



STANDARDS
for
GASKETED PLATE HEAT EXCHANGERS

FIRST EDITION

HEAT EXCHANGE INSTITUTE, INC.

PUBLICATION LIST

TITLE

Standards for Steam Surface Condensers,
11th Edition 2012

**Standards for Direct Contact Barometric
and Low Level Condensers,**
8th Edition 2010

Standards for Steam Jet Vacuum Systems,
7th Edition 2012

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HEAT EXCHANGE INSTITUTE, INC.

STANDARDS for GASKETED PLATE HEAT EXCHANGERS

FIRST EDITION

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HEAT EXCHANGE INSTITUTE, INC.

GASKETED PLATE HEAT EXCHANGERS

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CONTENTS

Page

FOREWORD	v
1.0 SCOPE AND PURPOSE.....	1
1.1 Scope	1
1.2 Purpose	1
2.0 DEFINITION OF TERMS	1
3.0 PLATE HEAT TRANSFER TECHNOLOGY	4
3.1 Heat Transfer Correlations – Various Geometries	4
3.2 General Features and Benefits of Gasketed Plate Heat Exchangers	4
3.3 General Design Recommendations of Gasketed Plate Heat Exchangers	4
4.0 THERMAL AND HYDRAULIC HEAT EXCHANGER PERFORMANCE.....	5
4.1 Heat Exchanger Performance	5
4.2 Minimum Data Required to be Supplied by the Purchaser.....	5
4.3 Balance Flow	5
4.4 Temperature Profile.....	6
4.5 Pressure Loss	6
4.6 Fouling.....	6
4.7 Pass Arrangement.....	7
4.8 Connections	8
4.9 Flow Direction	8
5.0 MECHANICAL DESIGN STANDARDS.....	9
5.1 Code Requirements	9
5.2 Pressure-Retaining Parts	9
5.3 Design Pressures.....	9
5.4 Design Temperatures.....	9
5.5 Frame Components	9
5.6 Plates	10
5.7 Gaskets	11
5.8 Materials of Construction	12
5.9 Corrosion Allowance	12
5.10 External Loads	12
6.0 ASSEMBLY/FABRICATION	12
7.0 TESTING AND PREPARATION.....	13
7.1 Hydrostatic Testing.....	13
7.2 Other Testing	13
7.3 Preparation and Protection for Shipment	13
8.0 OPERATIONAL CONSIDERATIONS.....	13
8.1 Safety Requirement	13
8.2 Filters/Strainers	13
8.3 Drip Pan	13
8.4 Site Storage	13
8.5 Installation	13
8.6 Cleaning.....	14

CONTENTS (continued)

8.7	Initial Startup Precautions	14
8.8	Service and Maintenance.....	14
8.9	Spare Parts and Special Tools.....	14

APPENDICES

Appendix A	Heat Transfer Equations	15
Appendix B-1	Heat Exchanger Specification Sheet.....	19
Appendix B-2	Heat Exchanger Specification Sheet.....	20
Appendix C	Trouble-Shooting Guide.....	21
Appendix D	Metric Conversion Factors.....	23

TABLES

Table 1	Materials of Construction.....	12
Table 2	Spare Parts and Special Tools	14

FIGURES

Figure 1	Typical Assembly for Gasketed Plate Heat Exchanger.....	3
Figure 2	Turbulent Flow in Corrugated Plate Channel	4
Figure 3	Temperature Approach	6
Figure 4	Single Pass Unit.....	7
Figure 5	Multi Pass Unit 2x2 Pass Arrangement	8
Figure 6	Diagonal Flow.....	8
Figure 7	Parallel Flow	8
Figure 8	Counter-Current.....	8
Figure 9	Co-Current.....	8
Figure 10	Studded Port Connection	10
Figure 11	Extended Flange Connection.....	10
Figure 12	NPT Connection	10
Figure 13	Plate Anatomy	10
Figure 14	Plate Chevron Angles: Low Theta Plate	11
Figure 15	Plate Chevron Angles: High Theta Plate	11
Figure 16	Low Plate + Low Plate = L channels.....	11
Figure 17	Low Plate + High Plate = M channels	11
Figure 18	High Plate + High Plate = H channels.....	11
Figure 19	Plate Gap	11
Figure 20	Drip Pan.....	13
Figure 21	Back Flush Diagram	14
Figure 22	Counter Current Flow.....	16
Figure 23	Co-Current Flow.....	17

FOREWORD

The First Edition of the “Standards for Gasketed Plate Heat Exchangers” represents another step in the Heat Exchange Institute’s continuing program to provide Standards that reflect the latest technological advancement in the field of heat exchange equipment.

This standard provides users of gasketed plate heat exchangers with information on plate heat transfer technology, thermal and hydraulic heat exchange performance, mechanical design standards, assembly and fabrication, testing and preparation, and operational considerations. Please visit the HEI website, www.heatexchange.org, for more information.

The Heat Exchange Institute anticipates a continuing program to extend and amplify the coverage presented in these Standards and this may require the periodic issuance of addenda to these Standards. As a result, users of these Standards should make sure that they are in possession of all such addenda by enquiry to the Heat Exchange Institute offices.

The Heat Exchange Institute solicits comments from all interested parties regarding areas where further treatment or more detailed treatment is desired or felt necessary. Contact the Institute at 1300 Sumner Ave., Cleveland, OH, 44115, or visit the HEI website at www.heatexchange.org.

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1.0 SCOPE AND PURPOSE

1.1 Scope

This standard applies to completely assembled, inspected, and tested Gasketed Plate Heat Exchangers with elastomeric gaskets and carbon steel frames used in power plants.

Some of the commonly used names for gasketed plate heat exchangers to which these standards apply are listed below. This list is not intended to be all-inclusive or solely limited to those heat exchangers named, but is open to other applications as well.

- a. Amine Interchangers
- b. Amine Coolers/Heaters
- c. Closed Loop Cooling Exchangers
- d. Component Cooling Exchangers
- e. Condensate Coolers/Heaters
- f. Fuel Pool Coolers
- g. Geothermal Exchangers
- h. Glycol Coolers/Heaters
- i. Jacket Water Coolers

j. Oil Coolers

k. Reactor Building Cooling Water Exchangers

l. Seal Water Coolers

1.2 Purpose

This quality standard has been developed to be used by Engineers, Purchasers, and Manufacturers to delineate some of the pertinent hydraulic, mechanical, and thermal design features and requirements for gasketed plate heat exchangers to be used in power plants.

It is the intention that this standard provide a basis for a mutual understanding and interpretation of gasketed plate heat exchanger requirements between the Purchaser and the Manufacturer to assist in the specification, design, fabrication, and use of gasketed plate heat exchangers.

Gasketed plate heat exchangers referenced in this standard may also be required to conform to the applicable ASME Boiler and Pressure Vessel Code.

2.0 DEFINITIONS

2.1 Approach Temperature

The difference between the opposing fluids' inlet and outlet temperatures. For example, the difference between the hot inlet and the cold outlet.

2.2 Average Plate Gap

The pressing depth of the plate pattern. (See Figure 19).

2.3 Channel Plate

All heat transfer plates in a plate pack that are not end plates or turning plates.

2.4 Cleanliness Factor

The cleanliness factor is the ratio of the inservice overall heat transfer coefficient to the clean overall heat transfer coefficient.

2.5 Code

For the purpose of these standards, Code refers to the applicable ASME Boiler and Pressure Vessel Code.

2.6 Design Point

The set of operating conditions and constraints that are to be satisfied by the gasketed plate heat exchanger.

2.7 Design Pressures

The pressures for which the gasketed plate heat exchanger is structurally designed.

2.8 Design Temperatures

The temperatures for which the gasketed plate heat exchanger is structurally designed.

2.9 Distribution Zone

The area on the plate used to direct the flow evenly into the main heat transfer zone.

2.10 Drip Tray/Pan

A tray or pan that is located beneath the heat exchanger, used to prevent water and other liquids from draining onto the floor when dismantling a gasketed plate heat exchanger.

2.11 End Plate

An end plate is a plate that prevents the fluids in a gasketed plate heat exchanger from contacting the fixed and movable frames.

There are two (2) end plates, one at each end of the plate pack. Other terms for these plates are start plate and seal plate.

2.12 Excess Surface Area

The heat transfer area provided in addition to the amount of surface area required to do the duty. This is typically expressed as a percentage of the total surface area.

2.13 Fouling Resistance

A resistance to heat transfer caused by the deposition of minerals, scale, dirt, or other foreign material on plate surfaces.

2.14 Frame

Component of a gasketed plate heat exchanger that provides the structural support and pressure containment of the plate pack.

2.15 Gasketed Plate Heat Exchanger

Assembly of a gasketed plate pack and its supporting frame. (See Figure 1.)

2.16 Heat Exchanger Duty

The heat transferred per unit of time from one fluid to another.

2.17 Heat Transfer Area

The sum of the surface areas of one side of all plates in contact with both heat transfer fluids. Since the end plates are not in contact with both fluids, they are not included in this area.

2.18 Heat Transfer Plate

Sheet of material precision pressed and formed into a corrugated pattern by the gasketed plate heat exchanger manufacturer.

2.19 Logarithmic Mean Temperature Difference (LMTD)

The logarithmic mean temperature is a mathematical relationship expressing the integrated thermal driving potential for transferring heat between the plates.

2.20 Number of Thermal Units (NTU)

The maximum temperature change achievable for one stream of the heat exchanger (Delta T) in relation to the given amount of thermal driving potential (LMTD). This mathematical relationship expresses the difficulty of the heat transfer duty.

2.21 Operating Pressures

The pressures for which the gasketed plate heat exchanger are specified.

2.22 Operating Temperatures

The temperatures for which the gasketed plate heat exchanger are specified.

2.23 Overall Heat Transfer Coefficient (Overall U-Value)

The overall heat transfer coefficient is the average heat transfer rate between the hot side and cold side fluids under specified design conditions.

2.24 Pass

The movement of fluid through a heat transfer channel in one direction.

2.25 Plate Chevron Angle

The angle formed between the corrugated plate pattern and the horizontal axis. (See Figures 14 and 15.)

2.26 Plate Pack

The grouping of all plates contained within a frame.

2.27 Plate Thickness

The thickness of the heat transfer sheet prior to pressing.

2.28 Port

The distribution header that is formed by the opening in the corner of the plate when the plates are compressed in a plate pack.

2.29 Pressure Loss or Pressure Drop

The pressure loss of the fluid traveling through the heat exchanger plates, which consists of irrecoverable loss in operating pressure as the fluid stream travels from the inlet to the outlet connection. The pressure loss includes the loss in the inlet and outlet connections and ports plus the loss through the plate channels.

2.30 Shroud

A removable covering for the top and sides of the plate pack of a gasketed plate heat exchanger.

2.31 Turning Plate/Pass Plate

Plate used to change the pass arrangement of the fluid flow for a multi-pass design gasketed plate heat exchanger.

2.32 Wall shear stress

A measure of the force of friction from a fluid acting on a plate surface in the path of that fluid.

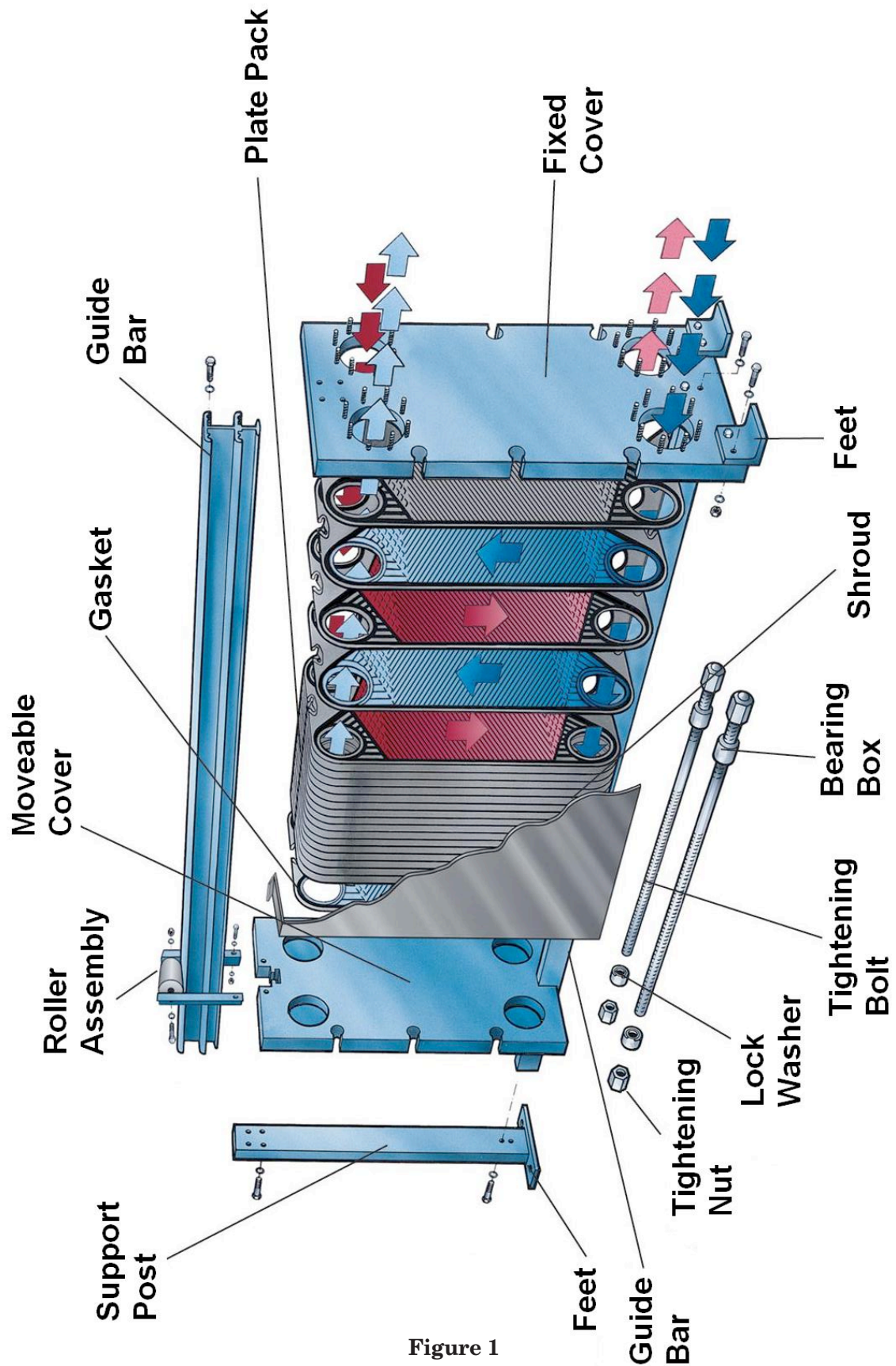


Figure 1
Typical Assembly for
Gasketed Plate Heat Exchanger

3.0 PLATE HEAT TRANSFER TECHNOLOGY

3.1 Heat Transfer Correlations – Various Geometries

There are two main geometries in heat transfer equipment: round pipe and corrugated plate. The effectiveness of heat transfer is dependent on achieving turbulent flow.

It is proven that fluid dynamics of various types of heat exchangers—when the transition from laminar to turbulent flow takes place—are very dependent on the configuration and the geometry of the flow channels.

Inside a smooth, circular pipe within a tubular exchanger, turbulent flow begins for water-like fluids when the Reynolds number is above 2,300.

In a corrugated plate flow channel with standard chevron plate geometry, turbulent flow begins for water-like fluids when the Reynolds number is as low as 100.

This turbulent flow phenomenon at relatively low Reynolds numbers translates to high individual heat transfer coefficients on both the hot and cold side flow channels in a gasketed plate heat exchanger, which then creates a very high overall U-value for the duty. (See Figure 2).

3.2 General Features and Benefits of Gasketed Plate Heat Exchangers

3.2.1 New Equipment – High Thermal Efficiency

Due to its high thermal efficiency, true counter-current, and turbulent flow, the gasketed plate heat exchanger can handle temperature approaches as close as 2°F with heat recovery rates up to 95%, eliminate stagnant areas, and minimize fouling.

With water-like fluids, it is common to see U-values, which are significantly greater than other types of heat exchangers. The overall high thermal efficiency translates to compact designs and low material usage in both the thermal and the mechanical designs. The end result is often the most economical heat exchanger technology for a given heat load

3.2.2 Plant Expansions – Compact and Flexible Designs

Gasketed plate heat exchangers may be designed so their heat transfer capacity can be expanded within the originally installed compact footprint. This is a great benefit, especially when there are future plans for expansions and/or efficiency improvements at the power plant. A gasketed plate heat exchanger can then be adapted to the new thermal conditions. This operation can be planned and performed during a regular scheduled maintenance shutdown.

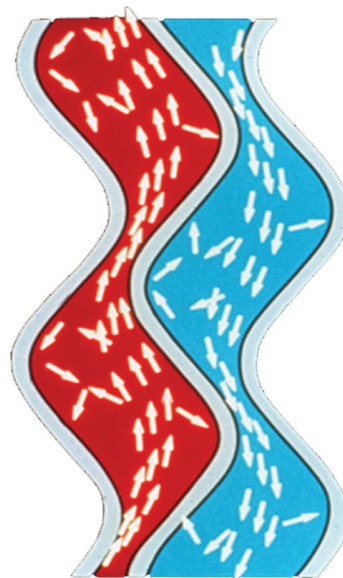


Figure 2

Turbulent Flow in Corrugated Plate Channel

3.2.3 Replacement or Removal – Modular Construction

Gasketed plate heat exchangers have very few structural welds and can be disassembled on-site. They are mechanically designed using bolted construction. This modular construction allows the gasketed plate heat exchanger to be easily maintained, replaced, or removed. This design is a great benefit especially if the existing heat exchanger is in a difficult-to-access location due to complex piping or other large equipment.

3.3 General Design Recommendations of Gasketed Plate Heat Exchangers

3.3.1 Flow and Pressure Drop Characteristics

The gasketed plate heat exchanger should be designed for maximum flow rate by minimizing unproductive pressure losses in the connections and the port holes. In case of water-like fluids, the pressure drop in the connections of a gasketed plate heat exchanger is normally the limiting factor.

The most productive pressure loss in a gasketed plate heat exchanger takes place over the main heat transfer zone in the corrugated plate channel. Here, the pressure loss is effectively used to produce maximum heat transfer.

The combined pressure drop in the connections and port holes of a single pass gasketed plate heat exchanger is typically less than 30% of the total used pressure drop, and the remainder should be used in the channels. Gasketed plate heat exchangers in power plants are often

designed with total pressure losses between 5 and 15 PSIG for water-like fluids.

The nominal channel velocities in a gasketed plate heat exchanger for water-like fluids in turbulent flow are 1 to 3 ft/s, but true velocities in certain regions could be higher by a factor of up to four due to the effect of the corrugations. All heat transfer and pressure drop relationships are, however, based on the nominal velocity calculated based on the average plate gap and the flow rate per channel.

In order to maximize the efficiency of a gasketed plate heat exchanger with its inherent design of similar flow channels on both hot and cold sides, the optimum flow rates and allowable pressure drops should be balanced between the hot and cold side. The ratio between the flow rates on the two sides should be balanced.

3.3.2 Thermal and Temperature Characteristics

The thermal performance of a heat exchanger could be expressed in terms of NTU. Gasketed

plate heat exchangers can perform in a single pass at high NTU up to values of 4 – 8 per pass. This is achieved because the flow directions are fully counter-current, which maximizes the effective value of the temperature difference between the two fluids. This also results in a heat exchanger that can achieve very close temperature approaches (inlet temperature versus the outlet temperature of both fluids) as close as 2°F.

In addition, the exchanger can achieve a thermal performance involving a high degree of temperature cross (outlet temperature of cold fluid much higher than the outlet temperature of the hot fluid).

These unique thermal characteristic of a gasketed plate heat exchanger could give a power plant the option of saving a considerable amount in energy and pumping cost by designing and specifying both crossing temperatures and high NTU duties profiles. Thus, lower flow rates on both sides can be used to achieve the same amount of heat load.

4.0 THERMAL AND HYDRAULIC HEAT EXCHANGER PERFORMANCE

4.1 Heat Exchanger Performance

Although the gasketed plate heat exchanger may be operated under several different operating conditions, the design should be predicated on one specific set of operating conditions termed the “Design Point.” For the specified flow rates and inlet temperatures, the heat transfer requirements must be satisfied by meeting the heat exchanger duty and the outlet temperatures. Also, for the specified flow rates, the maximum pressure losses must not be exceeded.

4.2 Minimum Data Required to be Supplied by the Purchaser

4.2.1 General Information

- a. Plant location
- b. Application, service of unit, item/tag number
- c. Preferred pass arrangement
- d. Space limitations (length, width, and height)
- e. Heat exchanger duty
- f. Plate material
- g. Gasket material
- h. Percentage excess surface
- i. Applicable code section/division/class

4.2.2 Hot and Cold Side Parameters

- a. Fluid
- b. Fluid flow rate
- c. Fluid inlet temperature
- d. Fluid outlet temperature
- e. Fluid pressure drop allowed
- f. Preferred connection sizes
- g. Operating pressure
- h. Design pressure
- i. Test pressure
- j. Design temperature

Thermodynamic properties of the fluids should be supplied if fluid properties do not readily exist. The properties should include values for density, viscosity, specific heat, thermal conductivity, and latent heat as required. Heat curves and property curves can also be supplied if they exist.

4.3 Balance Flow

Since the geometry of the hot and cold side channels in a gasketed plate heat exchanger are similar, it is

important to balance the volumetric flow of the two sides. The more balanced the flow profile, the greater the overall efficiency of the heat exchanger. Large variations between the hot and cold fluid flow rates (for example, 2X hot-side vs. cold-side fluid flow) can result in inefficient use of allowable pressure drop, fouling, low heat transfer rates, and increased surface area.

4.3.1 Bypass

Bypass is the process of diverting a portion of either the hot or cold fluid around the heat exchanger using an internal or external design. For internal bypass, a number of channels are added at the end of the plate pack. These channels contain only one of the fluids (no heat transfer). For external bypass, a portion of the flow is routed around the heat exchanger. The bypassed fluid then rejoins the appropriate stream beyond the heat exchanger, resulting in the final temperature conditions required. Either of these two methods effectively reduces the higher of the two flows, thus creating a more balanced flow profile and effective use of available pressure drop.

4.4 Temperature Profile

The Purchaser, by stipulating the design point, specifies the heat exchanger approach temperature. Generally, as the approach temperature decreases, the required heat transfer surface area increases. The selection of the approach temperature affects the hot and cold fluid flows, which, in turn, affects plant operating costs. Care should be taken to consider capital costs versus operating costs. (See Figure 3)

4.5 Pressure Loss

The allowable gasketed plate heat exchanger pressure losses should be specified by the Purchaser. Commonly used pressure losses vary between 5 and 15 psi for water-like fluids. Since both flow channels in a gasketed plate heat exchanger are similar in nature, the optimum pressure losses specified on either side should be proportionate to the volumetric flow rates of the hot and cold side fluids. Generally,

as the pressure drop required decreases, the required heat transfer area increases.

Pressure loss occurs and is calculated in the following locations for a gasketed plate heat exchanger:

4.5.1 Connections

The pressure loss through the inlet and outlet nozzles. The pressure losses in connections should be minimized if possible.

4.5.2 Port

The pressure loss through the port of the plates, which, when in a plate pack, acts as a manifold system in a parallel arrangement.

4.5.3 Channel

The pressure loss through the gap between the plates in the plate pack.

4.6 Fouling

4.6.1 Types of Fouling

Most types of fouling that occur in gasketed plate heat exchangers can be classified as follows:

4.6.1.1 Biological

Fouling caused by a number of organisms that can attach to the plates, such as algae, mussels, etc. They can build up rapidly, reducing the heat transfer rate and, in some cases, severely restricting the flow.

4.6.1.2 Chemical

The formation of salt scale, especially calcium carbonate, on the plates as a result of minerals in the water in excess of the saturation point. When hydrocarbons are exposed to high temperatures, a hard crust can form on the plates.

4.6.1.3 Solids

Typically caused by silt, fibers, corrosion particles, rags, or other foreign objects. These can cause plugging of the ports or channel passes.

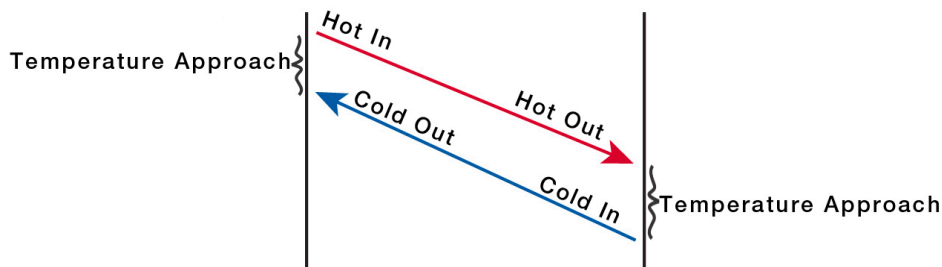


Figure 3

Temperature Approach

4.6.2 Fouling Factor

The gasketed plate heat exchanger is made up of corrugated plates assembled to form parallel channels. As the fluid flows down these channels, turbulent flow is established and a high wall shear stress is achieved at low Reynolds numbers. Both the high wall shear stress and the turbulence lead to a self-cleaning and scrubbing effect on the plate surface, resulting in lower fouling. When designing a gasketed plate heat exchanger, manufacturers compensate for fouling by using either a percent excess surface or a cleanliness factor. It is recommended to use these values in lieu of a fouling factor.

4.6.3 Excess Surface Area

Typical values range from 5 to 15% for gasketed plate heat exchangers in the power industry.

4.6.4 Cleanliness Factor

Cleanliness factor is an alternate way of adding surface area to the gasketed plate heat exchanger to account for fouling. Typical values range from 85% to 95%.

4.6.5 Minimizing Fouling

The following suggestions should be considered to minimize fouling:

- a. Avoid gross excess surfacing.
- b. Operate at design conditions.
 - i. Minimize turn-down of flow rates.
 - ii. Consider parallel units.
 - iii. Shut off one unit.
- c. Maximize turbulence through plate channel.
- d. Incorporate filters or strainers in heat exchanger design.

4.7 Pass Arrangement

The most common arrangement is a single pass design. In some cases, however, where approach temperature requirements or available space/footprint are very low, a multi-pass arrangement may be required.

4.7.1 Single Pass

Single pass design locates all connections, both hot and cold fluids, on the front of the heat exchanger. This is the optimum design for installation and servicing of a gasketed plate heat exchanger. The fluids in a single pass unit make one vertical pass through the exchanger. (See Figure 4)

Example Designation: 1×1 Pass

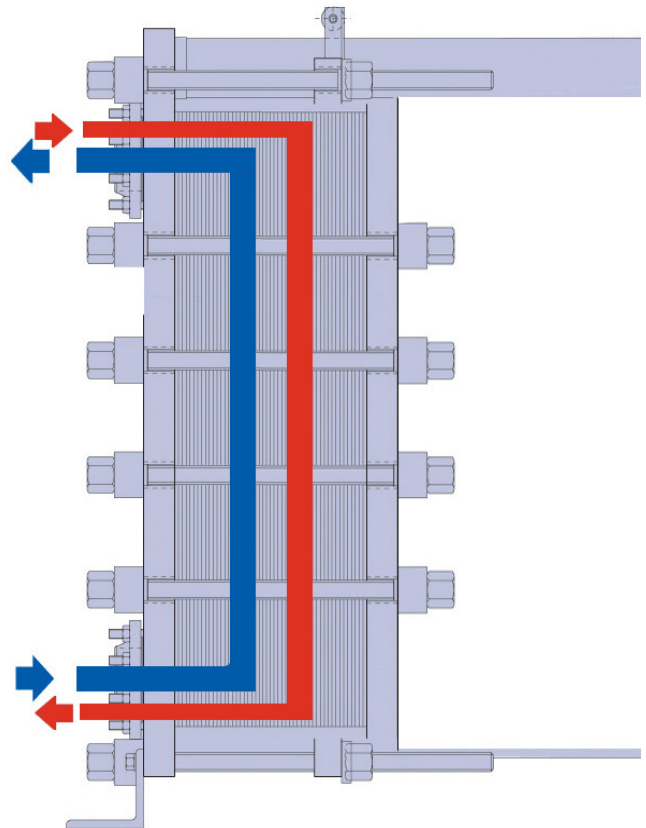


Figure 4
Single Pass Unit

4.7.2 Multiple Pass

Multi-pass designs are required for high NTU or close temperature approach applications. The fluids make more than one vertical pass through the exchanger. The heat exchanger has one or several plates installed to turn the fluid in the opposite direction, either on one or both of the fluids. Once a gasketed plate heat exchanger is a multi-pass unit, connections will be on the back of the unit, mounted on the movable frame. (See Figure 5)

Example Designation: 2×2 Pass, 3×3 Pass, 1×3

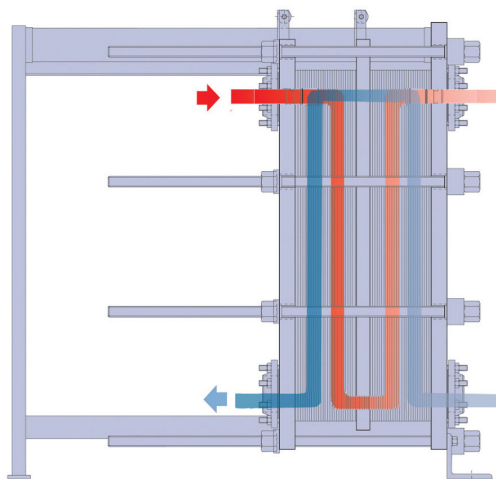


Figure 5
Multi Pass Unit
2x2 Pass Arrangement

4.8 Connections

4.8.1 Sizes

Connection sizes can typically range from 1 inch up to 20 inches in diameter. The Purchaser should specify if a certain size connection is preferred for a given design or flow rate. Due to geometry and header design, liquid connection velocities up to 25ft/sec can be used reliably in gasketed plate heat exchangers.

4.8.2 Arrangement

The connection arrangement can be in one of two ways, diagonal or parallel. (See Figures 6 and 7.)

Counter-Current Diagonal and Parallel Flow Connection Arrangements

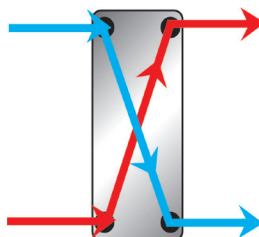


Figure 6
Diagonal Flow

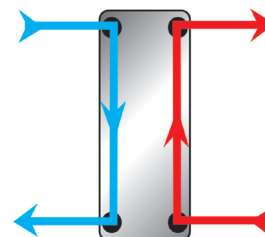


Figure 7
Parallel Flow

The Manufacturer will specify the optimal connection arrangement.

4.9 Flow Direction

There are two flow directions in a gasketed plate heat exchanger: counter-current and co-current.

4.9.1 Counter-Current

The most common flow direction due to its higher heat transfer efficiency. The fluids flow in opposite directions within the gasketed plate heat exchanger. (See Figure 8.)

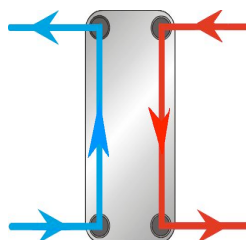


Figure 8
Counter-Current

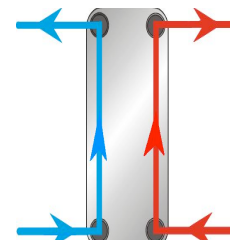


Figure 9
Co-Current

4.9.2 Co-Current

Less common flow direction, in which the fluids flow in the same direction within the gasketed plate heat exchanger. (See Figure 9.)

5.0 MECHANICAL DESIGN STANDARDS

5.1 Code Requirements

Gasketed plate heat exchangers are considered pressure vessels, and thus the rules of the authority having jurisdiction must be followed. It is the responsibility of the Purchaser to specify the applicable rules required.

5.2 Pressure-Retaining Parts

The pressure-retaining parts are the fixed cover, movable cover, heat transfer plates, extended nozzles, and the tightening bolts.

5.3 Design Pressures

The Purchaser shall specify separate design pressures for the hot and cold sides. This shall include any vacuum that may be applicable.

5.4 Design Temperatures

The Purchaser shall specify separate design temperatures for the hot and cold sides. Particular attention shall be given to both minimum and maximum design temperatures.

5.5 Frame Components

5.5.1 Fixed and Movable Covers

Fixed and movable covers are painted carbon steel plates, which compress the gasketed plates to the required dimension. For gasketed plate heat exchangers with tightening bolts of 1 inch and larger, frames shall be furnished with slotted holes. The thickness of the fixed and movable covers is determined by the Code.

5.5.2 Guide Bars (Top and Bottom Bar)

The guide bar design shall incorporate a means for alignment of the plate pack. The top guide bar shall have a smooth surface (either stainless steel or aluminum) for the plates to slide on during assembly. The top bar shall be designed to carry the weight of the movable cover, the plates, and the hold-up volume. For units with a port diameter of 6 inches and up, the unit shall have a roller, which allows for easy opening and closing of the unit. The plates shall be fully supported by the carrying and guide bars.

5.5.3 Tightening Bolts

The number and the thickness of the bolts are determined by the Code. Each tightening bolt shall have one fixed nut and one running nut. Bolts will be either zinc coated or covered in rust-inhibiting grease. Welding the nut to the tightening bolt is prohibited. Bearings boxes or washers may be supplied on the main tightening bolts to reduce the friction involved in opening and closing the gasketed plate heat exchanger.

5.5.4 Shroud

The gasketed plate heat exchanger may be provided with a removable shroud. The shroud shall be aluminum or stainless steel. The Purchaser shall specify if a shroud is needed on the unit.

5.5.5 Nameplate

The gasketed plate heat exchanger shall be provided with a permanent stainless steel nameplate. The nameplate shall contain the following information as a minimum:

- a. Manufacturer's name
- b. Equipment serial number
- c. Year built
- d. Maximum allowable working pressure
- e. Maximum design temperature and minimum design metal temperature
- f. Maximum and minimum plate pack tightening dimensions
- g. Code stamp

5.5.6 Lifting Devices

The frame shall be provided with suitable lifting lugs or holes for lifting and handling of the gasketed plate heat exchanger.

5.5.7 Future Expansion

Future expansion is the amount of additional plate area as required by the Purchaser. This percent typically applies to the guide bars' length and ability to hold an increased amount of plates beyond design. Future expansion may not apply to a unit's ability to accept increased flow through the existing nozzle sizes.

5.5.8 Feet

The feet shall be designed to support the exchanger and resist all specified nozzle loadings, seismic forces, and all other external loads. Feet can be either bolted on or welded to the frame. The feet are used to anchor the gasketed plate heat exchanger to the foundation.

5.5.9 Connections

Connections shall be either studded port, extended flange or NPT. (See Figures 10, 11, and 12.) Studded ports and extended flanges may be lined.

All bolt holes shall straddle major centerlines.

Studded port and extended flange connections shall be compatible with ASME B16.5.

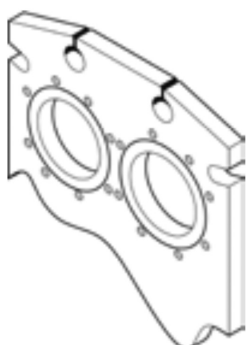


Figure 10
**Studded Port Con-
nection**

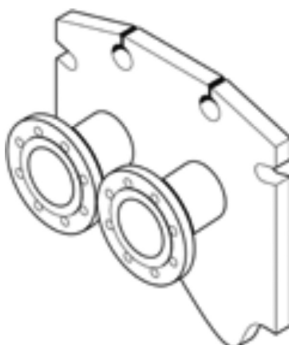


Figure 11
Extended Flange
Connection

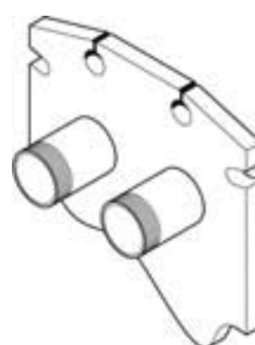


Figure 12
NPT Connection

Materials for wetted portions of the studded port or extended flanges shall be specified by the Purchaser.

Minimum thickness of the connection lining shall be equal to or greater than the plate thickness.

The projection of flanged connections shall allow for installation and removal of the flange bolts from either side of the flange.

Connections shall be designed to withstand forces and moments as specified by the Purchaser.

If one of the fluids has particulates, this inlet should be at the bottom of the exchanger. With this configuration, any debris in the fluid will tend to settle in the port area and not block the flow entrance to the plates. In addition, an inspection/cleanout port can be added to the movable cover to allow for cleanout of this port area.

5.6 Plates

The plates shall be pressed into a corrugated pattern to optimize heat transfer with minimal pressure loss. Corrugation to be designed to provide support to adjacent plates and to ensure plate-to-plate contact for structural integrity.

The plate shall be designed for full differential pressure, with one side at design pressure and the other at atmospheric pressure.

Plate material shall be specified by the Purchaser to ensure its compatibility with the fluids. The nominal thickness of the plates prior to pressing shall be sufficient to meet design conditions, but shall in no case be less than 0.4mm.

Plates shall be individually replaceable without having to remove other plates.

All plates shall have identification stamps for material traceability.

5.6.1 Plate Anatomy

(See Figure 13.)

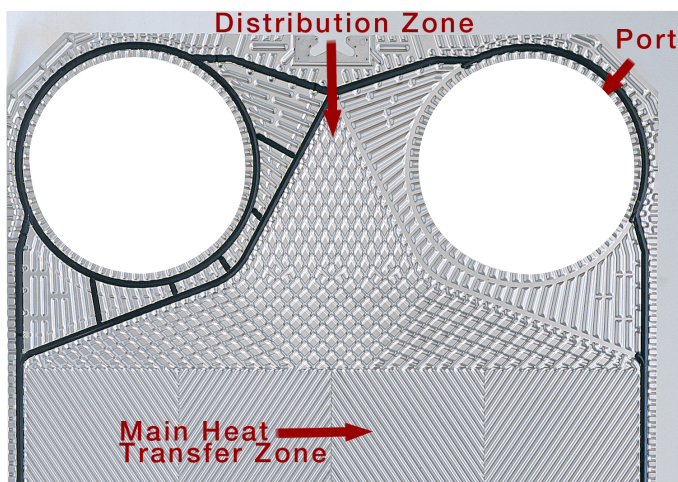


Figure 13
Plate Anatomy

5.6.2 Plate Configurations

There are typically two types of plate chevron angles on heat transfer plates: high theta and low theta. High theta heat transfer plates are used at higher NTUs and induce higher heat transfer rates and higher pressure drops. Low theta heat transfer plates are used at lower NTUs and create lower pressure drops and lower heat transfer rates. (See Figures 14 and 15)

The plate configuration can be either all high theta or all low theta or a mix of the two (See Figures 16, 17, and 18). The Manufacturer will determine the optimal arrangement of plates to meet the thermal and hydraulic requirements supplied by the Purchaser.



Figure 14

Plate Chevron Angles: Low Theta Plate

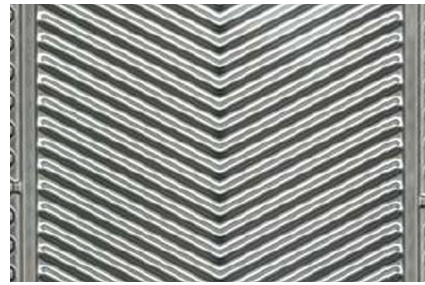


Figure 15

High Theta Plate



Figure 16

Low Plate + Low Plate = L channels

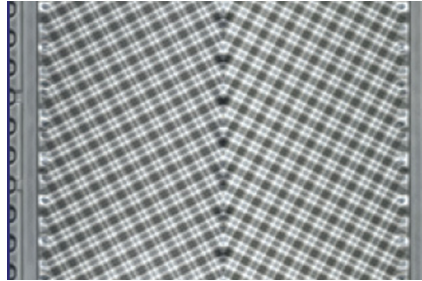


Figure 17

Low Plate + High Plate = M channels

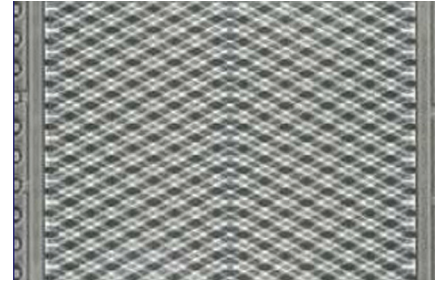


Figure 18

High Plate + High Plate = H channels

5.6.3 Average Plate Gap

The depth of the corrugated pattern that is pressed into the plates can range from approximately 2mm - 6mm. This creates a flow path between the plates up to twice the pressing depth. Thus the average plate gap is equal to the pressing depth. (See Figure 19).

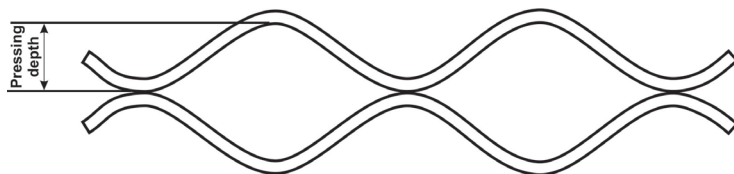


Figure 19

Plate Gap

5.7 Gaskets

Gaskets shall be positioned in the grooves around the heat transfer surface and the port holes of the plate. Gaskets shall be secured to the plates with either clips and/or a glue system.

Gaskets shall be compressed to achieve metal-to-metal contact between the plates.

Through-flow port areas of the plates shall be double gasketed and vented to atmosphere such that cross-contamination of the fluids cannot occur without readily detectable external evidence.

Gasket material shall be specified by the Purchaser to ensure its compatibility with the fluids.

All gaskets shall be permanently marked to identify material and manufacturer.

5.8 Materials of Construction

The materials used for pressure-retaining parts and for external supports shall, where applicable, be in accordance with the Code.

The purchaser is responsible to specify the materials for the plates and gaskets so as to be compatible with their application, specifically fluid chemistry and temperature. The remainder of the materials of construction will be per manufacturer's standard unless otherwise specified by purchaser.

The most commonly used materials and the parts for which they are used are given in Table 1.

Table 1
Materials of Construction

Fixed and Movable Covers	Plates	Gaskets	Tightening Bolts	Connections
SA-516 GR70, GR60	SA-240 GR316, GR316L, GR304, GR304L	Nitrile	SA-193-B7	SA-240 GR316, GR 316L, GR304, GR304L, Carbon Steel
	Titanium GR1, Titanium GR11	EPDM		Titanium GR1, GR2, GR7, GR11
	Hastelloy®	Fluoro-elastomer		Hastelloy®
	SMO254			SMO254
	AL-6XN™			AL-6XN™
	NI-200			NI-200

5.9 Corrosion Allowance

Corrosion allowance does not typically apply for a gasketed plate heat exchanger because the alloy materials specified for the wetted surfaces are chosen such that they are resistant to corrosion. Thus the corrosion allowance for heat transfer plates and the connection lining shall be zero. If the connections are not of alloy material or lined with alloy material, a corrosion allowance may be specified.

5.10 External Loads

The following external loads may be considered in the design of the gasketed plate heat exchanger:

5.10.1 Seismic

The Purchaser must specify the following:

- a. Applicable building code
- b. Specific site data
 - i. Mapped spectral accelerations (Ss)
 - ii. Site class
 - iii. Seismic design category
 - iv. Occupancy category
 - v. Site coefficient (Fa)
 - vi. Component importance factor (I)

5.10.2 Wind

The Purchaser must specify the following:

- a. Basic wind speed
- b. Exposure category
- c. Building and structure classification category
- d. Importance factor

5.10.3 Nozzle Loads

When the Purchaser requires nozzle load analysis, it shall be his responsibility to specify the magnitude and direction of the forces and moments that act at the piping juncture.

6.0 ASSEMBLY AND FABRICATION

The gasketed plate heat exchanger shall be fabricated and assembled in a facility holding both an ISO-9001 and an ASME certificate.

The plate pressing shall be performed by the Manufacturer of the gasketed plate heat exchanger.

The manufacturer shall have a quality management system that controls the manufacturing, testing, and inspection of the gasketed plate heat exchanger.

All plates shall be clean and dry before gasketing.

Frame surfaces to be painted shall be blasted to SSPC-SP6 prior to painting. Painting shall take place prior to assembly using Manufacturer's standard paint. Special paint systems can be accommodated, Purchaser to specify.

The plate pack shall be tightened to a specific dimension specified by the Manufacturer. Torque values shall not be used to tighten the bolts.

7.0 TESTING AND PREPARATION

7.1 Hydrostatic Testing

The hot and cold sides are to be hydrostatically tested in accordance with the design code. Each side shall be tested at design pressure with the other side open to atmosphere. A final test shall be conducted at 1.3 times the design pressure or as required by the Code.

The hydrostatic test water shall have a maximum chloride content of 50ppm.

Upon completion of the hydrotest, the gasketed plate heat exchanger shall be drained.

7.2 Other Testing

Any additional non-destructive testing may be specified by the purchaser. This could include, but

is not limited to, dye penetrant testing, light box inspection, ultrasonic testing, x-ray, or impact testing.

7.3 Preparation and Protection for Shipment

The gasketed plate heat exchanger shall have all openings covered before shipment. The nozzle opening covers may be plastic covers, plywood covers, or metal covers bolted in place.

Any specific requirements for drying will be specified by the Purchaser.

Any additional shipping or preservation requirements shall be specified by the Purchaser. This may include but is not limited to export crating, nitrogen purge/fill.

8.0 OPERATIONAL CONSIDERATIONS

The Manufacturer's instructions, if provided, should be consulted in conjunction with the following subsections:

8.1 Safety Requirement

The Code specifies a variety of measures for the protection of heat exchangers against overpressure. The Purchaser shall install protective devices in the system to prevent thermal and mechanical transients from exceeding those conditions for which the heat exchanger is designed.

8.1.1 Relief Valves

Relief valves are normally beyond the scope of the heat exchanger Manufacturer's responsibility. Pressure and temperature relief requirements are most appropriately specified for the entire piping loop, including the heat exchanger.

8.2 Filters/Strainers

The gasketed plate heat exchanger has relatively small flow channels; therefore, the use of strainers is recommended in supply lines ahead of the exchanger when the streams contain significant solids or fibers. This may reduce the requirements for back flushing or opening the exchanger for maintenance.

8.3 Drip Pan

To prevent water and other liquids from draining on to the floor when dismantling the heat exchanger, a drip pan can be used (See Figure 20).

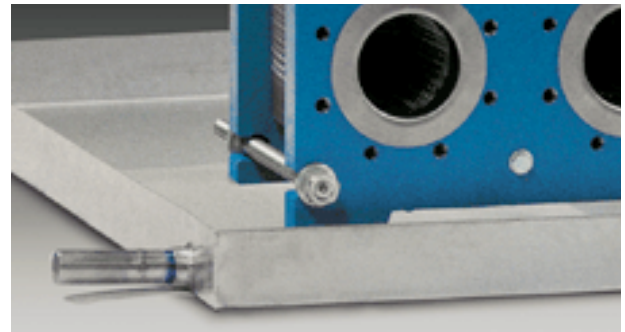


Figure 20
Drip Pan

8.4 Site Storage

All sources of ozone, such as operating electric motors or welding equipment, shall be removed from the storage area to preclude ozone attack on gaskets.

To prevent damage to the gaskets, do not store organic solvents or acids in the room and avoid direct sunlight, intensive heat radiation, or ultra-violet radiation.

For storage in excess of 6 months, refer to the Manufacturer's long-term storage procedure.

8.5 Installation

Heat exchangers shall be installed with sufficient clearance to allow for convenient and proper maintenance of the units without disturbing adjacent equipment. A minimum free space is needed for

lifting plates in and out. Refer to Manufacturer’s detailed drawings or instruction manual for this minimum space.

8.5.1 Instrumentation

It is recommended that pressure and temperature gauges be installed at the entrance and exit of Purchaser's piping.

8.6 Cleaning

It is suggested that provisions be made so that heat exchangers can be cleaned when necessary. The removal of foulants from the plate surfaces is required to maintain the thermal performance of the heat exchanger. The Purchaser shall select a cleaning method (mechanical, chemical, etc.) that is appropriate for the conditions of service.

8.6.1 Back Flush

Back flushing helps remove particles trapped within the heat exchanger and dislodge scale and other deposits. This can be accomplished by periodically flushing the heat exchanger with the fluid in a reverse flow pattern to the normal operating direction. Piping and valves may also be arranged to allow for operation of the unit in back flush mode. (See Figure 21.)

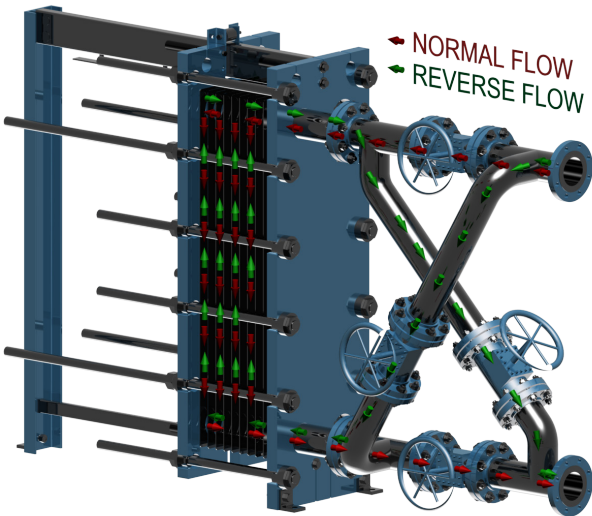


Figure 21
Back Flush Diagram

8.6.2 Cleaning In Place (CIP)

CIP is accomplished by circulating a suitable cleaning solution through the gasketed plate heat exchanger instead of opening it. CIP works best in the reverse direction of normal flow. Good results are also possible with same directions flow and at higher velocities than the product flow velocity. The cleaning solution must be circulated at sufficient velocity to flush out the product. Higher viscosity products generally require higher velocity flushing to properly clean. The cleaning solution must be able to

dissolve the fouling on the plates and great care must be taken to select a proper cleaning solution that does not damage plates or gaskets.

8.6.3 Manual Cleaning

Manual cleaning is the most common procedure to clean and maintain gasketed plate heat exchangers. The units are opened, plates cleaned, then closed per the Manufacturer’s Installation and Operation Manual. The plates are cleaned separately while either in or removed from the unit. Typical cleaning is with a high pressure water spray or soft, non-metallic brush.

8.7 Initial Startup Precautions

Before connecting to any piping, make sure all foreign objects have been flushed out of the piping system that will be connected to the gasketed plate heat exchanger. Before start-up, check that all tightening bolts are firmly tightened, using the measurement of the plate pack dimension as shown on the gasketed plate heat exchanger drawing or nameplate. To avoid water hammer, do not use fast-closing valves.

8.8 Service and Maintenance

To maximize the life expectancy of a gasketed plate heat exchanger, regular and routine maintenance is recommended. Refer to the equipment manual or contact the original equipment manufacturer for issues concerning service and maintenance.

8.9 Spare Parts and Special Tools

The following list of typical spare parts and special tools should be considered by the Purchaser of heat exchangers. The specific parts and quantities should be listed in the specification.

Table 2
Spare Parts and Special Tools

Spare Part	Typical Quantity
Gasketed End Plate 1	1
Gasketed End Plate 2	1
Gasketed Channel Plate	5% of plate pack
Channel Plate Gaskets	10% of plate pack

Special Tools	Typical Quantity
Spanner Wrench	1
Hydraulic Openers	Can be rented or purchased from Manufacturer as needed

APPENDIX A
HEAT TRANSFER EQUATIONS
A1.0 BASIC HEAT TRANSFER EQUATIONS

A1.1 The heat transfer rate on the Cold Stream, Q_{cs} , shall be calculated as:

$$Q_{cs} = w_{cs} c_{p,cs} (T_{cs,out} - T_{cs,in}) \quad A1$$

where: $c_{p,cs}$ is the average of the specific heat at inlet, outlet, and average temperatures.

A1.2 The heat transfer rate on the Hot Stream, Q_{hs} , shall be calculated as:

$$Q_{hs} = w_{hs} c_{p,hs} (T_{hs,in} - T_{hs,out}) \quad A2$$

where: $c_{p,hs}$ is the average of the specific heat at inlet, outlet, and average temperatures.

A1.3 The heat transfer rate for a Hot or Cold Vapor Stream, $Q_{hs} = Q_{cs}$ shall be calculated as:

$$Q_{hs} = w_{hs} \lambda_{hs} \quad A3$$

$$Q_{cs} = w_{cs} \lambda_{cs} \quad A4$$

A1.4 The system must have a heat balance, where the heat transfer rate on the Cold Stream and the Hot Stream are the same, calculated as:

$$Q_{cs} = Q_{hs} \quad A5$$

$$w_{cs} c_{p,cs} (T_{cs,out} - T_{cs,in}) = w_{hs} c_{p,hs} (T_{hs,in} - T_{hs,out}) \quad A6$$

A1.5 The Number of Transfer Units, NTU of the heat exchanger is calculated as follows:

$$NTU_{max} = \frac{\Delta T_{max}}{LMTD} \quad A7$$

where: ΔT_{max} is the greater of ΔT_{hs} or ΔT_{cs} .

Derivation of NTU :

$$NTU = \frac{U \cdot A}{C_{min}} \quad A8$$

where: $C = w \cdot c_p$ = Capacity Rate and C_{min} is the lesser of $(w \cdot c_p)_{hs}$ or $(w \cdot c_p)_{cs}$

$$NTU = \frac{U \cdot A}{(w \cdot c_p)_{min}} \quad A9$$

$$\text{From: } Q = U A LMTD \quad A10$$

$$U \cdot A = \frac{Q}{LMTD} \quad A11$$

APPENDIX A
HEAT TRANSFER EQUATIONS
A1.0 BASIC HEAT TRANSFER EQUATIONS (continued)

$$Q = (w \cdot c_p) (\Delta T) = Q_{hs} = Q_{cs}$$

$$Q = (w \cdot c_p)_{\min} (\Delta T)_{\max} = (w \cdot c_p)_{\max} (\Delta T)_{\min}$$

$$(w \cdot c_p)_{\min} = \frac{Q}{(\Delta T)_{\max}} \quad A12$$

Substituting equations A11 and A12 in A8:

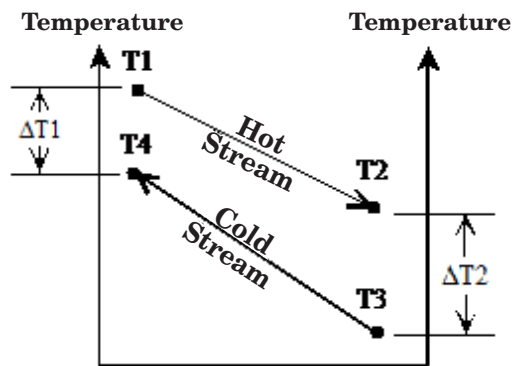
$$NTU = \left[\frac{Q}{LMTD} \right] \left[\frac{\Delta T_{\max}}{Q} \right]$$

$$NTU = \frac{\Delta T_{\max}}{LMTD} \quad A7$$

where:

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln \left(\frac{\Delta T_1}{\Delta T_2} \right)} \quad A13$$

with ΔT_1 and ΔT_2 defined in Figures 22 and 23 below:



Note: $LMTD = \Delta T$
 If $\Delta T_1 = \Delta T_2$

Figure 22
Counter Current Flow

APPENDIX A
HEAT TRANSFER EQUATIONS
A1.0 BASIC HEAT TRANSFER EQUATIONS (continued)

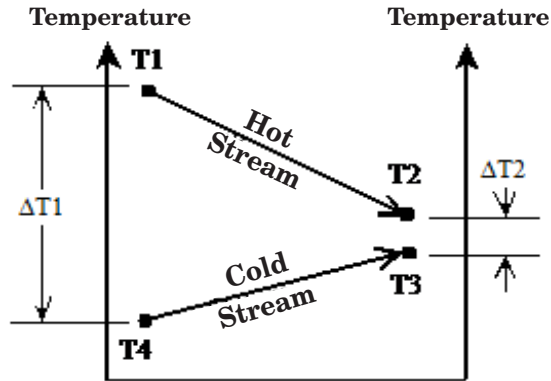


Figure 23
Co-Current Flow

A1.5 *Determine Overall Heat Transfer Coefficient for Clean Surfaces.* Calculate the overall heat transfer coefficient, U_c for clean heat transfer surface(s) using the following method:

$$U_c = \frac{Q_c}{(A) \cdot (LMTD_c)}$$

A14

A1.6 *Determine Overall Heat Transfer Coefficient for Fouled Surfaces.* The reciprocal of the overall heat transfer coefficient for fouled surface(s) is determined by mathematically adding the specified Field Fouling Allowance to the reciprocal coefficient for clean heat transfer surfaces, U_c .

A1.6.1 The following equation is for fouling for Plate Heat Exchangers:

$$U_f = \frac{1}{\frac{1}{U_c} + r_f}$$

A15

A1.7 *Determine Required Surface Area with Fouling Allowances.* Calculate the surface area required with fouling allowances using the following relationship:

$$A = \frac{Q_c}{(U_f) \cdot (LMTD_c)}$$

A16

A1.8 *Determine Basic Pressure Drop for Plate Heat Exchangers.* The basic relationship used to determine pressure drop thru a plate heat exchanger can be represented as follows:

$$\Delta P = \frac{fL\rho V^{1.9}}{2gD}$$

A17

where:

$$D = \frac{4 * \text{cross section of the flow channel}}{\text{wetted perimeter of the flow channel}}$$

A18

APPENDIX A
HEAT TRANSFER EQUATIONS (continued)

A1.9 Symbols and Subscripts. The symbols and subscripts used in Equations A1 through A18 are as follows:

Symbols:

A	=	Surface area / Total heat transfer surface, ft ²
C	=	Capacity rate, Btu/h °F
c_p	=	Specific heat of liquid, Btu/lb _m °F
D	=	Hydraulic diameter of plate / channel, in
f	=	friction factor, dependent on chevron style
g	=	Gravitational constant, ft/sec ²
L	=	Length of Plate, in
$LMTD$	=	Log mean temperature difference as defined in Equation A13, °F
NTU	=	Number of Thermal Units
ΔP	=	Pressure change associated with a given fluid across the heat exchanger
Q	=	Heat transfer rate, Btu/h
R	=	Heat transfer resistance, h ft ² °F /Btu/h
T	=	Temperature, °F
ΔT	=	Temperature change ΔT_1 or ΔT_2 associated with the liquid
ΔT_1	=	Temperature difference as defined in Figures 22 and 23, $(T_1 - T_4)$, °F
ΔT_2	=	Temperature difference as defined in Figures 22 and 23, $(T_2 - T_3)$, °F
U	=	Overall heat transfer coefficient, Btu/h ft ² °F
V	=	Nominal velocity across the plate / channel, ft/sec
λ	=	Latent heat of flow of vapor, Btu/lb _m
ρ	=	Density of fluid at the average of the inlet, outlet and average temperatures, lb _m / ft ³
w	=	Mass rate of flow of liquid, lb _m /h

Subscripts:

c	=	Clean
cs	=	Cold stream
f	=	Fouled or fouling
hs	=	Hot stream
in	=	Entering
max	=	Maximum
min	=	Minimum
out	=	Leaving
$tavg$	=	Total average

APPENDIX B-1
HEAT EXCHANGER SPECIFICATION SHEET
ENGLISH UNITS

CUSTOMER INFORMATION				
Date:		Your Reference:		
Plant Location:		Project Name:		
Company:		Contact Name:		
Address:		Title:		
Address:		Phone:		
City:		Fax:		
State, Zip:		Email:		
APPLICATION DETAILS				
Service:				
Tag Number:				
Number of Units (parallel/series):				
		Hot Side		Cold Side
Fluid Name				
		Inlet	Outlet	Inlet Outlet
Total Flow Entering	GPM			
- Liquid	lbs/hr			
- Vapor	lbs/hr			
- Steam	lbs/hr			
- Non-condensable	lbs/hr			
Operating Temperature	°F			
Specific Gravity or Density	lb/ft ³			
Specific Heat	Btu/lb °F			
Thermal Conductivity	Btu/hr °F ft ²			
Viscosity	cp			
Operating Pressure	PSIG			
Allowable Pressure Drop	PSIG			
Heat Exchanged	Btu/hr			
Percentage of Undissolved Solids				
Type of Solid (e.g., fibrous, powder, size)				
% Excess Surface				
% Future Expansion				
CONSTRUCTION DETAILS				
Design Pressure (PSIG):	Test Pressure (PSIG):		Design Temperature (°F):	
Plate Material:	☐ 304 SS	☐ 316 SS	☐ Titanium	☐ Other -
Connection Material:	☐ 304 SS	☐ 316 SS	☐ Titanium	☐ Other -
Gasket Material:	☐ NBR Nitrile	☐ EPDM	☐ Fluoroelastomer	☐ Other -
Design Code:	☐ ASME VIII	☐ ASME III	☐ CRN	☐ Other -
COMMENTS				

APPENDIX B-2
HEAT EXCHANGER SPECIFICATION SHEET
SI UNITS

CUSTOMER INFORMATION	
Date:	Your Reference:
Plant Location:	Project Name:
Company:	Contact Name:
Address:	Title:
Address:	Phone:
City:	Fax:
State, Zip:	Email:

APPLICATION DETAILS	
Service:	
Tag Number:	
Number of Units (parallel/series):	

		Hot Side		Cold Side	
Fluid Name		Inlet	Outlet	Inlet	Outlet
Total Flow Entering	m ³ /hr				
- Liquid	kg/hr				
- Vapor	kg/hr				
- Steam	kg/hr				
- Non-condensable	kg/hr				
Operating Temperature	°C				
Specific Gravity or Density	kg/m ³				
Specific Heat	kJ/kg, °C				
Thermal Conductivity	W/m, °C				
Viscosity	Pa,s				
Operating Pressure	bar				
Allowable Pressure Drop	bar				
Heat Exchanged	kW				
Percentage of Undissolved Solids					
Type of Solid (e.g., fibrous, powder, size)					
% Excess Surface					
% Future Expansion					

CONSTRUCTION DETAILS				
Design Pressure (bar):	Test Pressure (bar):		Design Temperature (°C):	
Plate Material:	☐ 304 SS	☐ 316 SS	☐ Titanium	☐ Other -
Connection Material:	☐ 304 SS	☐ 316 SS	☐ Titanium	☐ Other -
Gasket Material:	☐ NBR Nitrile	☐ EPDM	☐ Fluoroelastomer	☐ Other -
Design Code:	☐ ASME VIII	☐ ASME III	☐ CRN	☐ Other -

COMMENTS

APPENDIX C

TROUBLESHOOTING GUIDE

Problem	Possible Causes	Suggested Solutions
1. Reduced heat transfer	a. The inlet temperatures or flow rates do not correspond to the original design. b. Plate surfaces have become fouled on either the product or service side. c. Freeze-up.	a. Correct temperatures or flow rates to design conditions. b. Open the heat exchanger and clean the plates or clean the plates without opening by circulating a suitable cleaning agent or back flush to dislodge debris. c. Correct temperatures or flow rates to design conditions.
2. Increased pressure drop or reduced flow rate	a. Plate surfaces have become fouled on either the product or service side. b. Debris is blocking the flow channels.	a. See paragraph 1(b) above. Open the heat exchanger and clean the plates. b. Screens or filters must be installed to prevent debris from entering the unit. Back flush to dislodge debris.
3. Visible leaks	a. Operating pressure exceeds the rating of the heat exchanger. b. The heat exchanger is not tightened adequately for the operating conditions. c. Sealing surfaces of plates or gaskets maybe damaged or dirty. d. Chemical attack on the gaskets e. Cracks in liner or nozzle	a. Reduce the operating pressure to the rating of the heat exchanger. If the unit continues to leak after the pressure is reduced, the plates or gaskets might be damaged or gaskets may require replacement. b. Tighten the heat exchanger further in increments of .001 inch (0.025 mm) per plate, checking for leakage each time. Do not tighten below the minimum dimensions given in the detailed drawing. If leaks continue, see paragraph below. c. Open the heat exchanger and inspect the plates and gaskets. There must not be any cuts, cracks, debris or flat spots on the gaskets. Glue free gaskets must not have any debris under the gasket. The plates must be clean and free of heavy scratches or dents on both sides. Replace any defective parts. d. Identify the source of chemical attack and correct either by eliminating the corrosive agent or changing the material of the gaskets. e. Use an appropriate dye penetrant to look for small cracks in the liner or nozzle. Pay particular attention to corners and welds. Replace the liner and nozzle components or weld repair.

APPENDIX C
TROUBLESHOOTING GUIDE (continued)

Problem	Possible Causes	Suggested Solutions
4. Mixing of fluids	a. Cracks in one or more plates. These may be caused by fatigue resulting from pressure fluctuations during operation. b. Holes in the plates caused by corrosion.	a. Open the heat exchanger and inspect the plates. Replace the defective parts. Identify the source of pressure fluctuations and correct. Dye-penetrant or alternative in situ testing may be required to identify cracks in the plates. If this is the case, refer to Factory Service. b. Identify the source of corrosion and correct by either eliminating the corrosive agent or changing the plate material.

APPENDIX D
METRIC CONVERSION FACTORS
NOMENCLATURE

NAME		SYMBOL	OTHER UNITS
inch/inches		in	
foot/feet		ft	
meter	(SI)	m	
millimeter		mm	
square inch		in ²	
square foot		ft ²	
square meter	(SI)	m ²	
square centimeter		cm ²	
square millimeter		mm ²	
cubic inch		in ³	
cubic foot		ft ³	
gallon (US liquid)		gal	
cubic meter	(SI)	m ³	
liter		L	
pound mass (avoirdupois)		lbm	
kilogram	(SI)	kg	
pound force (avoirdupois)		lbf	
kilogram force		kgf	
newton	(SI)	N	m • kg/s ²
degree Fahrenheit		°F	
kelvin	(SI)	K	Note 5.
degree Celsius	(SI)	°C	Note 5.
British thermal unit (International Table)		Btu	
kilocalorie (International Table)		kcal	
joule	(SI)	J	N • m, m ² • kg/s ²
kilojoule		kJ	
second (customary)		sec	
second	(SI)	s	
minute		min	
hour (customary)		hr	
hour (metric)		h	
watt	(SI)	W	J/s, N • m/s, m ² • kg/s ³
megawatt		MW	
pound force/square inch		psi	lbf/in ²
inches of mercury		in Hg	
feet of water		ft H ₂ O	
pascal	(SI)	Pa	N/m ² , kg/(m • s ²)
kilopascal		kPa	
bar		bar	
millimeter of mercury		mmHg	
torr		torr	
centipoise		cp	

Notes:

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

APPENDIX D
METRIC CONVERSION FACTORS
NOMENCLATURE (continued)

PREFIXES DENOTING DECIMAL MULTIPLES OR SUBMULTIPLES

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

CONVERSION FACTORS

LENGTH

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

AREA

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

VOLUME

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

MASS

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

FORCE

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

APPENDIX D
METRIC CONVERSION FACTORS
NOMENCLATURE (continued)

TEMPERATURE

K = 5 (°F + 1 459.67)/1.8	K = (°C + 273.15)	(SI)
°C = 5 (°F – 32)/1.8	°C = (K – 2 273.15)	(SI)
°F = 1.8 °C + 32	°F = 1.8 K – 459.67	

ENERGY, WORK OR QUANTITY OF HEAT

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

POWER (ENERGY/TIME)

MULTIPLY	BY	TO OBTAIN	
Btu/hr	2.930711×10^{-1}	W	(SI)
Btu/hr	2.930711×10^{-7}	MW	
Btu/hr	2.519958×10^{-1}	kcal/h	

PRESSURE OR STRESS (FORCE/AREA)

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

VELOCITY (LENGTH/TIME)

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

MASS FLOW RATE (MASS/TIME)

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

APPENDIX D
METRIC CONVERSION FACTORS
NOMENCLATURE (continued)

TEMPERATURE

$K = 5 ({}^{\circ}F + 1\,459.67)/1.8$	$K = ({}^{\circ}C + 273.15)$	(SI)
${}^{\circ}C = 5 ({}^{\circ}F - 32)/1.8$	${}^{\circ}C = (K - 2\,773.15)$	(SI)
${}^{\circ}F = 1.8\,{}^{\circ}C + 32$	${}^{\circ}F = 1.8\,K - 459.67$	

ENERGY, WORK OR QUANTITY OF HEAT

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

POWER (ENERGY/TIME)

MULTIPLY	BY	TO OBTAIN	
Btu/hr	2.930711×10^{-1}	W	(SI)
Btu/hr	2.930711×10^{-7}	MW	
Btu/hr	2.519958×10^{-1}	kcal/h	

PRESSURE OR STRESS (FORCE/AREA)

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

VELOCITY (LENGTH/TIME)

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

MASS FLOW RATE (MASS/TIME)

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

APPENDIX D
METRIC CONVERSION FACTORS
NOMENCLATURE (continued)

VOLUME FLOW RATE (VOLUME/TIME)

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

MASS VELOCITY (MASS/TIME-AREA)

MULTIPLY	BY	TO OBTAIN	
lbm/(hr • ft ²)	1.35623 × 10 ⁻³	kg/(s • m ²)	(SI)
lbm/(hr • ft ²)	4.882428	kg/(h • m ²)	
lbm/(sec • ft ²)	4.882428	kg/(s • m ²)	(SI)

SPECIFIC VOLUME (VOLUME/MASS)

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

DENSITY (MASS/VOLUME)

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

ENTHALPY (ENERGY/MASS)

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

HEAT CAPACITY AND ENTROPY (ENERGY/MASS-TEMPERATURE)

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

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

MULTIPLY	BY	TO OBTAIN	
Btu • in/(hr • ft ² • °F)	1.442279 × 10 ⁻¹	W/(m • °C)	(SI)
Btu • in/(hr • ft ² • °F)	1.240137 × 10 ⁻¹	kcal • m/(h • m ² • °C)	
Btu • ft/(hr • ft ² • °F)	1.730735	W/(m • °C)	(SI)
Btu • ft/(hr • ft ² • °F)	1.488164	kcal • m/(h • m ² • °C)	

APPENDIX D
METRIC CONVERSION FACTORS
NOMENCLATURE (continued)

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

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

HEAT FLUX DENSITY (ENERGY/TIME-AREA)

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

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

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

FOULING RESISTANCE (TIME-AREA-TEMPERATURE/ENERGY)

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

NOTES

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