detected.

TEMA Recommendations:

This method can be used as an alternative to eddy current testing, when dictated by tubing material or other conditions.

G-2.3.12 FLUX LEAKAGE TESTING (MFL)

Ferromagnetic tubes or pipes can be inspected by the magnetic flux leakage method. A probe containing a magnet and flux leakage sensors is passed through the length of the tube. Similar to magnetic particle testing, flaws or defects in the parts being tested produce changes in the magnetic field. These changes are detected by the probe and displayed for the operator.

TEMA Recommendations:

This method can be used as an alternative to eddy current testing to monitor ferromagnetic tubes for corrosion or flaws. It is not recommended unless specified by the end user.

G-2.3.13 VISUAL INSPECTION (VT)

As the name implies, visual testing is performed by direct, careful observation of the part being tested. Any suspected flaws can be investigated further by other methods such as dye penetrant testing. Although visual testing is fast and can be performed on any visible part or weld, it is a surface inspection only and not as accurate as other NDE types. Adequate illumination is required for VT, and optical instruments such as magnifying glasses, mirrors, boroscopes, etc. may be used to improve the inspection.

TEMA Recommendations:

TEMA recommends all exchangers be 100% visually inspected after fabrication is complete and before hydrostatic testing. The inspection should include a full dimensional verification.

G-2.4 SHOP OPERATION

The detailed methods of shop operation are left to the discretion of the manufacturer in conformity with these Standards.

G-3 NAMEPLATES**G-3.1 MANUFACTURER'S NAMEPLATE**

A suitable manufacturer's nameplate of corrosion resistant material shall be permanently attached to the head end or the shell of each TEMA exchanger. The nameplate may be attached via a bracket welded to the exchanger and shall be visible outside any insulation.

G-3.1.1 NAMEPLATE DATA

In addition to all data required by the Code, a nameplate shall also include the following (if provided):

User's equipment identification

User's order number

G-3.1.2 SUPPLEMENTAL INFORMATION

The manufacturer shall supply supplemental information where it is pertinent to the operation or testing of the exchanger. This would include information pertaining to differential design and test pressure conditions, restrictions on operating conditions for fixed tubesheet type exchangers, or other restrictive conditions applicable to the design and/or operation of the unit or its components. Such information can be noted on the nameplate or on a supplemental plate attached to the exchanger at the nameplate location.

G-3.2 PURCHASER'S NAMEPLATE

Purchaser's nameplates, when used, are to be supplied by the purchaser and supplement rather than replace the manufacturer's nameplate.

G-4 DRAWINGS AND CODE DATA REPORTS**G-4.1 DRAWINGS FOR APPROVAL AND CHANGE**

The manufacturer shall submit an outline drawing containing information necessary for the customer to locate piping to the exchanger and footings or structure necessary to support the exchanger. The outline shall be submitted for the customer's approval and shall show the following information as a minimum: nozzles sizes and locations, flange ratings for nozzles, overall dimensions, support locations and base plate dimensions, and exchanger weight. Other drawings may be furnished as agreed upon by the purchaser and the manufacturer. The drawing will be submitted electronically, in PDF format, unless another format is agreed upon by the purchaser and the manufacturer. It is anticipated that a reasonable number of minor changes may be required due to customer comments to this initial submittal. Any changes that cause additional expense are chargeable to the customer and it is the manufacturer's responsibility to advise the customer of the commercial impact. Purchaser's approval of drawings does not relieve the manufacturer of responsibility for compliance with this Standard and applicable Code requirements. The manufacturer shall not make any changes on the approved drawings without express agreement of the purchaser.

G-4.2 DRAWINGS FOR RECORD

After approval of drawings, the manufacturer shall furnish drawings for record. The drawings will be submitted electronically, in PDF format, unless another format is agreed upon by the purchaser and the manufacturer.

G-4.3 PROPRIETARY RIGHTS TO DRAWINGS

The drawings and the design indicated by them are to be considered the property of the manufacturer and are not to be used or reproduced without permission, except by the purchaser for internal use.

G-4.4 CODE DATA REPORTS

After completion of fabrication and inspection of an exchanger to its Code, the manufacturer shall furnish copies of the Code Manufacturer's Data Report or Certification, as agreed upon by the purchaser and the manufacturer.

G-5 GUARANTEES**G-5.1 GENERAL**

The specific terms of the guarantees should be agreed upon by the manufacturer and purchaser. Unless otherwise agreed upon by the manufacturer and purchaser in writing, the following paragraphs in this section will be applicable and will govern even over the contrary terms of any other writing between the manufacturer and the purchaser unless that writing specifically states that it is intended to override the provisions of this section.

G-5.2 PERFORMANCE

The purchaser shall, in writing, furnish the manufacturer with all information needed for clear understanding of performance requirements, including any special requirements. The manufacturer shall guarantee thermal performance and mechanical design of a heat exchanger, when operated at the design conditions specified by the purchase order or shown on the exchanger specification sheet furnished by the manufacturer (Figure G-1). This guarantee shall extend for a period of twelve (12) months after shipping date. Notwithstanding this guarantee, the manufacturer shall have no responsibility or liability for excessive fouling of the apparatus by material such as coke, silt, scale, or any foreign substance that may be deposited, and the manufacturer shall have no responsibility or liability for any other performance problem wholly or partially caused by circumstances beyond the manufacturer's complete control or that the manufacturer did not have the ability to prevent. Without limiting the generality of the foregoing, such circumstances shall include (i) faulty installation of the exchanger by anyone other than the manufacturer, (ii) any modification or repair made to the exchanger by the purchaser or anyone other than the manufacturer and (iii) combination of the exchanger with other equipment not furnished by the manufacturer. The thermal guarantee shall not be applicable to exchangers where the thermal performance rating was made by anyone other than the manufacturer.

G-5.2.1 THERMAL PERFORMANCE TEST

A performance test shall be made if it is established after operation for a sufficient period of time that the performance of the exchanger does not meet the written performance requirements previously furnished by the purchaser to the manufacturer, provided the thermal performance rating was made by the manufacturer. Test conditions and procedures shall be selected by agreement between the purchaser and the manufacturer to permit extrapolation of the test results to the specified design conditions.

G-5.2.2 DEFECTIVE PARTS

The manufacturer shall repair or replace F.O.B. its plant any parts proven defective within the guarantee period but does not assume liability for the cost of removing defective parts or reinstalling replacement parts. The manufacturer shall be responsible only for the direct costs associated with repair of its defect or non-conforming product. Finished materials and accessories purchased from other manufacturers, including tubes, are warranted only to the extent of the original manufacturer's warranty to the heat exchanger fabricator. The manufacturer will endeavor to provide the purchaser with a copy of any warranty information given to the manufacturer by suppliers of parts incorporated into the exchanger by the manufacturer but cannot be responsible for the accuracy or completeness of that information.

G-5.3 DAMAGES EXCLUSION

In no event shall the manufacturer be held liable for any indirect, special, incidental, punitive, exemplary or consequential damages, such as damages for loss of goodwill, work stoppage, lost profits, lost revenue, loss of clients, lost business or lost opportunity, or any other similar damages of any and every nature, under any theory of liability, whether in contract, tort, strict liability, or any other theory.

G-5.4 CORROSION AND VIBRATION

The manufacturer assumes no responsibility for deterioration of any part or parts of the equipment due to corrosion, erosion, flow induced tube vibration, or any other causes, regardless of when such deterioration occurs after leaving the manufacturer's premises, except as provided for in Paragraphs G-5.2 and G-5.2.2.

G-5.5 REPLACEMENT AND SPARE PARTS

When replacement or spare tube bundles, shells, or other parts are purchased, the manufacturer guarantees satisfactory fit of such parts only if it was the original manufacturer. Parts fabricated to drawings furnished by the purchaser shall be guaranteed to meet the dimensions and tolerances specified.

G-5.6 DISCLAIMER OF WARRANTY

While the manufacturer provides guarantees as specifically offered by the manufacturer to the purchaser in writing, the manufacturer makes no other warranties or guarantees and assumes no liability in connection with any other warranty or guarantee, express or implied. WITHOUT LIMITING THE GENERALITY OF THE FOREGOING, THE MANUFACTURER SPECIFICALLY DISCLAIMS ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE IN CONNECTION WITH THE SALE OF EXCHANGERS, WHETHER OR NOT THE MANUFACTURER HAS BEEN ADVISED OF SUCH PURPOSE.

G-5.7 AGGREGATE LIABILITY

The aggregate total liability of manufacturer to customer for any direct loss, cost, claim, or damages of any kind related to any failure of performance by a heat exchanger shall not exceed the amount the purchaser has paid to the manufacturer for the exchanger.

G-5.8 INDEMNIFICATION

Notwithstanding any other contract language to the contrary, the manufacturer shall have no liability to indemnify, defend or hold the purchaser harmless against third-party claims, costs, losses and expenses relating in any way to the transaction between the manufacturer and the purchaser or to heat exchanger performance.

G-6 PREPARATION OF HEAT EXCHANGERS FOR SHIPMENT**G-6.1 CLEANING**

Internal and external surfaces are to be free from loose scale and other foreign material that is readily removable by hand or power brushing.

G-6.2 DRAINING

Water, oil, or other liquids used for cleaning or hydrostatic testing are to be drained from all units before shipment. This is not to imply that the units must be completely dry.

G-6.3 FLANGE PROTECTION

All exposed machined contact surfaces shall be coated with a removable rust preventative and protected against mechanical damage by suitable covers.

G-6.4 THREADED CONNECTION PROTECTION

All threaded connections are to be suitably plugged.

G-6.5 DAMAGE PROTECTION

The exchanger and any spare parts are to be suitably protected to prevent damage during shipment.

G-6.6 EXPANSION JOINT PROTECTION

External thin-walled expansion bellows shall be equipped with a protective cover which does not restrain movement.

G-7 GENERAL CONSTRUCTION FEATURES OF TEMA STANDARD HEAT EXCHANGERS**G-7.1 SUPPORTS**

All heat exchangers are to be provided with supports. The supports should be designed to accommodate the weight of the unit and contents, including the flooded weight during hydrostatic test.

For purposes of support design, forces from external nozzle loadings, wind and seismic events are assumed to be negligible unless the purchaser specifically details the requirements. When these additional loads and forces are required to be considered, they need not be assumed to occur simultaneously unless combinations are specifically defined.

The references under Paragraph G-7.1.3 may be used for calculating resulting stresses in the support structure and attachment. Acceptable methods for horizontal supports and vertical lugs are shown in the RGP section.

***G-7.1.1 HORIZONTAL UNITS**

For units with removable tube bundles, supports should be designed to withstand a pulling force equal to 1-1/2 times the weight of the tube bundle.

Horizontal units are normally provided with at least two saddle type supports, with holes for anchor bolts. The holes in all but one of the supports are to be elongated to accommodate axial movement of the unit under operating conditions. Other types of support may be used if all design criteria are met, and axial movement is accommodated.

***G-7.1.2 VERTICAL UNITS**

Vertical units are to be provided with supports adequate to meet design requirements. The supports may be of the lug, annular ring, leg or skirt type. If the unit is to be located in a supporting structure, the supports should be of sufficient size to allow clearance for the body flanges.

G-7.1.3 REFERENCES

- (1) Zick, L. P., "Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports," Pressure Vessel and Piping; Design and Analysis, ASME, 1972.
- (2) Vinet, R., and Dore, R., "Stresses and Deformations in a Cylindrical Shell Lying on a Continuous Rigid Support," Paper No. 75-AM-1, Journal of Applied Mechanics, Trans. ASME.
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- (4) Singh, K. P., Soler, A. I., "Mechanical Design of Heat Exchangers and Pressure Vessel Components," Chapter 17, Arcturus Publishers, Inc.
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- (7) Rodabaugh, E. C., Dodge, W. G., and Moore, S. E., "Stress Indices at Lug Supports on Piping Systems," Welding Research Council Bulletin No. 198.
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- (9) Jawad, M. H., and Farr, J. R., "Structural Analysis and Design of Process Equipment," John Wiley and Sons, Inc., 1984.
- (10) Bednar, H. H., "Pressure Vessel Design Handbook," Van Nostrand Reinhold Company.
- (11) Blodgett, O. W., "Design of Welded Structures," The James F. Lincoln Arc Welding Foundation, 1966.
- (12) Moss, Dennis R., "Pressure Vessel Design Manual: Illustrated Procedures for Solving Major Pressure Vessel Design Problems" Edition: 3, Publisher: Gulf Pub Co (December 18, 2003).
- (13) ASME Section VIII, Division 2, Part 4.15.3

***G-7.2 LIFTING DEVICES**

Channels, bonnets, and covers which weigh over 60 lbs. (30 kg) are to be provided with lifting lugs, rings or tapped holes for eyebolts. Unless otherwise specified, these lifting devices are designed to lift only the component to which they are directly attached.

Lugs for lifting the complete unit are not normally provided. When lifting lugs or trunnions are required by the purchaser to lift the complete unit, the device must be adequately designed.

- (1) The purchaser shall inform the manufacturer about the way in which the lifting device will be used. The purchaser shall be notified of any limitations of the lifting device relating to design or method of rigging.
- (2) Liquid penetrant examination of the lifting device attachment weld should be considered.
- (3) The design load shall incorporate an appropriate impact factor.
- (4) Plate-type lifting lugs should be oriented to minimize bending stresses.
- (5) The hole diameter in the lifting device must be large enough to accept a shackle pin having a load rating greater than the design load.
- (6) The effect on the unit component to which the lifting device is attached should be considered. It may be necessary to add a reinforcing plate, annular ring, or pad to distribute the load.
- (7) The adequacy of the exchanger to accommodate the lifting loads should be evaluated.

***G-7.3 WIND & SEISMIC DESIGN**

For wind and seismic forces to be considered in the design of a heat exchanger, the purchaser must specify the design requirements in the inquiry. The "Recommended Good Practice" section of these Standards provides the designer with a discussion on this subject and selected references for design application.

E-1 PERFORMANCE OF HEAT EXCHANGERS

Satisfactory performance and service life can be expected only from heat exchangers which are properly installed, operated in accordance with design conditions, and receive preventive maintenance and cleaning on an appropriate schedule. These requirements are the responsibility of the user.

The failure of heat exchanger equipment to perform satisfactorily may be caused by one or more factors, such as:

- (1) Excessive fouling.
- (2) Air or gas binding resulting from improper piping installation or lack of suitable vents.
- (3) Operating conditions differing from design conditions.
- (4) Maldistribution of flow in the unit.
- (5) Excessive clearances between the baffles and shell and/or tubes, due to corrosion.
- (6) Improper thermal design.
- (7) Flooding resulting from inadequate drainage of condensate.
- (8) Material selection.

E-2 INSTALLATION OF HEAT EXCHANGERS

E-2.1 HEAT EXCHANGER SETTINGS

E-2.1.1 CLEARANCE FOR DISMANTLING

For straight tube exchangers fitted with removable bundles, provide sufficient clearance at the stationary head end to permit removal of the bundle from the shell and provide adequate space beyond the rear head to permit removal of the shell cover and/or floating head cover.

For fixed tubesheet exchangers, provide sufficient clearance at one end to permit withdrawal and replacement of the tubes, and enough space beyond the head at the opposite end to permit removal of the bonnet or channel cover.

For U-tube heat exchangers, provide sufficient clearance at the stationary head end to permit withdrawal of the tube bundle, or at the opposite end to permit removal of the shell.

E-2.1.2 FOUNDATIONS

Foundations must be adequate so that exchangers will not settle and impose excessive strains on the exchanger. Foundation bolts should be set to allow for setting inaccuracies. In concrete footings, pipe sleeves at least one size larger than bolt diameter slipped over the bolt and cast in place are best for this purpose, as they allow the bolt center to be adjusted after the foundation has set.

E-2.1.3 FOUNDATION BOLTS

Foundation bolts should be loosened at one end of the unit to allow free expansion of shells. Slotted holes in supports are provided for this purpose.

E-2.1.4 LEVELING

Exchangers must be installed so that pipe connections are made without forcing, disassembling, or loosening of flanged assemblies.

E-2.2 CLEANLINESS PROVISIONS

E-2.2.1 CONNECTION PROTECTORS

All exchanger openings should be inspected for foreign material. Protective plugs and covers should not be removed until just prior to installation.

E-2.2.2 DIRT REMOVAL

The entire system should be clean before starting operation. Under some conditions, the use of strainers in the piping may be required.

E-2.2.3 CLEANING FACILITIES

Convenient means should be provided for cleaning the unit as suggested under "Maintenance of Heat Exchangers," Paragraph E-4.

E-2.3 FITTINGS AND PIPING**E-2.3.1 BY-PASS VALVES**

It may be desirable for purchaser to provide valves and by-passes in the piping system to permit inspection and repairs.

E-2.3.2 TEST CONNECTIONS

When not integral with the exchanger nozzles, thermometer well and pressure gage connections should be installed close to the exchanger in the inlet and outlet piping.

E-2.3.3 VENTS

Vent valves should be provided by purchaser so units can be purged to prevent vapor or gas binding. Special consideration must be given to discharge of hazardous or toxic fluids.

E-2.3.4 DRAINS

Drains may discharge to atmosphere, if permissible, or into a vessel at lower pressure. They should not be piped to a common closed manifold.

E-2.3.5 PULSATION AND VIBRATION

In all installations, care should be taken to eliminate or minimize transmission of fluid pulsations and mechanical vibrations to the heat exchangers.

E-2.3.6 SAFETY RELIEF DEVICES

When specified by the purchaser, the manufacturer will provide the necessary connections for the safety relief devices. The size and type of the required connections will be specified by the purchaser. The purchaser will provide and install the required relief devices.

E-3 OPERATION OF HEAT EXCHANGERS**E-3.1 DESIGN AND OPERATING CONDITIONS**

Equipment must not be operated at conditions which exceed those specified on the nameplate(s).

E-3.2 OPERATING PROCEDURES

Before placing any exchanger in operation, reference should be made to the exchanger drawings, specification sheet(s) and nameplate(s) for any special instructions. Local safety and health regulations must be considered. Improper start-up or shut-down sequences, particularly of fixed tubesheet units, may cause leaking of tube-to-tubesheet and/or bolted flanged joints.

E-3.2.1 START-UP OPERATION

Most exchangers with removable tube bundles may be placed in service by first establishing circulation of the cold medium, followed by the gradual introduction of the hot medium. During start-up all vent valves should be opened and left open until all passages have been purged of air and are completely filled with fluid. For fixed tubesheet exchangers, fluids must be introduced in a manner to minimize differential expansion between the shell and tubes.

E-3.2.2 SHUT-DOWN OPERATION

For exchangers with removable bundles, the units may be shut down by first gradually stopping the flow of the hot medium and then stopping the flow of the cold medium. If it is necessary to stop the flow of cold medium, the circulation of hot medium through the exchanger should also be stopped. For fixed tubesheet exchangers, the unit must be shut down in a manner to minimize differential expansion between shell and tubes. When shutting down the system, all units should be drained completely when there is the possibility of freezing or corrosion damage. To guard against water hammer, condensate should be drained from steam heaters and similar apparatus during start-up or shut-down. To reduce water retention after drainage, the tube side of water cooled exchangers should be blown out with air.

E-3.2.3 TEMPERATURE SHOCKS

Exchangers normally should not be subjected to abrupt temperature fluctuations. Hot fluid must not be suddenly introduced when the unit is cold, nor cold fluid suddenly introduced when the unit is hot.

E-3.2.4 BOLTED JOINTS

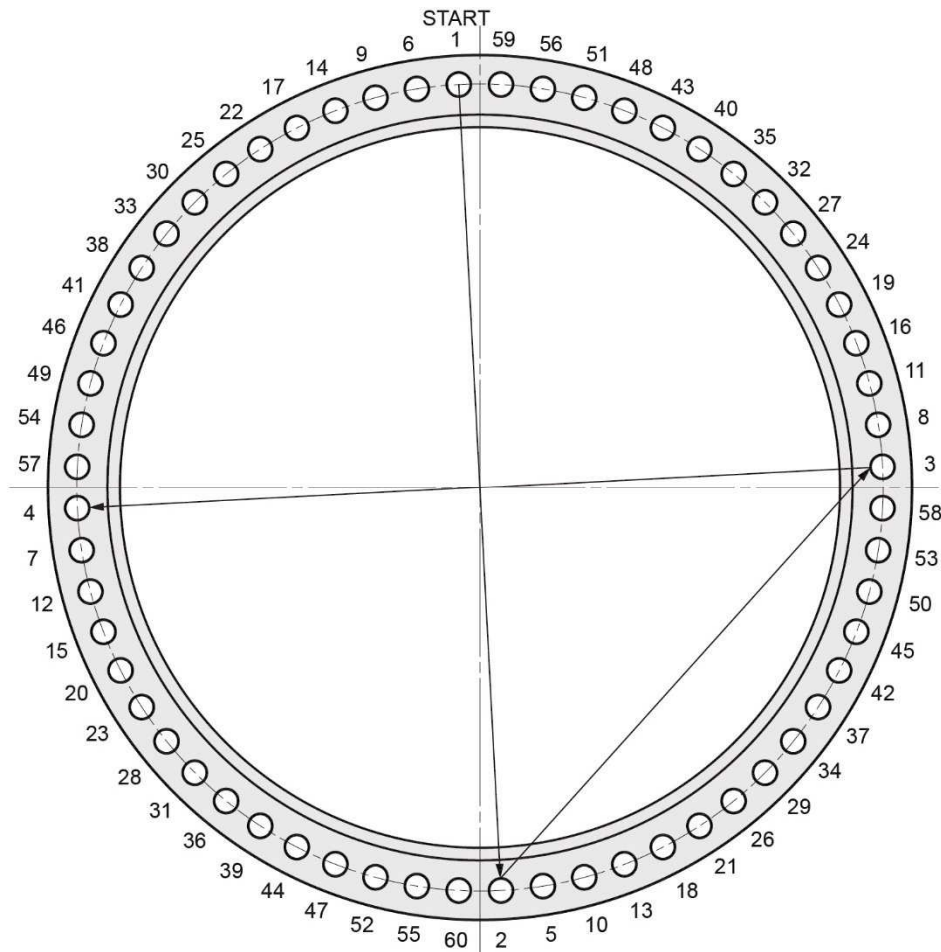
Heat exchangers are pressure tested before leaving the manufacturer's shop in accordance with Code requirements. However, normal relaxing of the gasketed joints may occur in the interval between testing in the manufacturer's shop and installation at the jobsite. Therefore, all external bolted joints may require retightening after installation and, if necessary, after the exchanger has reached operating temperature.

- E-3.2.4.1** It is possible for the bolt stress to decrease after initial tightening, because of slow creep or relaxation of the gasket, particularly in the case of the softer gasket materials.
- E-3.2.4.2** Excessive initial bolt stress can cause yielding of the bolt itself. This is especially likely with bolts of small diameter or bolting having relatively low yield values such as stainless steels.
- E-3.2.4.3** ASME PCC-1 Appendices N and P provide additional guidance for the reuse of bolts and for troubleshooting flanged joint leakage incidents.
- E-3.2.4.4** Selection of the appropriate bolt stress and/or torque shall be done so as to provide sufficient preload to seat the gasket within the capacity of the flange. Acceptable methods for this selection include, but are not limited to, past experience, recommendations from gasket manufacturers, considerations from ASME Code Appendix S, using guidelines from ASME PCC-1 Section 10 and Appendix O, or using WRC Bulletin 538. When using the Joint Component Approach as shown in ASME PCC-1 O-4 or WRC-538, it is recommended that this approach be performed during the flange design as this approach may increase flange thickness. Gasket seating stress values for use in ASME PCC-1 O-4 can be found from gasket manufacturers and PVP papers PVP2013-97900 for service sheet/non-asbestos gaskets and PVP2014-28434 for GMGC, CMGC, and spiral wound gaskets. Acceptable methods for converting bolt stress to target torque include, but are not limited to, ASME PCC-1 Section 12 and Appendices J and K.

E-3.2.5 RECOMMENDED BOLT TIGHTENING PROCEDURE

- E-3.2.5.1** All gasket joint surfaces shall be clean and free of oil or debris. If the gasket requires assistance to be held in place for installation, grease shall not be used. Any tape applied to a spiral wound gasket for shipping or assembly shall be removed prior to installing the gasket. No tape, string, or other object will be allowed to remain on the gasket surface once assembly is complete. ASME PCC-1 Section 6 provides additional guidance for the installation of gaskets.
- E-3.2.5.2** Thoroughly clean threads, nut faces and the flange where nut face bears. If roughness, burrs or any irregularity is present, dress it out to as smooth a surface as possible.
- E-3.2.5.3** Thoroughly lubricate threads on studs, nuts and contacting surfaces on nuts and flange. ASME PCC-1 Section 7 provides additional guidance for the lubrication of fasteners.
- E-3.2.5.4** The joint shall be snugged up squarely so the entire flange face bears uniformly on the gasket. ASME PCC-1 Section 5 and Appendix E provide additional guidance for the alignment of joints.
- E-3.2.5.5** Tightening of the bolts shall be applied in at least three equally spaced increments using a cross bolting pattern as illustrated in Figure E-3.2.5.5 or a pattern as recommended by ASME PCC-1 Sections 8 through 11.
- E-3.2.5.6** When the cross bolting pattern is used and is complete; a circular chase pattern shall be applied until no nut rotation occurs.

FIGURE E-3.2.5.5



E-4 MAINTENANCE OF HEAT EXCHANGERS

E-4.1 INSPECTION OF UNIT

At regular intervals and as frequently as experience indicates, an examination should be made of the interior and exterior condition of the unit. Neglect in keeping all tubes clean may result in complete stoppage of flow through some tubes which could cause severe thermal strains, leaking tube joints, or structural damage to other components. Sacrificial anodes, when provided, should be inspected to determine whether they should be cleaned or replaced.

E-4.1.1 INDICATIONS OF FOULING

Exchangers subject to fouling or scaling should be cleaned periodically. A light sludge or scale coating on the tube greatly reduces its efficiency. A marked increase in pressure drop and/or reduction in performance usually indicates cleaning is necessary. The unit should first be checked for air or vapor binding to confirm that this is not the cause for the reduction in performance. Since the difficulty of cleaning increases rapidly as the scale thickness or deposit increases, the intervals between cleanings should not be excessive.

E-4.1.2 DISASSEMBLY FOR INSPECTION OR CLEANING

Before disassembly, the user must verify that the unit has been depressurized, vented and drained, neutralized and/or purged of hazardous material.

To inspect the inside of the tubes and also make them accessible for cleaning, the following procedures should be used:

- (1) Front End Stationary Head
 - (a) Type A, C, D, and N, remove channel cover only
 - (b) Type B, remove bonnet
- (2) Rear End Head
 - (a) Type L, N, and P, remove channel cover only
 - (b) Type M, remove bonnet
 - (c) Type S and T, remove shell cover and floating head cover
 - (d) Type W, remove channel cover or bonnet

E-4.1.3 LOCATING TUBE LEAKS

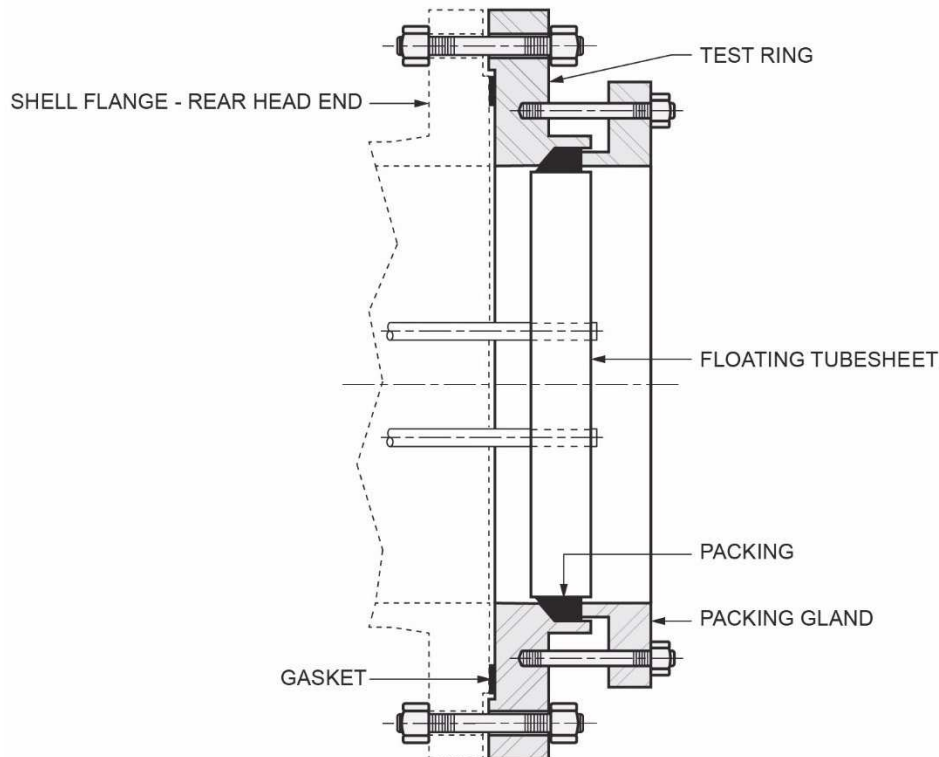
The following procedures may be used to locate perforated or split tubes and leaking joints between tubes and tubesheets. In most cases, the entire front face of each tubesheet will be accessible for inspection. The point where water escapes indicates a defective tube or tube-to-tubesheet joint.

- (1) Units with removable channel cover: Remove channel cover and apply hydrostatic pressure in the shell.
- (2) Units with bonnet type head: For fixed tubesheet units where tubesheets are an integral part of the shell, remove bonnet and apply hydrostatic pressure in the shell. For fixed tubesheet units where tubesheets are not an integral part of the shell and for units with removable bundles, remove bonnet, re-bolt tubesheet to shell or install test flange or gland, whichever is applicable, and apply hydrostatic pressure in the shell. See Figure E-4.1.3-1 for examples of some typical test flanges and test glands.

FIGURE E-4.1.3-1

- (3) Units with Type S or T floating head: Remove channel cover or bonnet, shell cover and floating head cover. Install test ring and bolt in place with gasket and packing. Apply hydrostatic pressure in the shell. A typical test ring is shown in Figure E-4.1.3-2. When a test ring is not available it is possible to locate leaks in the floating head end by removing the shell cover and applying hydrostatic pressure in the tubes. Leaking tube joints may then be located by sighting through the tube lanes. Care must be exercised when testing partially assembled exchangers to prevent over extension of expansion joints or overloading of tubes and/or tube-to-tubesheet joints.
- (4) Metal temperature during hydrostatic test should be at least 60°F (16°C) or as permitted by the applicable code.

FIGURE E-4.1.3-2



E-4.2 TUBE BUNDLE REMOVAL AND HANDLING

Bundles must be withdrawn from the stationary end as noted on the drawing. All parts such as glands, retainer rings, split shear rings and closure packing must be removed before attempting to remove the bundle. Threaded eyebolts may be attached to the stationary tubesheet when tapped holes have been provided for this purpose. When eyebolt tappings are not provided, rods may be passed through two or more tubes and attached to a steel bearing plate over the floating tubesheet. Provide a protective spacer between the bearing plate and tubesheet to protect the tube ends.

Tube bundles should not be handled with hooks or other devices which might damage the tubes. Bundles should be supported on cradles or skids. Horizontal tube bundles should be lifted by means of suitable slings. Care should be taken to avoid bending or damaging baffles during bundle removal. All gasket and packing contact surfaces should be protected from accidental damage since these areas are generally difficult to repair.

E-4.3 CLEANING TUBE BUNDLES

E-4.3.1 CLEANING METHODS

The heat transfer surfaces of heat exchangers should be kept reasonably clean to assure satisfactory performance. Convenient means for cleaning should be made available.

Heat exchangers may be cleaned by either chemical or mechanical methods. The method selected must be the choice of the operator of the plant and will depend on the type of deposit and the facilities available in the plant. Following are several cleaning procedures that may be considered:

- (1) Circulating hot wash oil or light distillate through tubes or shell at high velocity may effectively remove sludge or similar soft deposits.
- (2) Some salt deposits may be washed out by circulating hot fresh water.
- (3) Commercial cleaning compounds are available for removing sludge or scale provided hot wash oil or water is not available or does not give satisfactory results.
- (4) High pressure water jet cleaning.
- (5) Scrapers, rotating wire brushes, and other mechanical means for removing hard scale, coke, or other deposits.

- (6) Employ services of a qualified organization that provides cleaning services. These organizations will check the nature of the deposits to be removed, furnish proper solvents and/or acid solutions containing inhibitors, and provide equipment and personnel for a complete cleaning job.

E-4.3.2 CLEANING PRECAUTIONS

- (1) Tubes should not be cleaned by blowing steam through individual tubes since this heats the tube and may result in severe expansion strain, deformation of the tube, or loosening of the tube-to-tubesheet joint.
- (2) When mechanically cleaning a tube bundle, care should be exercised to avoid damaging the tubes.
- (3) Cleaning compounds must be compatible with the metallurgy of the exchanger.
- (4) Cleaning procedures, especially those which circulate hot fluids through the tubes, can cause significant temperature differentials between the shell and tubes. Such cleaning procedures can cause damage to fixed-tubesheet heat exchangers and should be avoided unless specifically provided for in the design of the heat exchanger.

E-4.4 TUBE EXPANDING

A suitable tube expander should be used to tighten a leaking tube joint. Care should be taken to ensure that tubes are not over expanded (see RCB-7.3.1).

E-4.5 GASKET REPLACEMENT

Gasket and gasket surfaces should be thoroughly cleaned and should be free of scratches and other defects. Gaskets should be properly positioned before attempting to retighten bolts. It is recommended that when a heat exchanger is dismantled for any cause, it be reassembled with new gaskets. This will tend to prevent future leaks and/or damage to the gasket seating surfaces of the heat exchanger. Composition gaskets become dried out and brittle so that they do not always provide an effective seal when reused. Metal or metal jacketed gaskets, when compressed initially, flow to match their contact surfaces. In doing so they are work hardened and, if reused, may provide an imperfect seal or result in deformation and damage to the gasket contact surfaces of the exchanger. Graphite faced gaskets are usually damaged in disassembly and as such cannot be reused.

Bolted joints and flanges are designed for use with the particular type of gasket specified. Substitution of a gasket of different construction or improper dimensions may result in leakage and damage to gasket surfaces. Therefore, any gasket substitutions should be of compatible design and the original manufacturer should be consulted prior to changing gasket type.

Any leakage at a gasketed joint should be rectified and not permitted to persist as it may result in damage to the gasket surfaces.

When metal jacketed filled type gaskets are used with a tongue and groove joint without a nubbin, the gasket should be installed so that the tongue bears on the seamless side of the gasket jacket. When a nubbin is used, the nubbin should bear on the seamless side.

E-4.6 DIAPHRAGM INSTALLATION PROCEDURE

- (1) Position diaphragm and tighten to remove all voids between diaphragm and component to which it will be welded. This may be accomplished by bolting the cover in place, by a series of clamps or any other means that guarantees that the diaphragm will not move during final bolt-up and crack the weld.
- (2) Make the diaphragm-to-component weld and inspect using liquid penetrant.
- (3) Install cover and tighten studs to required torque or tension.
- (4) Inspect weld again using liquid penetrant after tightening studs.

E-4.7 SPARE AND REPLACEMENT PARTS

The procurement of spare or replacement parts from the manufacturer will be facilitated if the correct name for the part, as shown in Section 1, Table N-2, of these Standards is given, together with the serial number, type, size, and other information from the nameplate. Replacement parts should be purchased from the original manufacturer.

E-4.8 PLUGGING OF TUBES

In U-tube heat exchangers, and other exchangers of special design, it may not be feasible to remove and replace defective tubes. Defective tubes may be plugged using commercially available tapered plugs with ferrules or tapered only plugs which may or may not be seal welded. Excessive tube plugging may result in reduced thermal performance, higher pressure drop, and/or mechanical damage. It is the user's responsibility to remove plugs and neutralize the bundle prior to sending it to a shop for repairs.

E-5 CHANGES TO CONFIGURATION OF HEAT EXCHANGERS

It may be desirable to change the configuration of the heat exchanger, upgrade materials, increase the design pressures and/or temperatures, or change the gasket types when replacing or reworking components of an existing heat exchanger. Reasons for these changes may range from a need to increase performance, to take advantage of new alloys, to support changes in other parts of the plant, to solve chronic problems in the heat exchanger itself or for economic considerations. Whenever changes are made to components of the heat exchanger, consideration should be given to the effect on the overall design of the heat exchanger. It is always advisable to consult the rules of the jurisdiction where the equipment is installed prior to making any changes. The requirements of the Code and TEMA shall also be satisfied. Some particular areas of concern are flange rating, material thickness, unsupported tube length, channel nozzle locations, pass partition configuration, and clearance between the end of the removable bundle and the shell (see Appendix B).

RCB-1 SCOPE AND GENERAL REQUIREMENTS**RCB-1.1 SCOPE OF STANDARDS****RCB-1.1.1 GENERAL**

The TEMA Mechanical Standards are applicable to shell and tube heat exchangers which do not exceed any of the following criteria:

- (1) inside diameters of 100 in. (2500 mm)
- (2) product of nominal diameter, in. (mm) and design pressure, psi (kPa) of 100,000 (17.5 x 10⁶)
- (3) a design pressure of 3,000 psi (21000 kPa)

The intent of these parameters is to limit the maximum shell wall thickness to approximately 3 in. (75 mm), and the maximum stud diameter to approximately 4 in. (100 mm). Criteria contained in these Standards may be applied to units which exceed the above parameters.

For units that exceed 100 in (2500 mm) inside diameter, it is recommended that the shell thicknesses, baffle and support plate clearances and thicknesses, and tie rod numbers and diameters used be no less than that for units up to 100 in (2500 mm). Note, however, that the actual thicknesses, clearances, numbers, and diameters used shall be evaluated by the manufacturer for suitability with the fabrication methods employed. Particular attention shall be given to the effect of shell ovality on baffle clearances, potential baffle and tube damage due to bundle weight during insertion and/or removal (see RCB-4.7.2), and verification that the actual clearances were addressed in the heat transfer calculations.

R-1.1.2 DEFINITION OF TEMA CLASS "R" EXCHANGERS

The TEMA Mechanical Standards for Class "R" heat exchangers specify design and fabrication of unfired shell and tube heat exchangers for the generally severe requirements of petroleum and related processing applications.

C-1.1.2 DEFINITION OF TEMA CLASS "C" EXCHANGERS

The TEMA Mechanical Standards for Class "C" heat exchangers specify design and fabrication of unfired shell and tube heat exchangers for the generally moderate requirements of commercial and general process applications.

B-1.1.2 DEFINITION OF TEMA CLASS "B" EXCHANGERS

The TEMA Mechanical Standards for Class "B" heat exchangers specify design and fabrication of unfired shell and tube heat exchangers for chemical process service.

RCB-1.1.3 CONSTRUCTION CODES

Unless otherwise specified, the individual vessels shall comply with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1. The chosen construction code is hereinafter referred to as the Code. Where references to specific sections of ASME Section VIII, Division 1 are made, these are hereinafter referred to as the ASME Code.

RCB-1.1.4 MATERIALS - DEFINITION OF TERMS

For purposes of these Standards, "carbon steel" shall be construed as any steel or low alloy falling within the scope of Part UCS of the ASME Code. Metals not included by the foregoing (except cast iron) shall be considered as "alloys" unless otherwise specifically named. Materials of construction, including gaskets, should be specified by the purchaser.

RCB-1.2 DESIGN PRESSURES

Design pressures for the shell and tube sides shall be specified separately by the purchaser.

RCB-1.3 TESTING**RCB-1.3.1 STANDARD TEST**

The exchanger shall be hydrostatically tested with water. The test pressure shall be held for at least 30 minutes. The shell side and the tube side are to be tested separately in such a manner that leaks at the tube joints can be detected from at least one side. Welded joints are to be sufficiently cleaned prior to testing the exchanger to permit proper inspection during the test. The minimum hydrostatic test pressure and temperature shall be in accordance with the Code.

Liquids other than water may be used as a testing medium if agreed upon between the purchaser and the manufacturer.

RCB-1.3.2 PNEUMATIC TEST

When liquid cannot be tolerated as a test medium the exchanger may be given a pneumatic test in accordance with the Code. It must be recognized that air or gas is hazardous when used as a pressure testing medium. The pneumatic test pressure and temperature shall be in accordance with the Code.

RCB-1.3.3 SUPPLEMENTARY AIR TEST

When a supplementary air or gas test is specified by the purchaser, it shall be preceded by the hydrostatic test required by Paragraph RCB-1.3.1. The test pressure and temperature shall be as agreed upon by the purchaser and manufacturer but shall not exceed that required by Paragraph RCB-1.3.2.

RCB-1.4 METAL TEMPERATURES**RCB-1.4.1 METAL TEMPERATURE LIMITATIONS FOR PRESSURE PARTS**

The metal temperature limitations for various metals are those prescribed by the Code.

RCB-1.4.2 DESIGN TEMPERATURE OF HEAT EXCHANGER PARTS**RCB-1.4.2.1 FOR PARTS NOT IN CONTACT WITH BOTH FLUIDS**

Design temperatures for the shell and tube sides shall be specified separately by the purchaser. The Code provides the allowable stress limits for parts to be designed at the specified design temperature.

RCB-1.4.2.2 FOR PARTS IN CONTACT WITH BOTH FLUIDS

The design temperature is the design metal temperature and is used to establish the Code stress limits for design. The design metal temperature shall be based on the operating temperatures of the shell side and the tube side fluids, except when the purchaser specifies some other design metal temperature. When the design metal temperature is less than the higher of the design temperatures referred to in Paragraph RCB-1.4.2.1, the design metal temperature and the affected parts shall be shown on the manufacturer's nameplate(s) as described in Paragraph G-3.1.

RCB-1.4.2.3 MINIMUM DESIGN METAL TEMPERATURE

The minimum design metal temperature shall be specified by the purchaser. Consideration should be given to operating temperatures, low ambient temperatures, and upset conditions such as auto refrigeration when specifying the minimum design metal temperatures. Minimum design metal temperatures shall be used to evaluate if impact testing is required for the various heat exchanger components.

RCB-1.4.3 MEAN METAL TEMPERATURES**RCB-1.4.3.1 FOR PARTS NOT IN CONTACT WITH BOTH FLUIDS**

The mean metal temperature is the calculated metal temperature, under normal operating conditions, of a part in contact with a fluid. It is used to establish metal properties under operating conditions. The mean metal temperature is based on the specified operating temperatures of the fluid in contact with the part.

RCB-1.4.3.2 FOR PARTS IN CONTACT WITH BOTH FLUIDS

The mean metal temperature is the calculated metal temperature, under normal operating conditions, of a part in contact with both shell side and tube side fluids. It is used to establish metal properties under operating conditions. The mean metal temperature is based on the specified operating temperatures of the shell side and tube side fluids. In establishing the mean metal temperatures, due consideration shall be given to such factors as the relative heat transfer coefficients of the two fluids contacting the part and the relative heat transfer area of the parts contacted by the two fluids.

RCB-1.5 STANDARD CORROSION ALLOWANCES

The standard corrosion allowances used for the various heat exchanger parts are as follows, unless the conditions of service make a different allowance more suitable and such allowance is specified by the purchaser.

RCB-1.5.1 CARBON STEEL PARTS**R-1.5.1.1 PRESSURE PARTS**

All carbon steel pressure parts, except as noted below, are to have a corrosion allowance of 1/8" (3.0 mm).

CB-1.5.1.1 PRESSURE PARTS

All carbon steel pressure parts, except as noted below, are to have a corrosion allowance of 1/16" (1.5 mm).

RCB-1.5.1.2 INTERNAL FLOATING HEAD COVERS

Internal floating head covers are to have the corrosion allowance on all wetted surfaces except gasket seating surfaces. Corrosion allowance need not be added to the recommended minimum edge distance in Table D-5.

RCB-1.5.1.3 TUBESHEETS

Tubesheets are to have the corrosion allowance on each side with the provision that, on the grooved side of a grooved tubesheet, the depth of the gasketed groove may be considered as available for corrosion allowance.

RCB-1.5.1.4 EXTERNAL COVERS

Where flat external covers are grooved, the depth of the gasketed groove may be considered as available for corrosion allowance.

RCB-1.5.1.5 END FLANGES

Corrosion allowance shall be applied only to the inside diameter of flanges where exposed to the fluids.

RCB-1.5.1.6 NONPRESSURE PARTS

Nonpressure parts such as tie-rods, spacers, baffles and support plates are not required to have corrosion allowance.

RCB-1.5.1.7 TUBES, BOLTING AND FLOATING HEAD BACKING DEVICES

Tubes, bolting and floating head backing devices are not required to have corrosion allowance.

RCB-1.5.1.8 PASS PARTITION PLATES AND WELDED-IN LONG BAFFLES

Pass partition plates and welded-in long baffles are not required to have corrosion allowance.

RCB-1.5.2 ALLOY PARTS

Alloy parts are not required to have corrosion allowance.

R-1.5.3 CAST IRON PARTS

Cast iron pressure parts shall have a corrosion allowance of 1/8" (3.0 mm).

CB-1.5.3 CAST IRON PARTS

Cast iron pressure parts shall have a corrosion allowance of 1/16" (1.5 mm).

RCB-1.6 SERVICE LIMITATIONS**RB-1.6.1 CAST IRON PARTS**

Cast iron shall be used only for water service at pressures not exceeding 150 psi (1000 kPa).

C-1.6.1 CAST IRON PARTS

Cast iron shall not be used for pressures exceeding 150 psi (1000 kPa), or for lethal or flammable fluids at any pressure.

RCB-1.6.2 EXTERNAL PACKED JOINTS

Packed joints shall not be used when the purchaser specifies that the fluid in contact with the joint is lethal or flammable.

RCB-1.7 ANODES

Selection and placement of anodes is not the responsibility of the heat exchanger manufacturer. If a heat exchanger is to be furnished with anodes, when requesting a quotation, the purchaser is responsible for furnishing the heat exchanger manufacturer the following information:

- (1) Method of anode attachment.
- (2) Quantity of anodes required.
- (3) Size and manufacturer of the anodes.
- (4) Anode material.
- (5) Sketch of anode locations and spacing.

If the heat exchanger manufacturer chooses to install anodes for a customer, the manufacturer is not responsible for the suitability of the anodes for the service they are installed in, the life of the anodes, the corrosion protection provided by the anodes, or any subsequent damage to the heat exchanger attributed to the anodes, the method of anode installation, or the installed location of the anodes in the heat exchanger.

RCB-1.8 FUTURE MACHINING ALLOWANCE OF GASKET SEATING SURFACES

Thickness allowance on a gasket seating surface is referred to as Future Machining Allowance and is specified separately from corrosion allowances otherwise applied to that pressure part. Gasket seating surfaces are not required to have future machining allowances unless specified by the customer. The impact from maintaining R1, R2, and R3 (figure F-3) shall be considered when applying a specified future machining allowance. Note that future machining allowance would generally assume the ability to increase the R4 depth from that originally applied. The customer should consider flexibility of piping before re-machining of surfaces critical to nozzle locations.