THE STANDARDS OF THE

BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGER

MANUFACTURERS' ASSOCIATION

ALPEMA

Second Edition
2000

Published by: The Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association (ALPEMA) - www.alpema.org

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PREFACE

This is the Second Edition of the Standards of the Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association (ALPEMA). It is the result of the work by a technical committee of all the Members to meet the objective of the Association to promote the quality and safe use of this type of heat exchanger. The Standards contain all relevant information for the specification, procurement, and use of Brazed Aluminium Plate-Fin Heat Exchangers.

The First Edition, published in 1994, has proved extremely successful and popular. The ALPEMA Members have reviewed the Standards every year since 1994 to consider whether updates are required and what these should be. Changes in the industry, experience with using the Standards and feedback from users has indicated that the time is right for the Second Edition. The additions and amendments which have been made are summarised here.

1. A new Section 3.10 has been added to the end of Chapter 3 on the procedures to follow in rectifying the non-conformities that occasionally occur in manufacture.
2. Chapter 4, previously titled *Installation*, has been re-titled *Installation, Operation and Maintenance* to reflect more accurately its contents. The following changes have also been made to this Chapter:
    - In section 4.9.1, an additional warning to the user has been added on pressure protection.
    - The recommended maximum cool-down and warm-up rates given in Sections 4.9.1 and 4.9.3, respectively, have been increased.
    - Section 4.11 on leak detection on-site, has been extended to give more detail and a new Section 4.12 added on repair of leaks.
3. Section 5.12.2.4 on nozzle loading has been modified with respect both to the point of application of the loads and the corresponding magnitudes of the typical allowable loads.
4. In Chapter 7, Section 7.3, which introduces thermal design, has been modified to emphasise the existence of more advanced and detailed calculation methods than the basic one included in Chapter 7. Also, Figure 7-3 and Figure 7-4, the typical specification sheets, have been tided up slightly.
5. Section 8.3 on corrosion has been expanded to give more information and guidelines on the use of brazed aluminium plate-fin exchangers in a variety of environments.
6. In addition to the above substantive changes, the wording has been revised in several places to improve clarity and remove typographical errors. Also, minor improvements have been made to a few of the Figures.

Comment by users of The Standards are welcomed.

NO WARRANTY EXPRESSED OR IMPLIED

The Standards herein are recommended by The Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association to assist users, engineers and designers who specify, design and install Brazed Aluminium Plate-Fin Heat Exchangers. These Standards are based upon sound engineering principles, research and field experience in the manufacture, design, installation and use of these exchangers. These Standards may be subject to revision as further investigation or experience may show is necessary or desirable. Nothing herein shall constitute a warranty of any kind, expressed or implied, and warranty responsibility of any kind is expressly denied.

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1 GENERAL DESCRIPTION AND NOMENCLATURE

1.1 GENERAL DESCRIPTION

1.1.1 Introduction

A brazed aluminium plate-fin heat exchanger consists of a block (core) of alternating layers (passages) of corrugated fins. The layers are separated from each other by parting sheets and sealed along the edges by means of side bars, and are provided with inlet and outlet ports for the streams. The block is bounded by cap sheets at the top and bottom.

An illustration of a multi-stream plate-fin heat exchanger is shown in Figure 1-1.

The stacked assembly is brazed in a vacuum furnace to become a rigid core. To complete the heat exchanger, headers with nozzles are welded to the side bars and parting sheets across the ports.

The size of a brazed aluminium plate-fin heat exchanger shall be specified by width W, stacking height H and length L of the rectangular block. (Figure 1-2).

The three dimensions shall be given always in the same sequence as $W \times H \times L$, e.g. 900 × 1180 × 6100 mm.

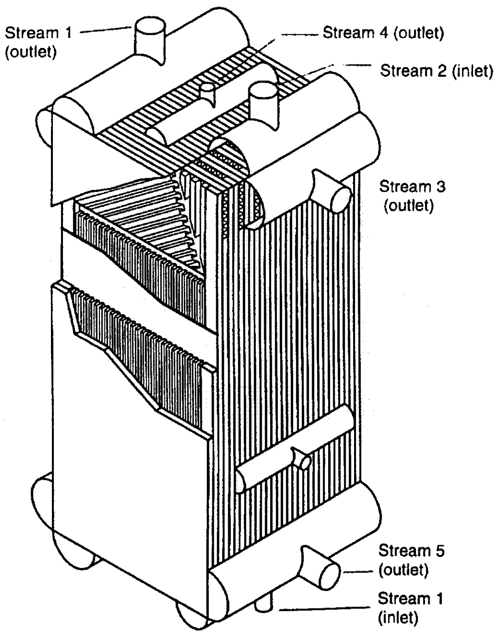


Figure 1-1: Illustration of a Typical Multi-Stream Brazed Aluminium Plate-Fin Heat Exchanger

1.1.2 Successful Applications for Brazed Aluminium Plate-Fin Heat Exchangers

1.1.2.1 Typical services

Most brazed aluminium plate-fin heat exchangers have been installed in process plants used to separate a feed gas into its constituents, for example by the partial liquefaction of the feed and subsequent distillation and separation. The products and waste streams are then re-warmed against the feed streams. Condensers and reboilers are associated with distillation columns. Often chillers using standard refrigerants are used. Brazed aluminium plate-fin heat exchangers are well suited for these and many other services. A partial listing includes:

Name	Service
Main exchanger	To cool inlet feed streams against return product and residue streams
Reversing exchanger	Air separation application to cool air and remove atmospheric water and CO_2
Subcooler	To subcool liquid products or other liquid streams
Reboiler	To reboil column bottoms or vaporise tray liquids. Often this exchanger is installed inside the column
Overhead condenser	To condense column overheads, usually against a refrigerant stream
Chiller	To cool a process stream with a vaporising refrigerant
Liquefiers	To liquefy the feed gas in a closed loop
Dephlegmators	To condense overheads and perform simultaneous heat and mass transfer
Aftercooler	To cool vapour coming from a compressor discharge

1.1.2.2 Plant types

Brazed aluminium plate-fin heat exchangers have been successfully used in the above services in a variety of applications. The major applications have been in the cryogenic separation and liquefaction of air (ASU); Natural Gas Processing (NGP) and Liquefaction (LNG); the production of petrochemicals and treatment of offgases; large refrigeration systems. Table 1-1 gives some typical applications where brazed aluminium plate-fin heat exchangers are used extensively and have proven reliable over many years of service.

1.1.3 Limits of Use - Maximum Working Temperature and Pressure

The maximum working pressure for brazed aluminium plate-fin heat exchangers varies from zero to over 100 bar g. It is possible to have over ten process streams, at various pressures, in a single heat exchanger.

The maximum temperature rating is typically specified at 65°C. An upper limit of 65°C is suitable for most applications, and it allows manufacturers to use 5083 aluminium alloy piping which is more economical. However, designs are available for up to +204°C at lower pressures, and design temperatures in excess of 65°C are common. The minimum design temperature is -269°C. See Chapter 6 for a full material listing.

1.1.4 Acceptable Fluids

Brazed aluminium plate-fin heat exchangers are capable of handling a wide variety of fluids in many different types of applications. In general, fluids should be clean, dry, and non-corrosive to aluminium. Trace impurities of H_2S, NH_3, CO_2, SO_2, NO_2, CO, Cl and other acid-forming gases do not create corrosion problem in streams with water dewpoint temperatures lower than the cold-end temperature of the brazed aluminium plate-fin heat exchanger.

Under specific conditions, mercury can corrode aluminium and therefore caution must be used when handling mercury-containing fluids. However, there are many instances where brazed aluminium plate-fin heat exchangers have been successfully used with fluids containing mercury provided that the proper equipment design and operating procedures are implemented. In all cases, it is recommended that the heat exchanger manufacturer is consulted about specific conditions.

Further information on corrosion guidelines is given in Section 8.3.

Proper filters should be installed upstream of the exchangers to prevent plugging from particulates such as pipe scale or molecular sieve dust. If a brazed aluminium plate-fin heat exchanger is accidentally plugged, proven cleaning procedures are available. Further information on this subject is given in Section 8.2.

Fluids containing compressor lube oils, and other heavy hydrocarbons are acceptable provided these contaminants do not precipitate out on the fin surface. In the event of heavy fouling, chemical solvent cleaning of the exchanger is a proven method of cleaning.

Table 1-1: Plant Types and Applications

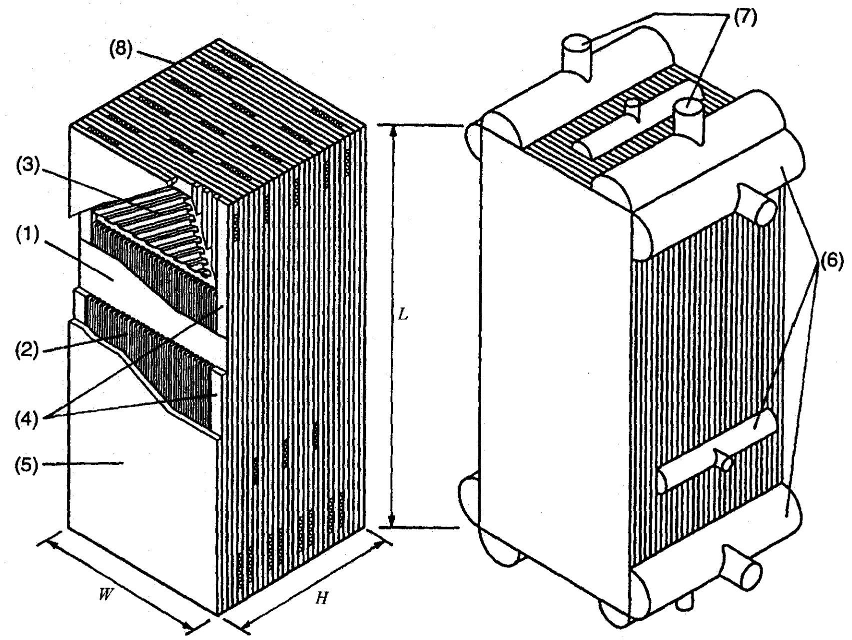
Plant Types	*Products & Fluids*	*Typical Temperature Range, °C*	*Typical Pressure Range, bar.a*
Industrial Gas Production - Air Separation - Liquefaction	Oxygen Nitrogen Argon Rare Gases Carbon Dioxide	+65 to -200	1 TO 60
Natural Gas Processing (NGP) - ExpanderType - Nitrogen Rejection Unit (NRU) - Liquefied Petroleum Gas (LPG) - Helium Recovery	Methane Ethane Propane Butane Pentane Nitrogen Helium Hydrogen Hexane Carbon Dioxide	+100 to -130	15 TO 100
Liquefied Natural Gas (LNG) - Base Load - Peakshaver	Liquefied Natural Gas Multi-Component Refrigerants	+65 to -200	5 TO 75
Petrochemical Production - Ethylene - MTBE - Ammonia - Refinery Off-Gas Purification	Ethylene Propylene Ethane Propane MTBE Ammonia Carbon Monoxide Hydrogen	+120 to -200	1 TO 100
Refrigeration Systems - Cascade Cooling - Liquefaction	Helium Freon Ethylene Propane Propylene Nitrogen Hydrogen Multi-Component Refrigerants	+100 to -269	15 TO 45

1.2 NOMENCLATURE OF THE COMPONENTS

Section 1.2 describes the components which are part of a brazed aluminium plate-fin heat exchanger. Typical geometrical dimensions are included in Chapter 5 of these Standards. Other items are described in the relevant chapters (e.g. supports are illustrated in Chapter 4 of these Standards).

1.2.1 Components of an Exchanger

For the purpose of establishing standard terminology, Figure 1-2 illustrates the components of an exchanger. The components are numbered for identification.



1. Parting sheet
2. Heat transfer fins
3. Distributor fins
4. Side bars
5. Cap sheet
6. Headers
7. Nozzles
8. Block (core)

L; Length
W; Width
H; Height

Figure 1-2: Components of a Brazed Aluminium Plate-Fin Heat Exchanger

1.2.2 Components of Manifolded Exchangers

Multiple brazed aluminium plate-fin exchangers may be connected in parallel, in series, or in parallel-series combination, to form one assembly.

Figure 1-3 illustrates an assembly of three brazed aluminium plate-fin heat exchangers connected in parallel. For this case, each individual stream enters the assembly through a manifold, is distributed to the inlet nozzles on each of the three heat exchangers, flows through the heat exchanger and leaves the assembly through the outlet manifold.

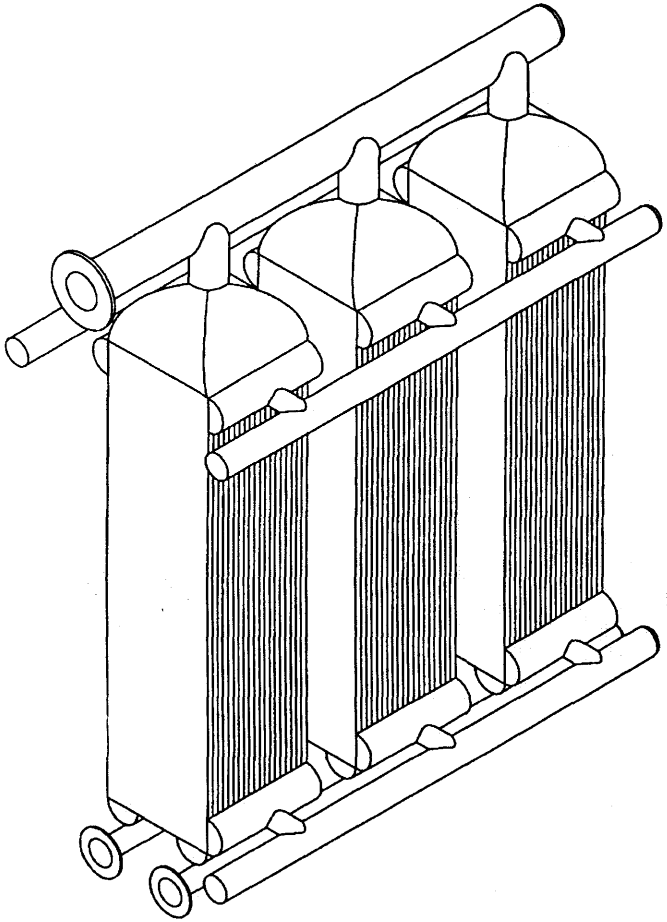


Figure 1-3: Typical Assembly of Three Brazed Aluminium Plate-Fin Heat Exchangers in Parallel

1.2.3 Module Construction

Two or more individually brazed aluminium plate-fin exchanger blocks may be welded together in parallel to form one composite block. In this way the stacking height of the exchanger can be increased above a dimension limited by the manufacturing process or other restrictions.

1.2.4 Connection Options

Several options are available for connecting a brazed aluminium plate-fin heat exchanger to plant piping.

1.2.4.1 Stub ends

This option is selected if the exchanger nozzles are to be directly (butt-) welded to the connecting aluminium pipes.

1.2.4.2 Flanges

This option is available if the heat exchanger is to be connected to steel piping or if installation of the heat exchanger without welding is desired. Under this option, the manufacturer provides the heat exchanger with aluminium flanges welded on the nozzles to fit with mating (normally steel) flanges on the piping.

1.2.4.3 Transition joints

This alternative to flanges is available if the heat exchanger is to be connected to steel piping. Under this option, the manufacturer provides the heat exchanger with transition joints welded to the nozzles. The transition joints are directly (butt-) welded to the connecting steel pipes.

1.2.5 Header/Nozzle Configurations

Streams to and from the heat exchanger enter and leave by means of various header/nozzle configurations.

The headers are normally made from half cylinders with flat and/or mitred ends or mitred dome headers. Typical variants are shown in Figure 1-4.

The nozzles may be radial, tangential or inclined to the header and can also be equipped with flanges or transition joints. There are many different and acceptable variations of header/nozzle configurations in use and some typical variations are shown in Figure 1-5.

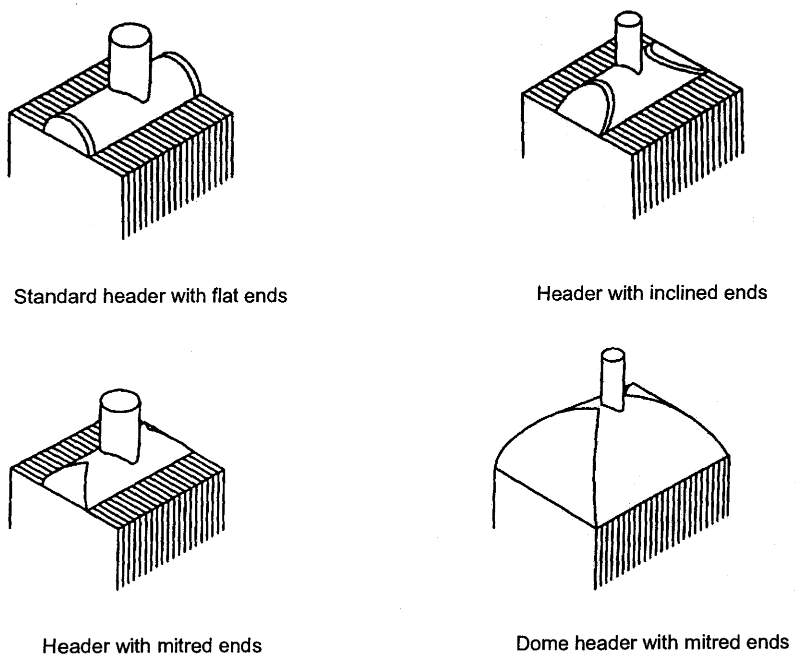


Figure 1-4: Typical Header Configurations

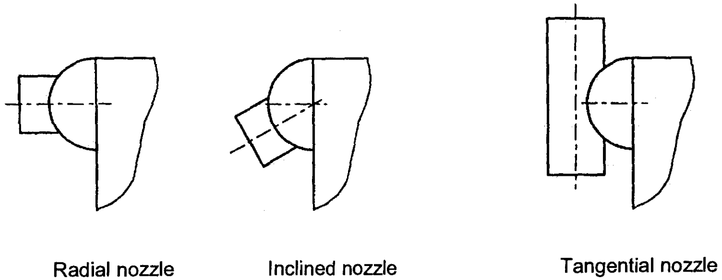


Figure 1-5: Typical Header/Nozzle Configurations

1.2.6 Fin Corrugations

Various shapes of corrugated fins are available.

1.2.6.1 Principal types of fin

The principal types are plain, serrated and herringbone as illustrated in Figure 1-6. Plain and herringbone fins may also be perforated as illustrated. For the thermal and hydraulic behaviour of each fin-type refer to Chapter 7 of these Standards.

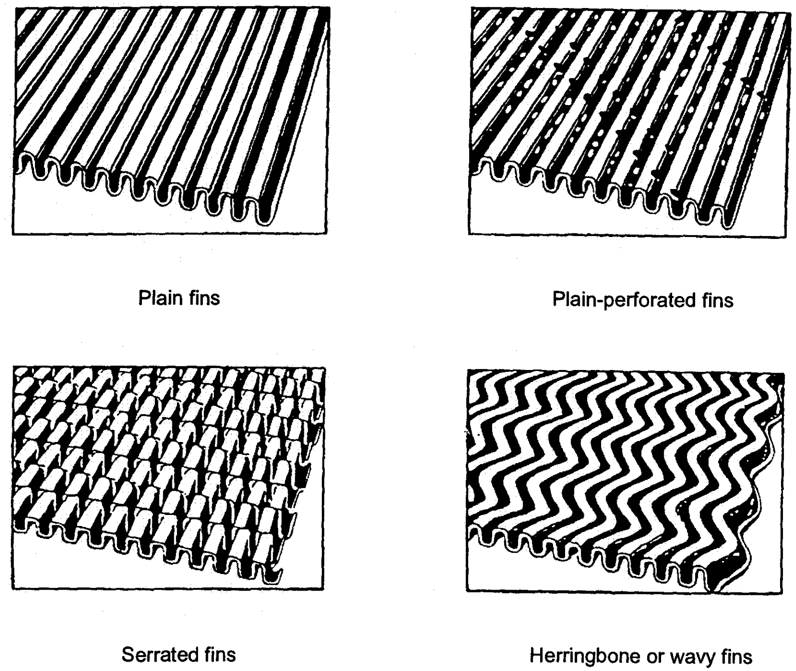


Figure 1-6: Principal Types of Fin

1.2.6.2 *Dimensions of fins*

Each type of fin is characterised by its height, h, thickness, t, and pitch, p, or by the number of fins per inch (FPI) as shown in Figure 1-7. Additionally, specification is required for the percentage perforation of perforated fins, (e.g. 5% of corrugated area); for l_s, the length of the serration of serrated fins, and for the distance between crests on herringbone fins.

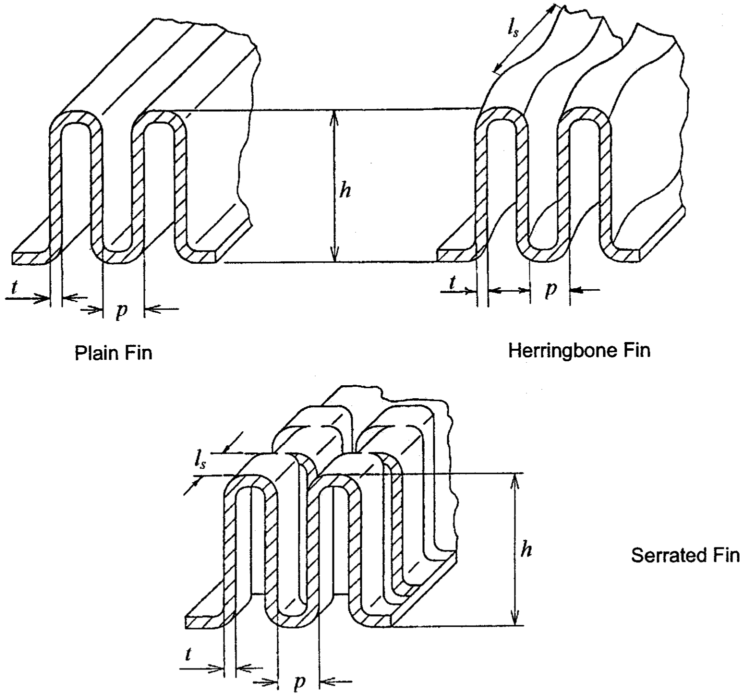


Figure 1-7: Definition of Fin Dimensions

1.2.7 Distributors

There are various distributor types available for streams entering or leaving a block.

The principal distributor types are:

- side distributor (mitred or diagonal)
- end distributor (left, right or central)
- intermediate distributor (special)

Some typical examples are shown in Figure 1-8. Manufacturers may offer other designs.

Special designs of distributor are offered for two-phase streams entering a block (Reference 4).

CHAPTER 1
General Description and Nomenclature

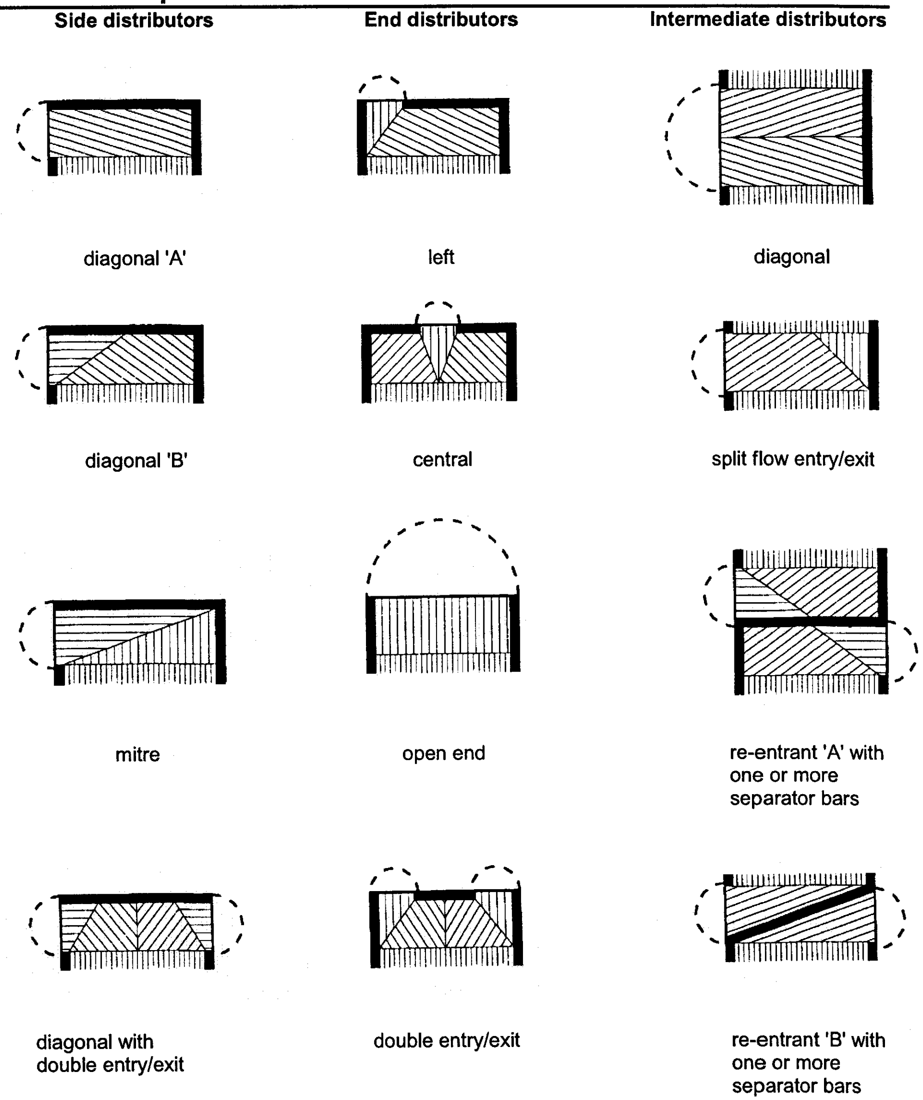


Figure 1-8: Examples of the Principal Distributor Types

1.2.8 Flow Arrangements

Figure 1-9a illustrates the structure of an individual layer. Internal distributor fins (1) conduct the stream from the narrow entry port across the full width of the layer to the heat transfer fins (2). Distribution fins (3) then conduct the stream to the exit port.

Figure 1-9b illustrates the fin arrangement of a layer with an intermediate port (see also Figure 1-8). Various arrangements of the layers for each of the streams provide various possible flow arrangements, as shown in Figure 1-10. Manufacturers may offer further arrangements.

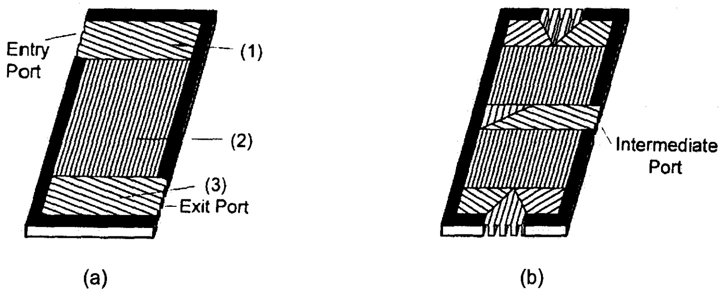
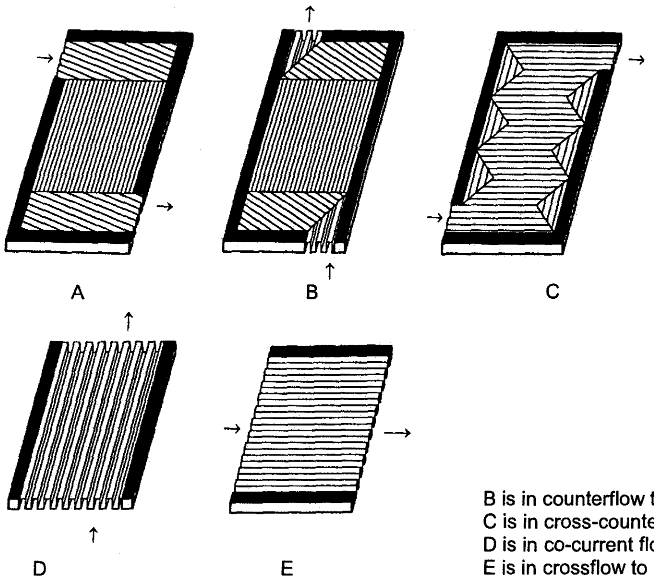


Figure 1-9: Structure of an Individual Layer



B is in counterflow to A
C is in cross-counterflow to A
D is in co-current flow to B
E is in crossflow to D

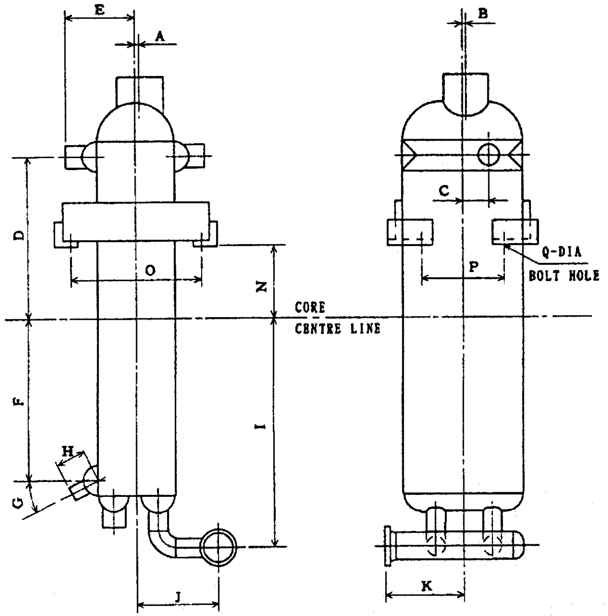
Figure 1-10: Flow Arrangements

2 TOLERANCES

Standard tolerances for the external dimensions of brazed aluminium plate-fin heat exchangers are shown in Figure 2-1 and Figure 2-2. The core centre line (Figure 2-1) and the base line of supports (Figure 2-2) are used here as datum lines to illustrate these dimensions. However, manufacturers may use other reference datum lines. The purchaser and manufacturer may adopt other tolerance values upon agreement.

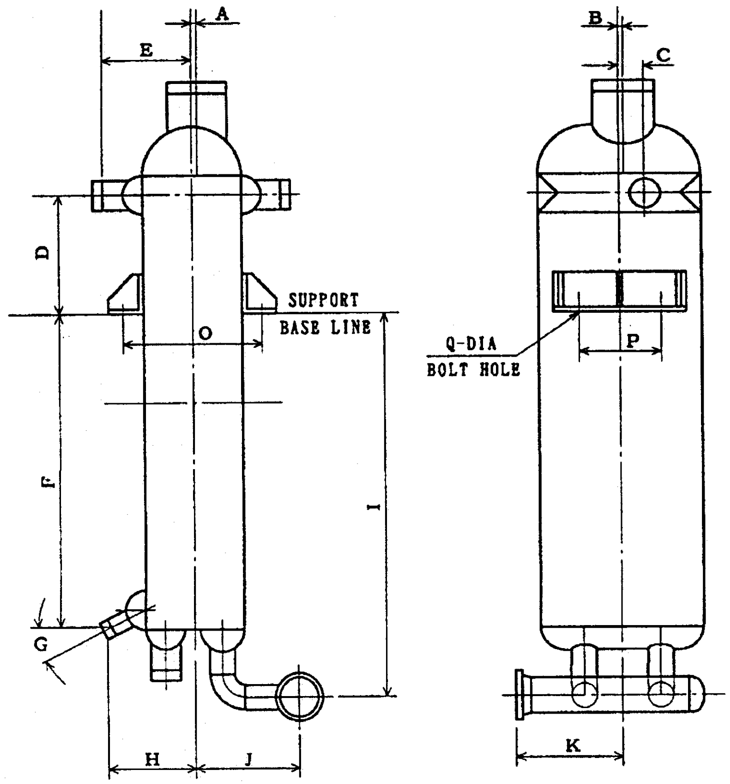
Figure 2-3 shows the tolerances for a manifolded assembly of two cores. Here, the base line of the supports may also be used as a datum line as shown in Figure 2-2. Details for flanges are also shown in Figure 2-3.

For spare and replacement exchangers these tolerances shall also be applied.



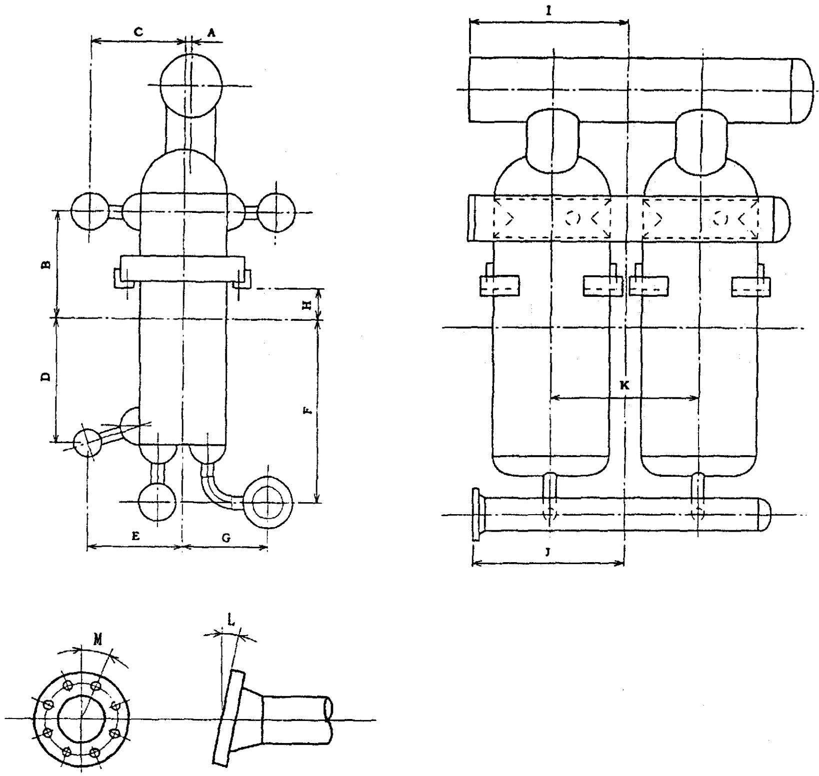
ITEMS	TOLERANCES	ITEMS	TOLERANCES
A, B, C, D, E, F	± 6mm for Dim ≤ 1000mm ± 8mm for 1000mm <Dim ≤ 2000mm ± 10mm for Dim>2000m	H, I, J, K	± 6mm for Dim ≤ 1000mm ± 8mm for 1000mm<Dim ≤ 2000mm ± 10mm for Dim>2000m
G	± 3°	N, O, P	± 3mm
		Q	± 1mm

Figure 2-1: Important External Dimensions of One Core using the Core Centre Line



ITEMS	TOLERANCES	ITEMS	TOLERANCES
A, B, C, D, E, F	± 6mm for Dim ≤ 1000mm ± 8mm for 1000mm <Dim ≤ 2000mm ± 10mm for Dim>2000m	H, I, J, K	± 6mm for Dim ≤ 1000mm ± 8mm for 1000mm<Dim ≤ 2000mm ± 10mm for Dim>2000m
G	± 3°	N, O, P	± 3mm
		Q	± 1mm

Figure 2-2: Important External Dimensions of One Core using the Support Base Line



ITEMS	TOLERANCES	ITEMS	TOLERANCES
A, B, C, D, E, F, G	±6mm for Dim≤1000mm ±8mm for 1000mm <Dim≤2000mm ±10mm for Dim>2000m	I, J, K	±6mm for Dim≤1000mm ±8mm for 1000mm<Dim≤2000mm ±10mm for Dim>2000m
H	±3mm	L	±1° ;max 5mm at flange periphery
		Q	±1° ;max 5mm at bolt circle

Figure 2-3: Important External Dimensions of a Manifolded Assembly of Two Cores: General Flange Details

3 GENERAL FABRICATION AND CONTRACTUAL INFORMATION

3.1 SHOP OPERATION

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

3.2 DESIGN CODE

The design of the equipment shall be performed by the manufacturer in complete compliance with the agreed code. As a minimum, the latest mandatory edition of the code in effect at the date of purchase order shall apply. For more information refer to Chapter 5 of these Standards.

3.3 INSPECTION

3.3.1 Third Party Inspection

Generally all brazed aluminium plate-fin heat exchangers are subject to an inspection by an independent third party inspection authority. The authority shall carry out the inspections and tests required by the agreed applicable code.

3.3.2 Manufacturer's Inspection

In some circumstances, certain codes allow the manufacturer to carry out the inspection and testing of the heat exchangers. For these circumstances, the amount of inspection, testing and judgement of the results, shall not be less than that required when performed by a third party inspection authority.

3.3.3 Purchaser's Inspection

The purchaser shall have the right to participate in any inspection and to witness any test that the purchaser has so requested. However, purchaser's inspections and witnesses shall be restricted to non-proprietary operations. Advance notification of inspections and tests shall be given as agreed upon between the manufacturer and the purchaser. Inspection by the purchaser shall not relieve the manufacturer of the manufacturer's responsibilities for compliance with the code and these Standards.

3.4 NAMEPLATE

3.4.1 Manufacturer's Nameplate

A suitable manufacturer's nameplate shall be permanently attached to each individual brazed aluminium plate-fin heat exchanger. The location of the nameplate shall allow easy access after installation of the heat exchanger in the plant.

The nameplate shall be of corrosion resistant material, which may be an aluminium alloy or austenitic stainless steel. When specified by the purchaser, the nameplate shall be attached to a bracket welded to the heat exchanger. If the heat exchanger is to be installed in a permanent enclosure, (e.g. a coldbox or vessel), a second identical (duplicate) nameplate shall be supplied loose by the manufacturer, for attachment onto the enclosure by others.

3.4.1.1 Nameplate structure

Because brazed aluminium plate-fin heat exchangers are capable of accommodating more than two streams, i.e. containing more than two independent pressure chambers, it is common practice that nameplates used by manufacturers are able to specify data for several streams. Alternatively, several nameplates can be used.

3.4.1.2 Nameplate data

The nameplate shall, as a minimum, include all data required by the code. The following data are typical for each stream: the maximum allowable working pressure and the maximum and minimum allowable working temperatures or design metal temperature. Other nameplate information normally given will be the manufacturer's name and address, the heat exchanger serial number and the year built.

3.4.1.3 Supplementary Information

The manufacturer may supply supplementary information pertinent to the identification, operation, or testing of the heat exchanger. This may include information about different design and test pressure conditions or other restrictive conditions applicable to the design and/or operation of the heat exchanger. Such information can be noted on the nameplate or on a supplementary plate attached to the heat exchanger, close to the nameplate location.

3.4.2 Purchaser's Nameplate

Purchaser's nameplate, when used, is to be supplied by the purchaser and supplement, rather than replace, the manufacturer's nameplate. The purchaser shall supply information about size and material of supplementary nameplates to the manufacturer at the date of order.

3.5 DRAWINGS AND CODE DATA REPORTS

General outline drawings shall be prepared and submitted by the manufacturer to the purchaser and the appointed third party inspection authority.

3.5.1 Drawings Information

The manufacturer's outline drawings shall contain all the necessary information for approval, and typically include the following:

- overall dimensions and material thickness, - supports and weight,
- specification and identification of materials, and if required by the code, type of material certificates,
- types of fins used,
- nozzle/flange location, identification numbering, and connection details, - type of fluid for each stream if required by purchaser or the code,
- fabrication and test data, extent and location of non-destructive examinations, extent of leak testing, test pressures and appropriate weld identification as required by the relevant code.

3.5.2 Drawings Approval and Change

The manufacturer shall submit the outline drawings for the purchaser's review and approval. An agreed number of prints of an outline drawing shall be submitted. Other drawings or documents may be furnished as agreed upon by the purchaser and the manufacturer.

Review and/or approval of drawings and documents shall be carried out by the purchaser within a reasonable agreed period.

The purchaser's approval of drawings shall not release the manufacturer from his liability and responsibility for compliance with these Standards and applicable code requirements.

3.5.3 Drawings for Record

After approval of drawings, the manufacturer shall furnish an agreed number of prints of all approved drawings.

3.5.4 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 his permission, except by the purchaser for his own internal use.

3.5.5 Code Data Reports

After completion of fabrication and inspection of the exchanger(s), the manufacturer shall furnish an agreed number of copies of the Manufacturer's Data Report.

3.6 GUARANTEES

Manufacturers are prepared to grant a thermal performance guarantee and a mechanical guarantee. Details shall be agreed upon by the purchaser and the manufacturer.

The following sections give an indication of terms of guarantees which may be expected from the manufacturer.

3.6.1 Thermal and Mechanical Guarantee

The manufacturer will warrant to the purchaser for a period of twelve (12) months from date of equipment startup, but not to exceed eighteen (18) months from date of shipment, whichever occurs first, that the equipment provided is (1) free from defects in material and workmanship, and (2) has the performance, i.e. capacities and ratings, set forth in the manufacturer's heat exchanger specifications, provided that no warranty is made against corrosion, erosion, or deterioration. The manufacturer will not warrant heat exchanger performance and/or mechanical design if the process conditions of flows, temperatures, pressures, fluid composition, mean temperature difference and turndown conditions are more severe than those specified on the manufacturer's specification sheets, or for pressures or temperatures outside the design range specified on the heat exchanger nameplate, or for damage due to improper installation or operation, or due to external forces applied to the heat exchanger from the connecting piping or support system, which exceed the manufacturer's specified allowable loads.

The manufacturer's obligation and liability, at the option of the manufacturer, is limited to the repair, modification, or replacement of the manufacturer's equipment if found not to be in compliance with the stated warranty. The manufacturer's obligations and liabilities are limited to furnishing replacement equipment, ex works, not conforming to this warranty.

3.6.2 Consequential Damage

In no event shall the manufacturer be held liable for any costs for gaining access, installing, lost product, lost production, lost profits or any incidental or consequential damages of any nature.

3.6.3 Corrosion

After delivery the manufacturer assumes no responsibility for any defect of the equipment due to corrosion, except where the manufacturer has expressively accepted the conditions and/or substances which have caused such corrosion.

3.7 PREPARATION OF BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGERS FOR SHIPMENT

3.7.1 General

Brazed aluminium plate-fin heat exchangers will be suitably protected to prevent damage during shipment. If there are no special instructions from the purchaser, the following terms shall apply.

3.7.2 Cleaning

Internal and external surfaces will be free from oil and grease and free from any loose scale or other foreign material.

3.7.3 Drying

The manufacturer will ensure that all pressure chambers are sufficiently dry before shipment.

3.7.4 Flange Protection

All exposed machined contact surfaces will be protected against mechanical damage by suitable covers.

3.7.5 Dummy Passages/Inactive Areas

Openings in dummy passages or inactive heat exchanger areas will be suitably protected to avoid ingress of water and dust.

Reference should be made to Chapter 4 of these Standards.

3.7.6 Pressurising

To avoid ingress of any moisture or dust during transport, brazed aluminium plate-fin heat exchangers will be shipped with flanges and nozzles hermetically sealed and all pressure chambers pressurised with dry, oil-free nitrogen gas or air to between 0,2 and 1,2 bar g.

All connections must carry warning labels stating that the heat exchanger is under pressure.

WARNING: REMOVAL OF END CLOSURES IS ONLY ALLOWED AFTER REDUCING THE PRESSURE TO ATMOSPHERIC IN THE RELEVANT CHAMBER BY THE INSTALLED GAUGE/VALVE.

The purchaser and manufacturer may agree that pressurising the heat exchanger for transport is not necessary. In that case it may be considered necessary to ship the heat exchanger packed in a plastic foil with a humidity-absorbing agent inserted.

3.8 SCOPE OF SUPPLY

Unless expressively agreed otherwise between the purchaser and the manufacturer, the scope of the manufacturer's supply is as follows:

(1) Heat exchanger core(s) complete with headers and nozzles, and, if applicable, manifolded to form an assembly.

(2) For stub pipe connections:

Nozzles are normally seal welded with closures for transport. The manufacturer will provide sufficient length of stub pipes to allow easy connection to the plant piping after cutting the closures.

(3) For flanged connections:

The manufacturer's scope of supply will end with the aluminium flanges, which are normally covered by blind flanges for transport. These blind flanges with pertinent bolts and gaskets are only included to protect the aluminium flange faces and to allow moderate pressurising of the individual chambers for transport.

Steel counterflanges, bolts and gaskets suitable for plant operation are normally not in the manufacturer's scope of supply.

(4) Insulation material is not included in the manufacturer's scope of supply.

(5) The manufacturer will supply suitable supports and lifting lugs/devices as described in Sections 3.9.1 and 3.9.2 below.

(6) Spare parts:

Normally there are no spare parts necessary for the equipment covered by these Standards.

3.9 GENERAL CONSTRUCTION FEATURES

3.9.1 Supports

Generally all brazed aluminium plate-fin heat exchangers are provided with supports. Any exceptions are to be agreed upon between purchaser and manufacturer.

The supports are designed to accommodate the weight of the heat exchanger and its contents, during both operating and test conditions.

For purposes of support design, manufacturers provide a design margin for external loads from nozzle, wind and seismic events. This margin is provided by, or is available upon request from the manufacturer. As an alternative, the purchaser may supply the manufacturer with the external loadings for the manufacturer's support design.

Wind and seismic loads will not be assumed to occur simultaneously.

Support details are described in Chapter 4 of these Standards.

3.9.2 Lifting Devices

Lifting lugs/devices shall be designed using one of the following methods:

(1) The purchaser shall inform the manufacturer of the way in which he plans to lift and move the heat exchanger,

(2) The manufacturer shall advise the purchaser of the approved method for lifting and moving the heat exchanger.

In either case, the manufacturer will adequately design a suitable device, or provide lifting lugs or equivalent on the heat exchanger, to safely lift and transport the heat exchanger into its installed position.

The manufacturer shall advise the purchaser of the proper use of the lifting device and lugs. If these do not exist, it is possible, with prior approval from the manufacturer, to lift the heat exchanger with belts or ropes, if attention is fully paid to suitable protection of the heat exchanger corners.

3.10 NONCONFORMITY RECTIFICATION

3.10.1 Introduction

Rectification work on a brazed plate-fin heat exchanger block is necessary if a nonconformity occurs during the manufacturing process. This section describes procedures and purchaser notifications to resolve a nonconformity.

The manufacturer judges the severity of the nonconformity and reviews contractual requirements in determining the involvement of the purchaser in deciding disposition.

Unless there are contractual requirements to the contrary, the following procedures are followed in performing nonconformity rectification.

3.10.2 Procedures and Documentation

All rectification work shall be carried out according to approved procedures based on sound engineering principles. All rectification must conform to code requirements, will assure leak integrity and not affect the structural integrity of the heat exchanger. The manufacturer will fully maintain the agreed mechanical guarantee.

A nonconformity record document shall be completed by the manufacturer and be available for the purchaser on request.

3.10.3 Side-bar-to-Sheet Joint Leak Rectification

A brazed aluminium plate-fin heat exchanger typically contains more than 1600 lineal metres of brazed, side-bar joints. Based on a very controlled brazing process the overall structural and leak integrity of the side-bar to parting sheet joint is excellent. However, due to the large number of potential leak sites, small leaks in the side-bar-to-sheet joint can sometimes occur.

Rectification is by seal welding using a proven procedure developed for this purpose.

External leaks at the brazed connection between side bars and parting sheets may be seal welded without notification of the purchaser.

3.10.4 Blocking of Layers

A typical brazed aluminium plate-fin heat exchanger contains more than a half million lineal metres of braze joints between fins and parting sheets, produced by the brazing process in excellent quality. However, due to manufacturing variation over the large number of fin-to-sheet braze sites, a small area of unacceptable brazing may occasionally occur within a layer and is detected by the pressure test.

Rectification is typically to block the layer using a proven procedure developed for this purpose. Blocking of an active layer requires notification of the purchaser.

The manufacturer shall perform calculations to estimate the influence of the blocked layer(s) on thermal performance and pressure drop for any exchanger designed by the manufacturer

3.10.5 Other Rectification Work

The purchaser will be notified and involved in any disposition decision if the rectification has impact on the performance guarantee or installation of the unit.

4 INSTALLATION, OPERATION AND MAINTENANCE

4.1 GENERAL

It is normal for brazed aluminium plate-fin heat exchangers to be installed in the vertical attitude, warm end up. There are, however, some exceptions to this such as reversing heat exchangers for air separation or cross flow sub-coolers. Heat exchangers are normally supplied with all the necessary supports to facilitate site installation.

Generally, mounting supports are, if possible, positioned in the warm half of the block. This reduces movement at the juncture of the bracket to the support beam during start-up and shut-down cycles.

In addition to the main supports, there may be a need for an additional sliding guide to restrict movement from the vertical plane. Several aspects need to be considered to determine if such a device is necessary, for example:

- Physical dimensions of the heat exchanger
- Weight of the heat exchanger
- Site conditions (earthquake, wind, pipeload etc.)
- Relative position of the main support plane to the centre of gravity of the heat exchanger.

Upon request, the manufacturer will provide values for the allowable forces and moments which may be applied at the junctions of the header tank to nozzle of the heat exchanger. The Purchaser should then ensure that these values are not exceeded for all connecting pipe runs (refer to Section 5.12.2.4 and Table 5-1 for typical values).

If the connecting pipe joints between the heat exchanger and the purchaser's pipework are to be made by means of welding, then this must be done using the relevant qualified weld procedures and welders. The weld filler materials used must be those approved for welding the materials to be joined. Details of the nozzle material are normally marked on the heat exchanger nozzles as well as being stated on the relevant drawing. The manufacturer should be asked if the installer has any doubts on this matter.

4.2 LIFTING AND HANDLING

Extreme care should be taken in the lifting and handling of brazed aluminium plate-fin heat exchangers. The manufacturer will ensure that a heat exchanger is provided with the means of lifting, e.g. lifting lugs, lifting attachments, specified nozzles, etc. The manufacturer will provide detailed instructions for lifting and handling; these instructions will be specific to each heat exchanger and must be strictly followed. If there are any doubts about lifting and handling of any heat exchanger, the manufacturer should be consulted.

WARNING: FAILURE TO FOLLOW THE MANUFACTURER'S LIFTING AND HANDLING INSTRUCTIONS FOR A SPECIFIC HEAT EXCHANGER COULD SERIOUSLY DAMAGE THE EXCHANGER.

4.3 SUPPORT BEAMS

The beams onto which the heat exchanger is to be mounted, unless within the scope of supply, are the responsibility of the purchaser. In the selection of these beams, in addition to the dead weight imposed by the heat exchanger, loads generated by applied external forces and moments should also be considered. It is a common practice in this evaluation to assume that the allowable forces and moments given in the manufacturer's design documents are not applied simultaneously. The mating faces of the support beam should be flat and be aligned so that, when installed, the deviation of the unit to the true vertical is a maximum of ½° or 15 mm measured over the block length. The alignment may be achieved with the aid of metal shims, but this is not preferred. For light applications the support beams may be manufactured from aluminium, however, it is normal for the beams to be made from the appropriate steel alloy.

4.3.1 Support Insulation

To prevent heat leakage, thermal insulation is required between the mating faces of the supports. The heat-break insulating material (for example Micarta*) must be capable of load bearing and allow movement on the support. The thickness of heat-break should be selected by the manufacturer depending on the operating conditions. If the heat exchanger is mounted in a cold box, a proportion of the required total thickness of heat-break may be fitted at the junction of the support beam and cold box, in addition to the mating face between the heat exchanger support and the support beam.

4.4 SLIDING GUIDE FRAME

For applications where externally applied forces due to wind, earthquake and pipeloads are large enough to cause lateral movement, it is necessary to limit horizontal movement of the heat exchanger.

The function of the sliding guide is to limit the horizontal movement. Details of typical support systems and guides are shown in Figure 4-1, Figure 4-2 and Figure 4-3. The guide frame should be separated from the heat exchanger with layers of heat-break material. To compensate for core contraction in service, the break must be tightly packed and fixed to the guide frame with stainless steel screws to prevent it from becoming detached. An additional wear plate (scuff plate) may be fitted to the heat exchanger for protection. The interface members of the frame should be made from the appropriate steel alloy and braced back to the main structural members of the cold box or support frame to give stability.

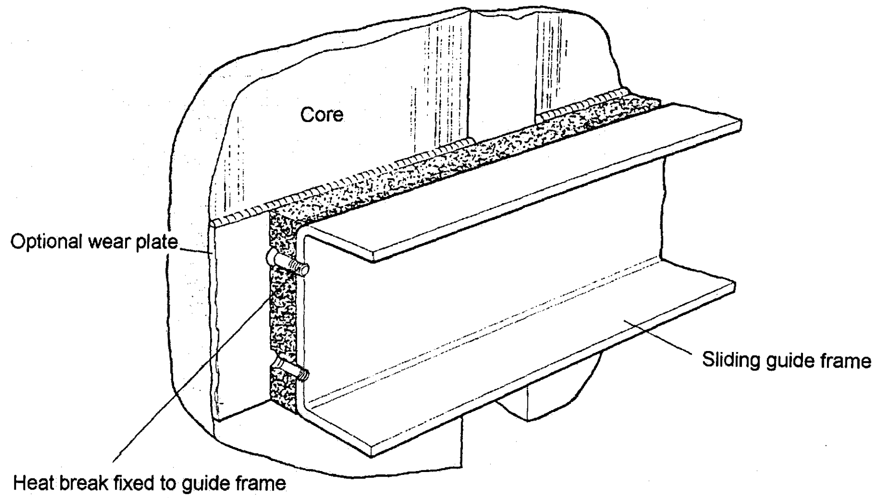


Figure 4-1: Typical Sliding Guide Frame

* Trade name

Figure 4-2 shows a typical assembly of three heat exchangers with a Shear Plate Support Arrangement. The heat exchangers are supported at the upper warm end and guided at the lower cold end.

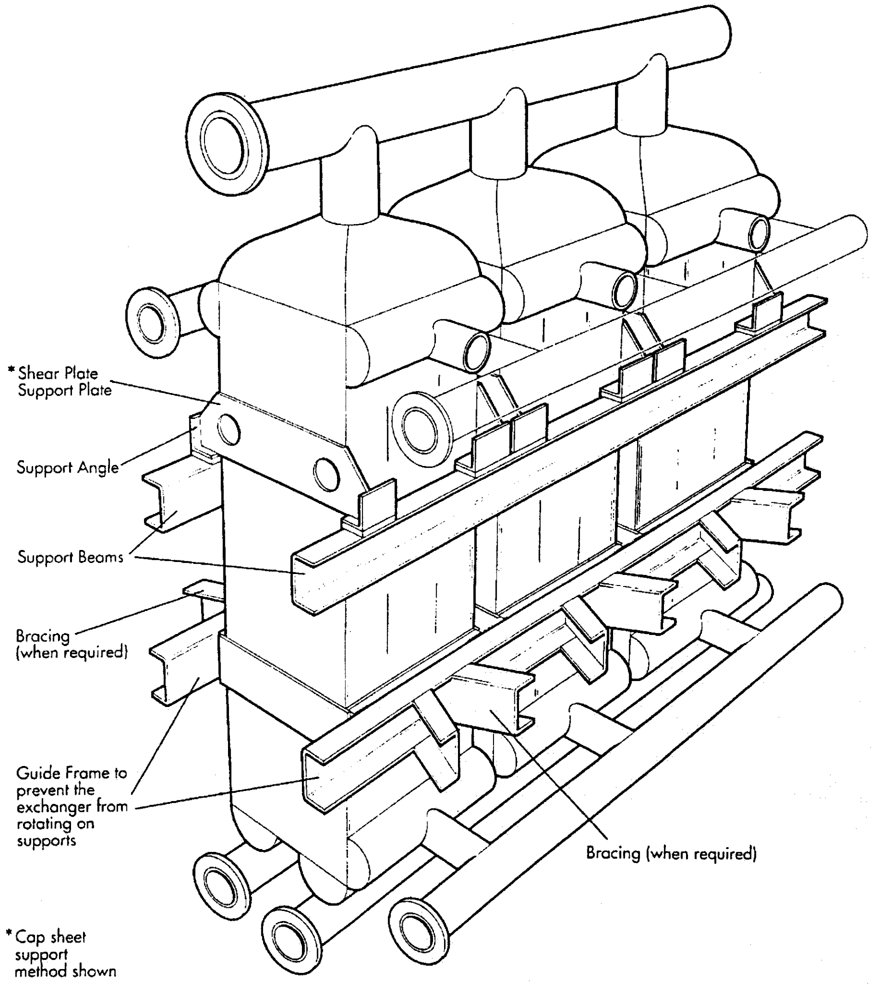


Figure 4-2: Typical Heat Exchanger Assembly of Three Cores Showing Shear Plate Supports

Figure 4-3 shows a typical assembly of three heat exchangers with an Angle Bracket Support Arrangement. The heat exchangers are supported from angle brackets welded onto the side-bar faces.

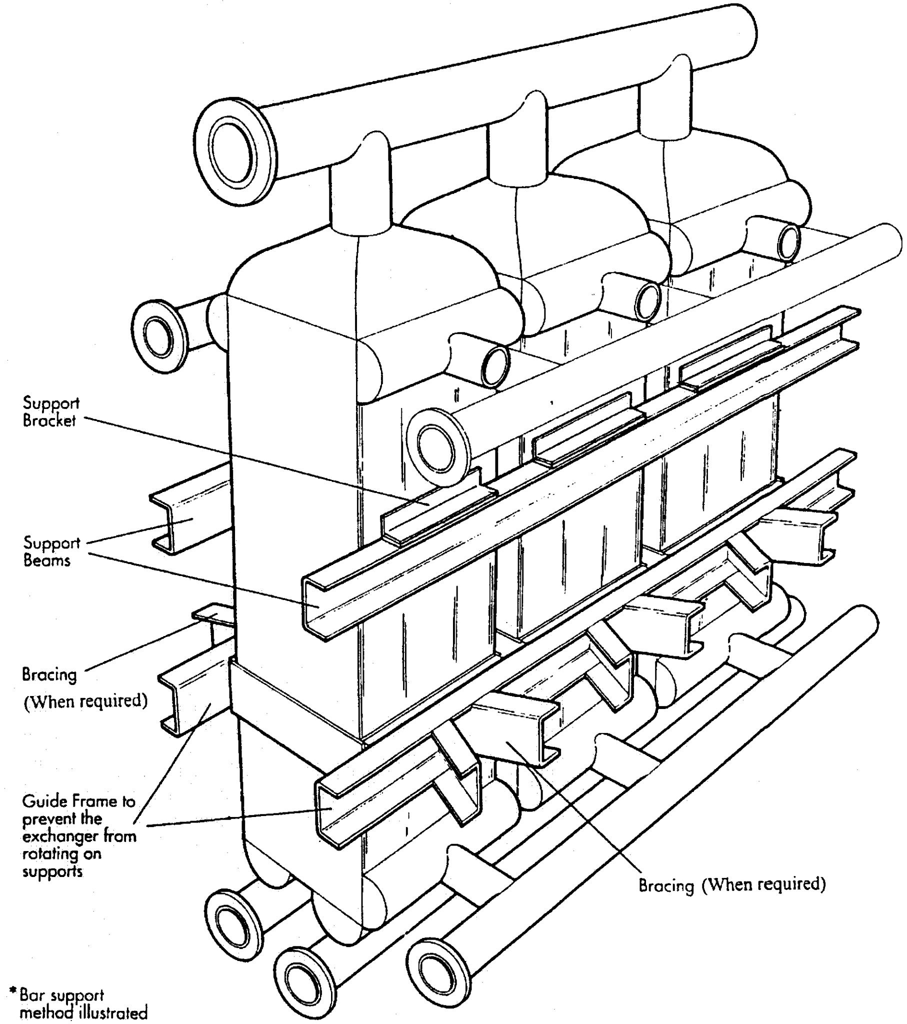


Figure 4-3: Typical Heat Exchanger Assembly of Three Cores Showing Angle Bracket Supports

4.5 FIXING (MOUNTING) BOLTS

There are several methods employed for locating heat exchangers on supports; a mounting bolt system is typical.

The object of the mounting bolt is to keep the heat exchanger in contact with the mounting beam. It is NOT to fix the heat exchanger rigidly, because a rigid attachment will lead to very high moments and forces being applied at the supports when the heat exchanger contracts or expands during start-up.

Manufacturers recommend a mounting assembly that allows differential contraction of the supports on the heat exchanger and the support beams.

A typical method of using mounting bolts is shown in Figure 4-5. With this method a stainless steel tube some 0.5 mm longer than the combined thickness of the support components is used to prevent rigid locking when the mounting bolt nut is tightened.

Alternatively, the mounting bolt nuts can be installed "finger-tight" to prevent rigid locking and the stainless steel sleeve omitted. However, the bolts should be installed "head-up" to avoid detachment should the nuts work loose and it is recommended that lock nuts or thread locks be used.

Typically, four mounting bolts per heat exchanger are employed, one at each corner. These should be manufactured from stainless steel, although for light applications an appropriate aluminium alloy may be used.

During start-up, the heat exchanger will contract or expand on the mounting beam in both horizontal directions.

WARNING: THE NECESSARY AMOUNT OF CLEARANCE MUST BE ALLOWED BETWEEN THE INSERT TUBE (OR BOLT ONLY WHEN USED) AND THE SUPPORT COMPONENTS.

The necessary clearance to take account of the expected thermal movement may be calculated from the following expression for both horizontal directions:

$$X = \alpha_\ell \Delta T_R s$$

Where:

- X : Required clearance distance (mm)
- α_ℓ : Coefficient of linear expansion at the average temperature between ambient and operating temperatures (m/m K) (from Figure 4-4)
- ΔT_R : Temperature range at support = difference between operating temperature and ambient temperature (K)
- s : Distance between the extreme bolts in a given plane (mm).

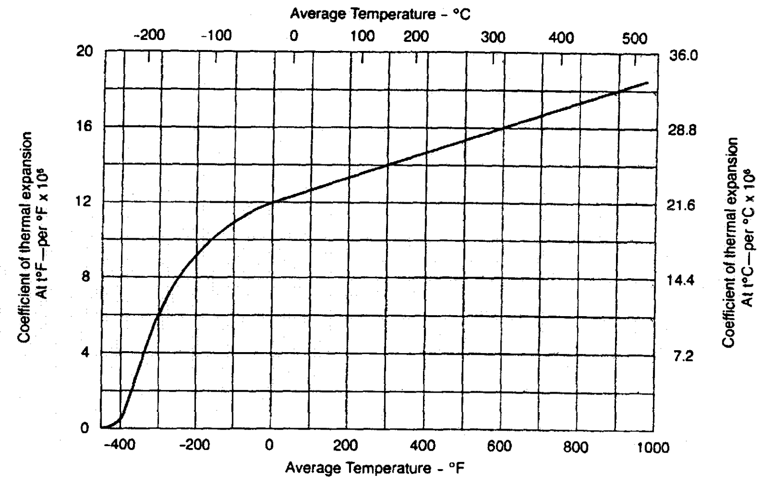


Figure 4-4: Coefficient of Thermal Expansion of Aluminium

For estimated clearances of up to 4 mm, clearance may be achieved by drilling the mounting hole in the support bracket oversize. For larger clearances, the support bracket must be slotted in the direction of the movement. For larger two-directional movements, clearance is maintained by slotting both support bracket and support beam, with the slots being positioned at 90° to each other.

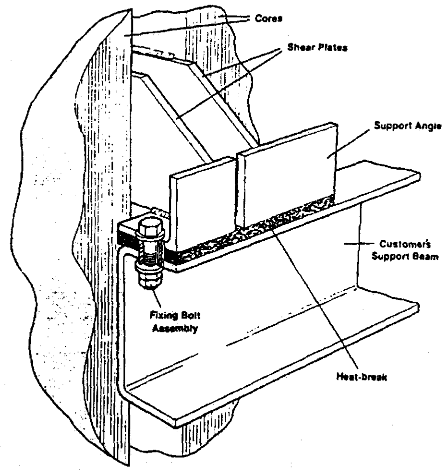


Figure 4-5: Typical Shear Plate Bolt Assembly

4.6 VENTING OF DUMMY/INACTIVE AREAS

Many brazed aluminium plate-fin heat exchangers contain void or inactive areas.

Typical examples of these inactive areas are:

1) Inactive or dummy layers on the top or bottom of the heat exchanger stack.
2) The space formed between two tandem streams having adjacent side headers.
3) The dead corner of an end distributor employing the slant bar drainability feature.
4) The modular space formed by welding together two heat exchanger blocks.
5) Other special features.

The presence of inactive areas is indicated by a note on the drawing; the positioning of open areas require that they are drainable.

Manufacturers take precautions to dry and seal the inactive areas prior to shipment.

WARNING: FOLLOWING INSTALLATION AND PRIOR TO SITE TESTING AND OPERATION, THE SHIPPING SEALS COVERING THE INACTIVE AREAS MUST BE REMOVED AND REPLACED WITH EITHER A VENT PLUG OR MONITORING VENT LINE, ETC., AS INSTRUCTED BY THE MANUFACTURER.

4.7 FIELD TESTING

4.7.1 Non-Destructive Testing

Manufacturers recommend the following non-destructive testing of the connecting pipework welds to be carried out to maintain an acceptable quality level.

1. A visual inspection of all connecting pipework root welds.
2. A liquid penetrant examination of all connecting pipework and cap welds.
3. A radiographic examination of a minimum of 10% of all closing butt welds. Representative samples of each welder's work should be examined.

The test procedures and acceptance criteria shall be in accordance with the relevant governing code authority.

4.7.2 Proof Pressure Testing

Most governing jurisdictions require a pressure test of the piping system after a heat exchanger is installed. The test shall meet the requirements of the relevant code authority with the following additional considerations fully taken into account.

It is highly recommended that a pressure test is NOT conducted with water as the test medium. Water removal after the heat exchanger is installed is difficult and residual water trapped within the heat exchanger can freeze during unit operation causing serious damage and lead to premature failure of the heat exchanger.

WARNING: SPECIAL PRECAUTIONS MUST BE TAKEN IF THE HEAT EXCHANGER IS TO BE PNEUMATICALLY TESTED. PNEUMATIC TESTING CAN BE HIGHLY DANGEROUS IF NOT CARRIED OUT BY FOLLOWING THE RELEVANT LOCALLY APPROVED PROCEDURES.

Each stream of the heat exchanger system must be tested individually, with the other streams unpressurised. Oxygen-free nitrogen of dewpoint -40°C or better should be used as the test medium.

WARNING: THE TEST PRESSURE MUST BE IN ACCORDANCE WITH THE LOCAL CODE REGULATIONS BUT SHOULD NOT UNDER ANY CIRCUMSTANCES EXCEED THE PROOF TEST PRESSURE OF THE HEAT EXCHANGER.

On completion of the proof test for the heat exchangers tested at values above the design pressure, each stream is firstly to be de-pressurised down to its design or operating pressure and a soap bubble leak test carried out on all pipe weld connections. For heat exchangers proof tested at the design pressure or less, the leak test is to be carried out at the operating pressure.

The evaluation of the proof pressure test must take into account any variation in ambient temperature from commencement of the pressure hold period to its completion. For the test pressure to have been satisfactorily held over this period, the final pressure can be calculated from:

$$\text{Final Pressure Reading} = \text{Initial Pressure Reading} \times \frac{\text{Final Ambient Absolute Temperature}}{\text{Initial Ambient Absolute Temperature}}$$

4.8 INSULATION

On completion of all field testing the heat exchanger will require to be insulated.

For heat exchangers mounted within a cold box the minimum insulated distance, in mm, between the heat exchanger and cold box wall is taken from Figure 4-6. The void space between the heat exchanger and wall must be packed with insulant. This may be either expanded perlite or rockwool. For perlite a density in the range of 60 to 80 kg/m^3 is normally used. When packing with rockwool care must be taken to avoid damage to the heat exchanger's connections. Prior to start-up, a continuous dry oxygen-free nitrogen purge is to be connected to the cold box.

For stanchion (pedestal) or frame mounted heat exchangers, the minimum thickness of insulation is also to be taken from Figure 4-6. The insulation used for this type of heat exchanger is usually of the spray-on polyurethane foam type. After application of the insulant, the heat exchanger must be sealed with a weatherproof jacket.

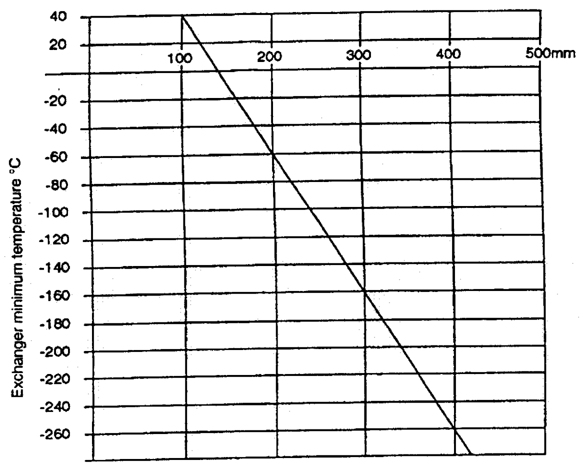


Figure 4-6: Recommended Minimum Insulation Thickness (mm).

4.9 OPERATION

4.9.1 Heat Exchanger Start-up

WARNING: TO ENSURE SAFE OPERATION EACH STREAM OF THE HEAT EXCHANGER MUST BE PROTECTED WITH A PRESSURE RELIEF DEVICE. IT IS THE RESPONSIBILITY OF THE USER TO PROVIDE AND ENSURE PROPER INSTALLATION OF THE PRESSURE RELIEF DEVICES. THE RELIEF PRESSURES SHALL BE SET NO HIGHER THAN THE MAXIMUM ALLOWABLE WORKING PRESSURE OF THE STREAMS, CONSIDERING BOTH THE HEAT EXCHANGER AND THE CONNECTING PIPING.

Prior to start-up, internals of the connecting pipework and vessels system must be thoroughly cleansed of all particulate matter such as rust, scale, grit or sand. The system should then be purged using oxygen-free nitrogen (dewpoint of -40°C or less). The objective of this purge is to remove any residual moisture and hydrocarbons, the presence of which could result in freeze damage to the heat exchanger during operation. Duration of the purge should range from 4 hours to about 24 hours depending on size, complexity and physical state of the heat exchanger system. The purge exit should be monitored until consistent readings of moisture content of less than 10 ppm are obtained and no trace of hydrocarbons is evident.

Cool-down of the heat exchanger is only permitted using gas (i.e. no liquid phase present). Cool-down should be carefully controlled to avoid thermal shocking of the heat exchanger and pipework. A rate of 2°C per minute maximum is normally recommended to allow for gradual dimensional adjustments but the manufacturer should be consulted if this rate is likely to be exceeded. With agreement of the manufacturer rates in excess of 2°C have been approved for certain heat exchanger applications. The cooling medium (gas) should be introduced to all streams simultaneously to prevent local thermal stresses developing. The medium when introduced to the system should not have a temperature difference greater than 30°C relative to the local metal temperature.

A record of all relevant data should be kept for each individual start-up. This will be required in the event of problems developing later in the life of the heat exchanger.

WARNING: THE MAXIMUM OPERATING PRESSURE FOR THE DESIGN OR WORKING TEMPERATURE SHOWN ON THE HEAT EXCHANGER'S NAMEPLATE AND THE MANUFACTURER'S DRAWINGS MUST NOT BE EXCEEDED.

4.9.2 Normal Operation

If all the recommended procedures have been followed, then the heat exchanger will give many years of trouble-free service.

Some industrial pollutants, notably mercury, sulphur dioxide, chlorine, nitrogen oxides, etc., can be extremely harmful and corrosive to aluminium. It is therefore advisable that reference be made to Chapter 8 on Recommended Good Practice on operation with potentially corrosive streams.

To prevent particulate matter from entering the heat exchanger, the heat exchanger system should be operated with mesh filters at the stream inlets. A valved bypass system should be considered to permit cleaning of filters without having to shut down. As a minimum, filtration should remove particles larger than 0.18 mm diameter (80 Mesh Tyler Standard).

All process fluids entering the heat exchanger should be in steady flow state. Pulsing or surging from pumps or compressors must be avoided, and the manufacturer should be consulted about permissible limits.

To prevent over-pressurisation, it is the user's responsibility to install sufficient and suitable pressure-relieving devices into each stream. The relief setting of the devices must not be greater than the stated maximum allowable working pressure. Relief settings and relief capacities must comply with the relevant governing code.

4.9.3 Shut-down

The cautions applicable to start-up in Section 4.9.1 also apply to shut-down. In particular, to prevent thermal shocking, warm-up should be accomplished slowly at no more than the recommended rate of 2° C per minute measured at a suitable location on the heat exchanger. As with start-up the manufacturer should be consulted if this rate is likely to be exceeded.

4.9.3.1 Warming Up

Warming up shall be performed with gas and only after all liquid has been drained from the heat exchanger.

On attainment of ambient temperature the heat exchanger is to be purged with oxygen free nitrogen of dewpoint -40°C or less. When a sterile internal atmosphere has been achieved then the heat exchanger should be blanked off using blind flanges. If the shut-down is to continue for any length of time, the streams should be pressurised with dry nitrogen to a pressure of 0.2 to 1.2 bar g.

4.10 MAINTENANCE

Other than the directives and recommendations outlined, no routine maintenance should be required. A log of all plant operational events which might affect the heat exchanger should be kept. The log should record details of all start-ups, shut-downs and any plant malfunctions together with any available routine operational data.

Problems with brazed aluminium plate-fin heat exchangers are rare. However, if problems develop, advice should be sought from the manufacturer. Rectification of problems should not be attempted without prior consultation with the manufacturer.

Extra care is required when investigating problems associated with heat exchangers installed in cold boxes:

The nitrogen purge for the cold box must be disconnected.

WARNING: PERSONNEL MUST NOT BE ALLOWED INTO THE COLD BOX UNTIL THE UNIFORM LEVEL OF OXYGEN IN THE BOX ATMOSPHERE HAS REACHED A MINIMUM OF 19% BY VOLUME.

A continuous alarm type monitor of the oxygen level in the cold box should be kept. The monitor should be checked at regular intervals of one hour by a second monitor. All monitoring should be at face level of working personnel.

If only part of the box insulation is to be removed to effect access to the heat exchanger, the working cavity so formed must be secured with scaffolding and planking to prevent the residual insulant from collapsing. If welding is to take place, the cavity should be lined with polyethylene sheeting or similar material.

WARNING: FOR PERSONNEL SAFETY, COLD BOXES INSULATED WITH PERLITE SHOULD BE COMPLETELY EMPTIED PRIOR TO PERMITTING PERSONNEL ACCESS INTO THE COLD BOX.

WARNING: COLD NITROGEN GAS CAN ACCUMULATE AT GROUND LEVEL AND HAVE FATAL RESULTS THROUGH ASPHYXIATION.

4.11 LEAK DETECTION

4.11.1 Introduction

External leaks will be evident by the appearance of localised freeze spots or vapour cloud on the outer casing of the insulation. In the case of heat exchangers installed in a cold box, an increase in or contamination of the purge gas flowing out of the cold box purge valve will be evident. The smell or sound of the escaping fluid may also be discernible.

Internal leaks can manifest themselves in the reduction of product purity and, if the leak is of sufficient magnitude, a redistribution of flow levels will occur between affected streams.

When a leak is suspected, it should be investigated fully and immediately and the manufacturer's repair procedure be put in action as soon as practicable, in the case of leakage where harmful substances are present immediate action is necessary.

WARNING: FAILURE TO RECTIFY LEAKING UNITS MAY RESULT IN PERSONNEL INJURY AND/OR SERIOUS DAMAGE TO THE UNIT AND COMPROMISE THE SAFETY OF THE PLANT.

To establish the existence of a leak the following procedures may be applied.

4.11.2 Site leak Detection Pressure Test

Prior to any site work taking place, all streams must be purged with either dry oxygen-free nitrogen or dry air. A gas analysis should be performed to ensure that any harmful gas residues are completely removed from the system. In the case of work being carried out within a Cold Box, the oxygen concentration within the Cold Box has to be controlled continually with good venting of the box maintained through openings on the top and bottom.

Each of the unit streams is isolated using blind blanking flanges fitted with suitable pressure gauges. In turn and on an individual basis each stream is pressurised; initially the test pressure should be set at a maximum of say 5 bar g since the majority of leaks will be detected at low pressure. Further tests at higher pressures may be necessary depending on the type of leak but the test pressure should not exceed the operating pressure of the stream being tested. The test should be carried out with either dry oxygen-free nitrogen or dry air. The pressure is held for a period of ten to twelve hours. If after this time the pressure level has decayed, and the amount of the decay was not caused by temperature changes, the presence of a leak has been established. The holding time will depend on the sensitivity of the pressure gauges and the volume of the streams on test. A coinciding rise in pressure of any of the adjacent isolated streams is indicative of an internal inter-stream leak. All streams must be fitted with a pressure relief systems to prevent over-pressurisation.

A check is to be carried out to ensure that no mechanical joints are leaking.

If no subsequent rise in adjacent stream pressure is evident then the leak is to the external.

Throughout this procedure the safety aspects covered in the Proof Pressure testing section 4.7.2 of this standard **MUST** be rigidly adhered to.

WARNING: PRECAUTIONS MUST BE TAKEN TO ENSURE THAT LEAKS HAVE NOT CREATED A COMBUSTIBLE SITUATION OR DISPLACED OXYGEN IN ENCLOSED SPACES.

WARNING: SPECIAL PRECAUTIONS MUST BE TAKEN IF THE HEAT EXCHANGER IS TO BE PNEUMATICALLY TESTED. PNEUMATIC TESTING CAN BE HIGHLY DANGEROUS IF NOT CARRIED OUT BY FOLLOWING THE RELEVANT LOCALLY APPROVED PROCEDURES.

All pressures recorded must be adjusted in accordance with the method described in the above proof testing section 4.7.2, to compensate for ambient temperature differences over the duration of the test.

To locate external leaks the soap bubble test described in the proof pressure testing section 4.7.2 of this standard is repeated.

4.11.3 Site Helium Leak Detection Test

The helium leak test may be used to locate the harder to find leaks, both internal and external. However, whilst helium leak testing is a valid testing procedure, especially when dealing with high purity applications, carrying out such tests and interpreting the results on site can be impractical. Highly trained personnel using specialised equipment must therefore only carry out such helium tests.

4.12 REPAIR OF LEAKS

Detected external leaks such as cracked pipe welds etc may be repaired by re-welding using an approved weld procedure and by a qualified aluminium alloy welder.

4.12.1 Repair of Leaks to the Brazed Aluminium Plate-Fin Heat Exchanger

Should the need arise to locate and repair a leak associated with the brazed aluminium plate-fin heat exchanger then this should be discussed with the manufacturer.

Dependent on the type of leak, the location of the leak, accessibility in the plant, together with other criteria, such as climatic conditions at site, a recommendation will be given by the manufacturer on how, where and when a repair should be carried out. The repair of internal and external leaks involving work on the brazed structure of the heat exchanger requires specialised knowledge and repair techniques. These repairs should not be attempted without prior consultation with the manufacturer. It is strongly recommended that any such repairs be carried out only by the manufacturers or a recognised specialist repair team who have at their disposal all necessary backup and equipment to effect such repairs.

As previously detailed under section 3.10, repair or rectification can be carried out during the manufacture of the heat exchanger; this is recognised to be a normal and acceptable practise in the industry. These same repair-welding techniques can be employed to repair a heat exchanger in the field, and when carried out by an approved specialist repair team the mechanical integrity of the heat exchanger should not be affected.

5 MECHANICAL STANDARDS

5.1 SCOPE

These Standards apply to all vacuum-brazed aluminium plate-fin heat exchangers.

In theory, there is no limit to the size of a brazed aluminium plate-fin heat exchanger core since the internal pressure forces are resisted by the internal structure (fins, sheets).

However, the wall-thickness and diameter of the headers, nozzles and piping connections for a given internal pressure will limit the practical size of the heat exchanger core.

5.2 DEFINITION OF A BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGER

A brazed aluminium plate-fin heat exchanger is an arrangement of a succession of layers, each being designed for heat exchange duties, flow characteristics and pressure, specific to given process conditions.

All the layers carrying the same stream are connected together by headers (inlet, outlet, intermediate) directly attached by welding onto the brazed core, as illustrated in Figure 1-2 of Chapter 1.

5.3 CODES FOR CONSTRUCTION

The design, construction and testing of brazed aluminium plate-fin heat exchangers are governed by the existing national rules applying to pressure vessels.

The design of a heat exchanger is the result of the mechanical strength analysis of:

- the plate-fin structure under pressure
- the influence of headers on the plate-fin structure
- the header/nozzle assembly

Specific details regarding the design of the individual components are given in Section 5.15.

Brazed aluminium plate-fin heat exchangers are commonly designed under the provisions of the existing codes, typically:

ASME VIII, Div. 1
AD-Merkblätter
CODAP
Japanese HPGS Law
AS 1210
Raccolta
Dutch Pressure Vessel Code
Swedish Pressure Vessel Code

5.4 TYPICAL MATERIALS OF CONSTRUCTION

Typical materials for use on the construction of brazed aluminium plate-fin heat exchangers are:

Core matrix (fins, plates, side bars)	3003 aluminium alloy (AlMnCu)
Headers/nozzles	5083 aluminium alloy (AlMg4,5Mn)

For a more comprehensive set of materials refer to Chapter 6.

5.5 DESIGN PRESSURES

A brazed aluminium plate-fin heat exchanger is a pressure vessel consisting of more than one independent pressure chamber, operating at the same or different pressures. It shall be designed to withstand the most severe condition of coincident pressures expected in service.

Design pressures for each individual stream shall be specified by the purchaser.

The purchaser shall also indicate the design pressure of the environment around the heat exchanger, in case it is to be installed inside a pressure vessel. In this case, the heat exchanger shall be designed to withstand the internal pressure forces independently from the external compression forces.

The purchaser shall also state if the heat exchanger is to be vacuum insulated (i.e. installed in a vacuum vessel) and the purchaser shall determine the design pressures of streams accordingly.

5.6 TESTING

5.6.1 Pressure Test

The brazed aluminium plate-fin heat exchanger must be pressure tested in accordance with the applicable design code. This may be carried out by either of the following methods:

5.6.1.1 Hydrostatic test

The heat exchanger is hydrostatically tested with water. Each individual chamber is to be pressurised up to its test pressure.

The minimum hydrostatic test pressure at room temperature shall be 1.3 times the design pressure, except where Code requirements rule otherwise.

5.6.1.2 Pneumatic test

The heat exchanger is subjected to a pneumatic test, where each individual chamber is pressurised up to its test pressure.

WARNING: A PNEUMATIC TEST MAY ONLY BE PERFORMED PROVIDED THE RULES OF SAFETY FOR SUCH PNEUMATIC TESTING ARE ADHERED TO.

The pneumatic test pressure shall be in accordance with Code requirements.

5.6.2 Leak Test

In order to ascertain the absence of leak from one chamber towards any other chamber or into the atmosphere, a leak test is necessary. The extent-of-leak testing as well as the allowable leakage rates have to be agreed upon between purchaser and manufacturer.

The leak test may be carried out by either, or a combination, of the methods listed below (5.6.2.1 and 5.6.2.2).

5.6.2.1 Air test

All chambers shall be tested for external and interstream (chamber to chamber) leakage. The test pressure, applied to one chamber only, is typically the design pressure for each individual chamber.

WARNING: AN AIR TEST MAY ONLY BE PERFORMED AFTER AND IF THE PRESSURE TEST DESCRIBED UNDER SECTION 5.6.1 HAS BEEN CARRIED OUT.

5.6.2.2 Helium test

The following test methods may be used:

- *External leak test*: helium vacuum test under non-metallic cover for checking the leak-tightness of the exchanger to the atmosphere.

All chambers of the heat exchanger are evacuated and directly connected with the gas detector. The heat exchanger is sealed within a non-metallic cover and the space between cover and exchanger is filled with helium.

Standard allowable leak rate 1 x 10^{-3} mbar litre/s (at pressure difference = 1 bar).

Interstream leak test: helium test for checking the leak-tightness between those chambers selected by the purchaser and the manufacturer.

Helium is successively admitted to the test chamber. The other chambers are evacuated and connected to the gas detector. Starting with the chamber with the highest operating pressure each chamber is tested for leaks into the other chambers

The standard allowable leak rate is 1 x 10^{-2} mbar litre/s (at pressure difference = design pressure) or 1 x 10^{-3} mbar litre /s (at pressure difference = 1 bar).

A helium test may only be performed after and if the pressure test described under section 5.6.1 has been carried out.

5.7 METAL TEMPERATURE LIMITATIONS

5.7.1 Metal Temperature Limitations

The metal temperature limitations for the typical materials used are those prescribed by the codes.

ALLOY	ASME	AD-MERKBLÄTT/VdTüV
3003	-269 / +204°C	-270 / +65°C
5083	-269 / +65°C	-270 / +80°C

Refer to Chapter 6 for further information.

5.7.2 Design Temperature

All aluminium alloys have advantageous behaviour at low temperatures, i.e. the values of rupture strength and yield strength increase as temperature decreases. Therefore, only the maximum design temperatures are of importance for aluminium alloys.

Higher temperatures may be allowed for short periods and reduced pressures (e.g. for deriming purposes); manufacturers should be consulted for details.

5.8 PERMISSIBLE TEMPERATURE DIFFERENCES BETWEEN ADJACENT STREAMS

Due to the nature of aluminium plate-fin heat exchangers which are produced by brazing, all internal components are metallurgically bonded to each other. The simultaneous presence of streams at different temperatures will produce contraction/expansion of the parts subjected to temperature, leading to thermal internal stresses.

The thermal stresses developed must remain within the acceptable limits for the material used. It is generally accepted that, for a typical geometry of a brazed aluminium plate-fin heat exchanger under steady state conditions, the maximum permissible temperature difference between streams is approximately 50°C.

However in more severe cases such as two-phase flows, transient and/or cyclic conditions, this temperature difference should be lower, typically 20 - 30°C.

For details, reference should be made to Chapter 8, Section 8.1, regarding thermal shock/ temperature differences.

There are two methods for reducing the temperature difference:

- either modify the process conditions (modifying the flow rate, installing a by-pass line, etc.) to reduce the imposed temperature difference to acceptable limits, or,

where applicable, design the heat exchanger to reduce the stresses, generally by absorbing the imposed temperature difference in a modified structure.

5.9 CORROSION ALLOWANCES

Brazed aluminium plate-fin heat exchangers are designed for operation with non-corrosive fluids.

There is no allowance for corrosion.

5.10 SERVICE LIMITATIONS

The service limitations of brazed aluminium plate-fin heat exchangers are described in Chapter 1, Section 1.1.2.

5.11 STANDARD SIZES

5.11.1 Parting Sheets

Standard parting sheet thicknesses typically vary between 0.8 mm and 2.0 mm and are selected by the manufacturer mainly according to the design pressures.

Parting sheets are normally clad on both sides with a brazing alloy. However, unclad parting sheets are available, where brazing is performed using brazing foils.

5.11.2 Cap Sheets

Standard cap sheet thicknesses are typically 5 and 6 mm. However, thicknesses from 2 mm to 10 mm are also used for special applications.

5.11.3 Side Bars

Side-bar heights are the same as the fin heights.

Side-bar width is selected by the manufacturer according to the design pressure and typically varies between 10 mm and 25 mm. Manufacturers use different shapes of side bars for manufacturing reasons.

5.11.4 Fins

Typically, fin height, thickness and density, vary within the following limits:

Fin height 3.8 mm to 12 mm

Fin thickness 0.15 mm to 0.61 mm

Fin pitch 1.15 mm to 4.5 mm (22 fpi to 6 fpi)

Not every manufacturer will use the whole range of these dimensions. In addition, as a result of the restrictions of manufacturing tools, not every combination of fin dimensions can be produced, e.g. large thickness with many fins per inch (fpi) may be excluded.

5.12 HEADERS AND NOZZLES

5.12.1 Headers

Headers are fabricated from half cylinders with welded end caps. Some typical configurations are shown in Chapter 1, Figure 1-4. Headers are usually made either from standard pipe sizes or formed from plates.

At elevated design pressures, the resulting required wall thickness of large diameter headers may exceed a reasonable or producable value. In that case, the use of multiple headers of smaller diameter is common practice.

The use of reinforcing pads around nozzles, common on conventional cylindrical pressure vessels, has limited application to headers as a result of the restricted distance from the block surface to the nozzle.

5.12.2 Nozzles

5.12.2.1 Nozzle construction

Nozzles are normally welded into the cylindrical part of the headers. Radial nozzles are considered as standard; other installations may be used (see Chapter 1, Figure 1-5).

Generally nozzles are selected from commercial seamless standard pipes. Large and special sized nozzles may be made from welded pipes or formed plates.

If the nozzle diameter is to be limited and acceptable flow velocities are to be maintained, several nozzles may be welded into one common header.

5.12.2.2 Flow velocities in nozzles

To prevent or reduce the risk of erosion of aluminium parts in the heat exchanger entrance and exit areas, velocity limits similar to other types of heat exchangers must be considered.

5.12.2.3 Nozzle installation

Nozzles shall be installed to ensure draining of the individual pressure chambers, as far as possible.

Additional drain connections to the header or connecting pipe (min. ¾" NPS) may be required.

Similar considerations apply to venting.

5.12.2.4 Nozzle loadings

The associated piping can impose forces and moments on the heat exchanger nozzles. Manufacturers will specify maximum allowable forces and moments, under the provision that these loads are not applied simultaneously.

These resultant forces, F_r, and moments, M_r, are defined by:

$$M_r = \sqrt{M_x^2 + M_y^2 + M_z^2}$$

$$F_r = \sqrt{F_x^2 + F_y^2 + F_z^2}$$

The three reference axes are shown in Figure 5-1.

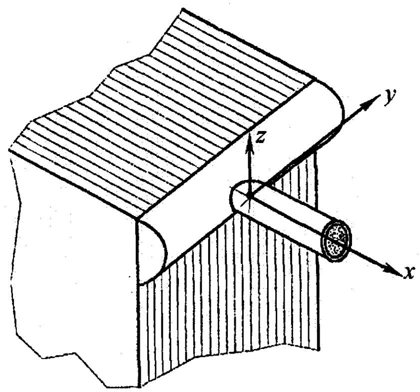


Figure 5-1: Positions of the Three Reference Axes

Some typical values of M_r and F_r can be taken from Table 5-1:

Table 5-1: Typical Resultant Forces and Moments Allowable at nozzle-to-header intersection

Nozzle size Inches	Moments (Nm) Resultant Moment M_r	Force (N) Resultant Force F_r
2	60	405
3	165	750
4	330	1330
6	765	1800
8	1080	2770
10	1350	3370
12	1650	4500
14	1950	5400
16	2320	6450
18	2700	7500
20	3000	8250
24	3600	10300

5.12.3 Flanges

Dimensions and facing of aluminium flanges shall comply with the applicable code, e.g. ANSI B16.5 or DIN. Usually, ring joint (RJ) or raised-face (RF) flanges are selected. Bolt holes shall straddle natural centre lines.

5.13 EFFECT OF PRODUCTION PROCESS ON MATERIALS

As a result of the manufacturing process of brazing, the core of the heat exchangers will be in the fully annealed condition, referred to as the 'O' temper.

5.14 ARRANGEMENT OF LAYERS

In principle there are no limitations or restrictions on permissible layer arrangements.

Usually the ratio of "warm" to "cold" passages varies between 1:1 (single banking) and 1:2 (double banking) or vice versa. Details are described in Chapter 7, Section 7.2.2.

5.15 BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGER AS A PRESSURE VESSEL

Brazed aluminium plate-fin heat exchangers are vessels, for which the mechanical design procedure is governed by a pressure vessel code. However, as a result of unique construction features, certain items need specific attention.

5.15.1 Fins

As well as their thermal performance behaviour, fins have to be selected by the manufacturer for their ability to resist the pressure loadings as structural members.

These loads essentially produce tensile stresses in the fins. The maximum allowable design pressure for the individual fins shall be determined either by calculation or by burst-test methods. The same fin corrugation may be acceptable up to different design pressures, depending on the requirements of the applicable codes.

5.15.1.1 Calculation procedure

Pressure vessel codes generally do not contain formulae for the fins in brazed aluminium plate-fin heat exchangers.

The calculation methods used by manufacturers have been approved by the applicable Code Authority. The stresses thus calculated are compared with the maximum allowable stress of the code. In the most common codes these allowable stresses are determined by using strength values based on the ultimate tensile strength divided by a figure of 3 to 4, or 0.2% tensile yield strength divided by 1.5, whichever is smaller.

5.15.1.2 Burst test method

A representative brazed sample is pressurised up to bursting. By applying a safety factor to the measured burst pressure, the allowable maximum design pressure for the particular fin type is derived. Depending on the applicable code, the safety factor shall be in the range of about 4 to 6, including adjustments for tolerances in material properties.

5.15.2 Parting Sheets

The parting sheet thickness must be sufficient to resist the tensile stresses from the pressure forces acting on the side bars. These stresses depend both on pressure loadings on the adjacent sides of the parting sheet and on the height of the adjacent side bars.

5.15.3 Side bars

The side-bar height is the same as the fin height. Side-bar width is chosen to take account of pressure loading from the header attachment and allow a reasonable mass for welding.

5.15.4 Cap Sheets

Due to their thickness, cap sheets are lightly stressed structural members of the heat exchanger. Their main task is to protect the core against physical damage and provide a base to allow welding of supports and other attachments.

5.15.5 Headers and Nozzles

It is common practice to determine wall thicknesses and reinforcement of openings from the requirements of the applicable code.

Manufacturers give consideration to the weld efficiency factors for the attachment of headers to the core, as required by the applicable code.

5.16 SPECIAL FEATURES

The Purchaser should indicate within the specification of the equipment any special conditions which may include vibration, seismic loading, thermal cycling, pressure cycling or vacuum or external pressure conditions. The Manufacturer will then take into account these effects in his design.

6 MATERIALS

6.1 TYPICAL MATERIALS OF CONSTRUCTION

The heat exchangers covered by these Standards are constructed from aluminium alloys. Materials are selected for their braze-ability, weld-ability and other characteristics. Typical materials used in construction, and their maximum applicable design temperatures, are shown in Table 6-1 and Table 6-2. Figure 1-2 details the components.

Table 6-1: Typical Materials Used in the Construction of Brazed Aluminium Plate-Fin Heat Exchangers and their Maximum Applicable Design Temperature (Celsius)

CODES	ASME		DIN		JAPANESE INDUSTRIAL ST'D (JIS)	
COMPONENTS	Alloy No.	Max. Applicable Design Temperature *1	Alloy No.	Max. Applicable Design Temperature *2	Alloy No.	Max. Applicable Design Temperature *3
Heat Transfer Fin	SB-209 3003 3004	 204°C 204°C	 Al Mn Cu	 65°C	H4000 A3003P A3004P	 200°C 200°C
Distributor Fin	SB-209 3003 3004	 204°C 204°C	 Al Mn Cu	 65°C	H4000 A3003P A3004P	 200°C 200°C
Side Bar	SB-221 3003	 204°C	 Al Mn Cu	 65°C	H4100 A3003S	 200°C
Centre Bar	SB-221 3003	 204°C	 Al Mn Cu	 65°C	H4100 A3003S	 200°C
Parting Sheet *4	SB-209 3003	 204°C	 Al Mn Cu	 65°C	H4000 A3003P	 200°C
Cap Sheet *4	SB-209 3003	 204°C	 Al Mn Cu	 65°C	H4000 A3003P	 200°C
Header	SB-209, 221 & 241 3003 5052 5083 5454 6061	 204°C 204°C 65°C 204°C 204°C	 Al Mg 3 Al Mg 4.5 Mn	 150°C 80°C	H4000 A3003P A5052P A5083P A5454P A6061P	 200°C 200°C 65°C 200°C 200°C
Nozzle	SB-209, 221 & 241 3003 5052 5083 5086 5454 6061 SB-221 & SB-241 6063	 204°C 204°C 65°C 65°C 204°C 204°C 204°C	 Al Mg 3 Al Mg 4.5 Mn	 150°C 80°C	H4080 & H4000 A3003TID&TE A3003P A5052TID&TE A5052P A5083TID&TE A5083P - A5086P A5454TE A5454P A6061 TD&TE A6061P A6063TID&TE	 200°C 200°C 65°C 65°C 200°C 200°C 200°C
Flange	SB-247 5083 6061	 65°C 204°C	 Al Mg 4.5 Mn Al Mg 3	 80°C 150°C	H4140 A5083FD A6061FD	 65°C 200°C
Support	SB-209 & 221 5052 5083 6061 6063	 204°C 65°C 204°C 204°C	 Al Mg 3 Al Mg 4.5 Mn G Al Si 7 Mg	 150°C 80°C 130°C	H4000 A5052P A5083P A6061P	 200°C 65°C 200°C

Remarks *1 : Maximum applicable temperature is as per ASME Sec. VIII, Div.1, where the official unit is British (degree F).
*2 : Maximum applicable temperature is as per AD-Merkblätter/Vd-TüV, where the official unit is Metric (degree C).
*3 : Maximum applicable temperature is as per Japanese High Pressure Gas Safety Law, where the official unit is Metric (degree C).
*4 : They may be clad

Table 6-2: Typical Materials Used in the Construction of Brazed Aluminium Plate-Fin Heat Exchangers and their Maximum Applicable Design Temperature (Fahrenheit)

CODES	ASME		DIN		JAPANESE INDUSTRIAL ST'D (JIS)	
COMPONENTS	Alloy No.	Max. Applicable Design Temperature *1	Alloy No.	Max. Applicable Design Temperature *2	Alloy No.	Max. Applicable Design Temperature *3
Heat Transfer Fin	SB-209 3003 3004	 400°F 400°F	 Al Mn Cu	 150°F	H4000 A3003P A3004P	 392°F 392°F
Distributor Fin	SB-209 3003 3004	 400°F 400°F	 Al Mn Cu	 150°F	H4000 A3003P A3004P	 392°F 392°F
Side Bar	SB-221 3003	 400°F	 Al Mn Cu	 150°F	H4100 A3003S	 392°F
Centre Bar	SB-221 3003	 400°F	 Al Mn Cu	 150°F	H4100 A3003S	 392°F
Parting Sheet *4	SB-209 3003	 400°F	 Al Mn Cu	 150°F	H4000 A3003P	 392°F
Cap Sheet *4	SB-209 3003	 400°F	 Al Mn Cu	 150°F	H4000 A3003P	 392°F
Header	SB-209, 221 & 241 3003 5052 5083 5454 6061	 400°F 400°F 150°F 400°F 400°F	 Al Mg 3 Al Mg 4.5 Mn	 302°F 176°F	H4000 A3003P A5052P A5083P A5454T A6061P	 392°F 392°F 150°F 392°F 392°F
Nozzle	SB-209, 221 & 241 3003 5052 5083 5086 5454 6061 SB-221 & SB-241 6063	 400°F 400°F 150°F 150°F 400°F 400°F 400°F	 Al Mg 3 Al Mg 4.5 Mn	 302°F 176°F	H4080 & H4000 A3003TID&TE A3003P A5052TID&TE A5052P A5083TID&TE A5083P - A5086P A5454TE A5454P A6061 TD&TE A6061P A6063TD&TE	 392°F 392°F 150°F 150°F 392°F 392°F 392°F
Flange	SB-247 5083 6061	 150°F 400°F	 Al Mg 4.5 Mn Al Mg 3	 176°F 302°F	H4140 A5083FD A6061FD	 150°F 392°F
Support	SB-209 & 221 5052 5083 6061 6063	 400°F 150°F 400°F 400°F	 Al Mg 3 Al Mg 4.5 Mn G Al Si7Mg	 302°F 176°F 266°F	H4000 A5052P A5083P A6061P	 392°F 150°F 392°F

Remarks *1 : Maximum applicable temperature is as per ASME Sec. VIII, Div.1, where the official unit is British (degree F).
*2 : Maximum applicable temperature is as per AD-Merkblätter/Vd-TüV, where the official unit is Metric (degree C).
*3 : Maximum applicable temperature is as per Japanese High Pressure Gas Safety Law, where the official unit is Metric (degree C).
*4 : They may be clad

7 THERMAL AND HYDRAULIC DESIGN

7.1 INTRODUCTION

The brazed aluminium plate-fin heat exchanger has special features and advantages which make it quite different from other types of heat exchangers:

1. A very large heat transfer surface area can be made available per unit volume of heat exchanger. This surface area is composed of primary and secondary (finned) surfaces. Even taking into account the fin efficiency of the secondary surface, the effective surface area per unit volume can be typically five times greater than that of a shell-and-tube heat exchanger.
2. A range of fin types is available. The fin type is selected to suit the characteristics of a stream. For example, serrated, wavy and perforated fins (Chapter 1, Figure 1-6) are particularly suitable for gas streams.
3. One heat exchanger can incorporate several streams and heat can be exchanged simultaneously amongst several streams in a multi-stream heat exchanger. Suitable headers and distributors also permit streams to enter and leave the heat exchanger at intermediate points along its length as well as at the ends.

7.2 FEATURES OF A BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGER

7.2.1 Primary and Secondary Heat Transfer Surfaces and Thermal Length

Heat is transferred from or into a stream within a finned passage. The primary heat transfer surface within the heat exchanger consists of the bare parting sheet and the fin base directly brazed to the parting sheet (Figure 7-1).

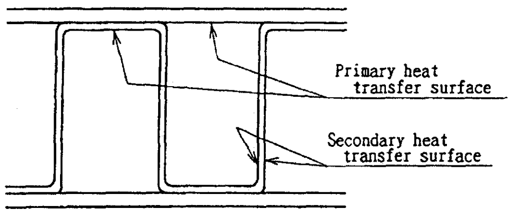


Figure 7-1: Cross Sectional View of Fin and Parting Sheet

The secondary heat transfer surface is provided by the fins. The effectiveness of the secondary surface to transfer heat is given by the fin efficiency.

Per unit area of each parting sheet:

the primary surface is given by : $2(1 - nt)$,

the secondary surface is given by : $2n(h - t)$

where n is the fin density (m^{-1}), i.e. number of fins per unit length

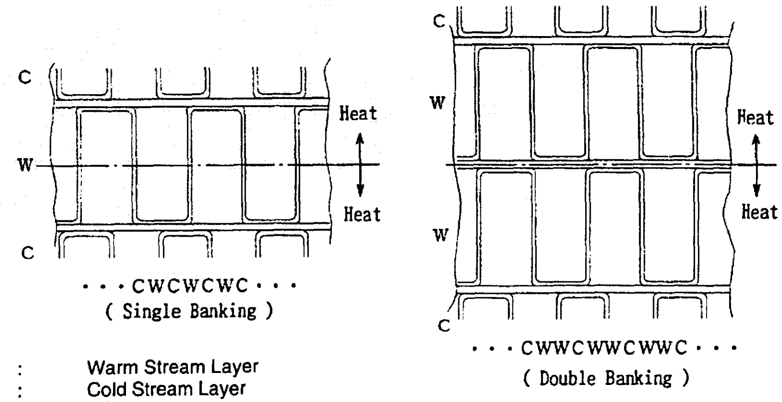
t is the fin thickness (m)

h is the fin height (m)

The thermal length of a brazed aluminium plate-fin heat exchanger is defined as the effective length of the finned region between, but not including, the distributors.

7.2.2 Single and Multiple Banking

There are two types of layer arrangement for a stream: single banking and multiple banking, (typically double banking, as in Figure 7-2).



W : Warm Stream Layer
C : Cold Stream Layer

Figure 7-2: Single and Double Banking

Single banking is the normal arrangement where each warm stream layer (W) is adjacent to a cold stream layer (C). The thermal efficiency of this fin arrangement is given in Section 7.4.5.

Double banking is also illustrated in Figure 7-2. Here, two layers of equal height are provided for a warm stream with a large flow rate within the allowable pressure drop. More than two layers can also be used. The thermal efficiency of double banking is also given in Section 7.4.5.

In double banking, the parting sheet between the two layers becomes a secondary surface and the fin efficiency is reduced because of the increased length of the heat path along the fins.

7.2.3 Multi-stream Brazed Aluminium Plate-fin Heat Exchangers

The brazed aluminium plate-fin heat exchanger is capable of accommodating many streams within its structure and heat can be exchanged among several streams simultaneously.

A multi-stream brazed aluminium plate-fin heat exchanger, with streams also entering and leaving at intermediate positions between its ends, can accommodate over ten different streams. The selection and design of the layer arrangement, layer finning and effective length of each stream is of crucial importance.

7.3 THERMAL DESIGN PROCEDURE

The design procedure for a brazed aluminium plate-fin heat exchanger is different, in many respects, from a traditional two-stream exchanger such as a shell and tube. The main differences are

1. In most cases, several streams must be handled.
2. The secondary surface area provided by the fins is a large portion of the total heat-transfer area.

3. There are a variety of fin types available for giving the best heat transfer and pressure drop characteristics for each individual stream (see Section 7.6.1).
4. A good sequence of layers is required where each layer is the flow channel for a given stream with the appropriate choice of finning. This is known as the layer stacking arrangement and is discussed in Section 7.6.2.
5. There is a strong inter-relationship between the mechanical and thermal-hydraulic design because key elements in the thermal design, such as fin density, height and thickness, are governed by the mechanical design.
6. Optimising a design involves working with a large number of variables, and this is best handled using good software combined with expert knowledge from an experienced designer.
7. The designer requires much more information to cover the many streams and the greater detail often required for each stream. Figure 7-3 and Figure 7-4 give examples of specification sheets which allow for this extra information.

The calculation method given in Section 7.4 is a simple one that effectively converts a multi-stream heat transfer process into a two stream one. The first step is to generate the temperature-enthalpy plot (T - Q curve) for all the cold streams and all the warm streams. Plotting these curves on the same chart is very revealing in showing where close temperature approaches (temperature pinches) arise, which require special care in design. An overall heat transfer coefficient is also calculated which combines the individual heat transfer coefficients for all the streams.

It is stressed that this calculation method is an approximation which can provide good solutions for simpler heat transfer processes. More rigorous calculation methods are available, which take into account the detailed variations from stream to stream including the temperature differences between individual parting sheets. An experienced designer should therefore be consulted at an early stage in detailed design.

7.4 THERMAL RELATIONS

7.4.1 Basic Heat Transfer Relation

The required surface area of a brazed aluminium plate-fin heat exchanger can be obtained from:

$$UA_r = \frac{Q}{MTD} \tag{1}$$

where

U	: Overall heat transfer coefficient between streams	($W/m^2 K$)
A_r	: Required overall effective heat transfer surface	(m^2)
Q	: Heat to be transferred	(W)
MTD	: Mean temperature difference between composite or combined streams	(K)

1	BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGER SPECIFICATION								
2	Customer			Project		Location			
3	Item number			Service			Date		Revision
4	Stream/fluid name		Units	A/	B/	C/	D/	E/	F/
5	Flow rate:	Total							
6		Vap./Liq. In		/	/	/	/	/	/
7		Vap./Liq. Out		/	/	/	/	/	/
8	Molecular weight	Vap. In/Out	-	/	/	/	/	/	/
9		Liq. In/Out	-	/	/	/	/	/	/
10	Density	Vap. In/Out		/	/	/	/	/	/
11		Liq. In/Out		/	/	/	/	/	/
12	Viscosity	Vap. In/Out		/	/	/	/	/	/
13		Liq. In/Out		/	/	/	/	/	/
14	Specific heat	Vap. In/Out		/	/	/	/	/	/
15		Liq. In/Out		/	/	/	/	/	/
16	Thermal conductivity	Vap. In/Out		/	/	/	/	/	/
17		Liq. In/Out		/	/	/	/	/	/
18	Temperature	In/Out		/	/	/	/	/	/
19	Operating pressure	In							
20	Allowable pressure drop								
21	Heat load								
22	Corrected MTD								
23	Fouling resistance								
24	Design pressure/hydro. test pressure			/	/	/	/	/	/
25	Design temperature max./min.			/	/	/	/	/	/
26	Number of cores:	In parallel:		In series:		Number of cores/assembly:		Number of assemblies:	
27	Core size: Width	Height		Length		Flow pattern: counter,	cross-counter,	cross,	parallel
28	Number of layers:	(including dummy layers)			Parting sheet thickness:		Cap sheet thickness:		Side bar width:
29	Approx. weight:	Core		(Empty)	(Operating)	Assembly	(Empty)		(Operating)
30	Number of layers		-						
31	Fin code: Heat transfer fin		-						
32	Distributor fin		-						
33	Effective width								
34	Effective thermal length								
35	Heat transfer surface/core								
36	Core opening size	In/Out		/	/	/	/	/	/
37	Nozzle size	In/Out		/	/	/	/	/	/
38	Manifold pipe size	In/Out		/	/	/	/	/	/
39	Calculated pressure drop								
40	Stacking arrangement:								
41	Code and/or regulation:								
42	Notes								
43									
44									

Figure 7-3: Typical Specification Sheet

BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGER SPECIFICATION

Stream identification

Fluid name

Composition | Component | Mole (%)

	Temp.	Heat load or specific enthalpy	Mass quality	Vapour Physical Properties: MW	Density	Heat capacity	Viscosity	Thermal conductivity	Liquid Physical Properties: MW	Density	Heat capacity	Viscosity	Thermal conductivity	Surface tension
Units														
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
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29														
30														

Notes:

Figure 7-4: Typical Specification Sheet

7.4.2 *MTD* and UA_r

The *MTD* can be obtained by calculating the logarithmic mean temperature difference (*LMTD*) in each section where both warm and cold T - Q curves are linear.

Equation (1) becomes:

$$UA_r = \sum \frac{Q_i}{LMTD_i} \qquad (2)$$

where

$$LMTD_i = \frac{\Delta T_{i+1} - \Delta T_i}{\ln(\Delta T_{i=1} / \Delta T_i)} \qquad (3)$$

ΔT_i ; ΔT_{i+1} : Temperature differences between warm and cold streams at each end of section *i* (K).

This *LMTD* can be used for counter-flow or parallel-flow.

For cross-flow and cross-counter-flow, however, the *LMTD* must be corrected. Details are given in Reference (1).

For a multi-stream brazed aluminium plate-fin heat exchanger, the *MTD* must be obtained from the two composite temperature-enthalpy curves for the combined warm and combined cold streams. Further information can be found in References (1) to (4).

7.4.3 Overall Effective Heat Transfer Surface of Exchanger

The overall effective heat transfer surface can be estimated from Equation (4). The thermal resistance of the parting sheet between the two streams can usually be ignored primarily because it is made from thin aluminium sheet.

$$\frac{1}{UA_d} = \frac{1}{\sum(\alpha_0 A)_{wi}} + \frac{1}{\sum(\alpha_0 A)_{ci}} \qquad (4)$$

where

α_0 : Effective heat transfer coefficient of a stream (W/m^{2}K)

A : Effective heat transfer surface of a passage or layers of a stream (m^2)

A_d : Designed (or estimated) overall effective heat transfer surface (m^2)

suffix wi, ci : Warm or cold stream i

7.4.4 Effective Heat Transfer Coefficient of Each Stream

The heat transfer coefficient of each stream can be estimated from Equation (5).

$$\alpha = \frac{j G_m C_p}{\mathrm{Pr}^{2/3}} \qquad (5)$$

where

α : Heat transfer coefficient of a stream (W/m^{2}K)

j : Colburn factor for a finned passage (-)

G_m : Mass flux of a stream (kg/m^{2}s)

C_p : Specific heat capacity of a stream at constant pressure (J/kg K)

Pr : Prandtl Number of a stream (-)

The effective heat transfer coefficient of each stream, α_o, can be estimated from Equation (6) which takes the fouling resistance into account.

$$\frac{1}{\alpha_0}=\frac{1}{\alpha}+r \qquad (6)$$

where

r : Fouling resistance of a stream (m^2K/W)

Equation (5) can be used for single phase streams, i.e. all vapour or all liquid flow. For two-phase condensing or vaporising flows, various equations are available for predicting the two-phase heat transfer coefficient; given for example in Reference (4). A manufacturer, however, will use calculation methods based on experience with two-phase streams.

The Colburn factor, j, is highly dependent on the type of fin, its nominal geometry and details of manufacture, as well as the Reynolds Number of the stream. Information about the Colburn factor j can also be obtained from Reference (2).

Heat transfer coefficients of each stream must be calculated locally where the thermodynamic and/or physical properties of the stream change rapidly, for example, at a phase-change or in the super-critical state. For these conditions, a step-by-step calculation along the stream will be necessary.

7.4.5 Heat Transfer Surface of Each Passage

The effective heat transfer surface area for a passage, A, can be estimated from Equation (7) for single banking and Equation (9) for double banking:

$$A=A_1+\eta_1\phi A_2 \qquad (7)$$

for single banking

$$\eta_1=\frac{\tanh(\beta/2)}{\beta/2} \qquad (8)$$

$$A=\frac{1}{2}A_1+\eta_2\left(\frac{1}{2}A_1+\phi A_2\right) \qquad (9)$$

for double banking

$$\eta_2=\left(\frac{1}{\beta+\gamma}\right)\left(\frac{B-1}{B+1}\right) \qquad (10)$$

where

$$\beta=h\left(\frac{2\alpha_o}{\lambda_m t}\right)^{0.5} \qquad (11)$$

$$\gamma=\frac{\beta}{2h}\left(\frac{1}{n}-t\right) \qquad (12)$$

$$B=\left(\frac{1+\gamma}{1-\gamma}\right)e^{2\beta} \qquad (13)$$

A_1 : Primary heat transfer surface of a stream (Figure 7-1) (m^2)

A_2 : Secondary heat transfer surface of a stream (Figure 7-1) (m^2)

η_1 : Passage fin efficiency for single banking (-)

η_2 : Passage fin efficiency for double banking (-)

h : Passage fin height (m)

t : Passage fin thickness (m)

n : Passage fin density (m^{-1})

α_o : Effective heat transfer coefficient of a stream (W/m^2K)

ϕ : Unperforated fraction [1 - (percentage perforation)/100] (-)

λ_m : Thermal conductivity of fin material (aluminium) (W/m K)

7.4.6 Rough Estimation of the Core Volume

To obtain a quick indication of the heat exchanger volume required for a certain duty, the following simple relation may be used:

$$V=\frac{Q/MTD}{C} \qquad (14)$$

where

V : Required volume of heat exchanger or heat exchangers (without headers) (m^3)
Q : Overall heat duty (W)
MTD : Mean temperature difference between streams (K)
C : Coefficient; 100,000 for hydrocarbon application (W/m^3K)
50,000 for air separation application

The values of 100,000 and 50,000 represent the product, $U\,A_d$, assuming an overall heat transfer coefficient of 200 W/m^2 K and 100 W/m^2 K respectively, and a mean geometric heat transfer surface density of 500 m^2/m^3.

The weight of a complete heat exchanger may be assumed to be 1000 kg per unit core volume (m^3). This value varies in practice between 650 and 1500 kg /m^3.

7.5 HYDRAULIC RELATIONS

The purchaser usually specifies the allowable pressure loss for each stream, within the manufacturer's scope of supply.

In the hydraulic design of the heat exchanger, the finning and passages are chosen to meet this pressure loss requirement. In order to ensure uniform flow distribution of a stream among its passages, the components of the pressure drop are evaluated. Uniform distribution of a stream over the width of a layer is provided by good design of the distributors.

7.5.1 Components of Pressure Loss

The individual pressure losses within a heat exchanger typically consist of (See Figure 7-5):

1. Expansion loss into the inlet header
2. Contraction loss at the entry to the core
3. Loss across the inlet distributor
4. Loss across the heat transfer length
5. Loss across the outlet distributor
6. Expansion loss into the outlet header
7. Contraction loss into the outlet nozzle

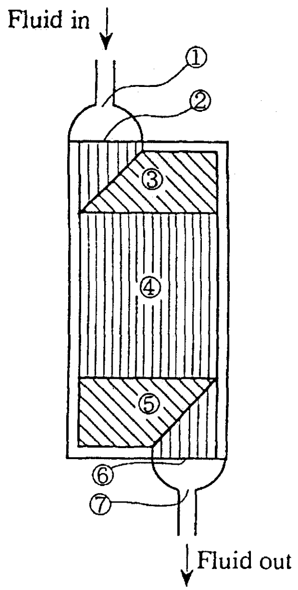

Figure 7-5: Pressure Loss Components

Additional pressure losses in piping and/or manifolding outside the manufacturer's scope of supply are to be accounted for by the purchaser.

General methods for predicting these pressure losses are given in Reference (4). Manufacturers make use of their experience to select the most appropriate method of estimating the losses given in Items 1 to 7 above.

7.5.2 Single-Phase Pressure Loss

The frictional pressure loss across a plate-fin passage and at any associated entry, exit and turning losses, can be expressed by:

$$\Delta P = 4\,f\left(\frac{l_p}{d_h}\right)\left(\frac{G_m^{\,2}}{2\rho}\right) + K\left(\frac{G_m^{\,2}}{2\rho}\right) \qquad (15)$$

where

f	:	Fanning friction factor	(-)
l_p	:	Passage length	(m)
d_h	:	Hydraulic diameter of passage	(m)
G_m	:	Mass velocity (mass flux) of stream	(kg/m^{2}s)
ρ	:	Density of a stream	(kg/m^3)
K	:	Expansion, contraction or turning loss coefficient	(-)
ΔP	:	Overall pressure drop	(Pa)

Note: By convention, the upstream mass flux is used for estimating expansion losses and the downstream for contractions.

7.5.3 Two-Phase Pressure Loss

In brazed aluminium plate-fin heat exchangers with two-phase streams where fluid quality and physical properties are changing, it is necessary to divide the heat exchanger into suitable increments of length in order to assess the overall pressure gradient simultaneously with the thermal design calculations.

The pressure gradient in a two-phase flow can be divided into three components:

- The frictional component,
- The static head component,
- The accelerational component.

Each manufacturer uses suitable design correlations for estimating these components from experience. General estimating methods are given in Reference (4).

7.6 GENERAL CONSIDERATIONS IN THE THERMAL AND HYDRAULIC DESIGN

7.6.1 Choice of Fin Geometry

Each fin must conduct the required amount of heat and also withstand the design pressure at the design temperature as a structural component.

Fin geometry is therefore selected to meet both requirements. Details of the required structural performance are given in Chapter 5. Details of the fin's required thermal performance are given earlier in Section 7.4.4.

The choice of fin will also influence the most economical design of an exchanger for a specific application. Table 7-1 provides general information on common applications for each type of fin (see Figure 1-6, Chapter 1).

Table 7-1: Common Applications for each Type of Fin

Corrugation	Description	Application	Features	
			Relative pressure drop	Relative heat transfer
Plain	Straight	For general use	lowest	lowest
Perforated	Straight with small holes	Most frequently used for any purpose. Sometimes used for the "hardway" finning	low	low
Serrated	Straight, offset half a pitch - usually about every 3-4 mm	Frequently used, especially for low pressure gas streams in air separation plants	highest	highest
Herringbone or long-lanced serrated	Smooth but in waves of about 10 mm pitch, or serrated with long serration pitch	Often used for gas streams with low allowable pressure drop	high	high

7.6.2 Layer Stacking Arrangement

With multi-stream heat exchangers, the choice of the stacking sequence or layer-pattern, must take into account the local heat balance among streams and any local non-linearity of the Enthalpy-Temperature Curves of each stream. A thermally well-balanced stacking arrangement would result in a nearly uniform metal temperature at any cross section of the heat exchanger, thus allowing the detailed design to proceed with the assumption of a common wall temperature.

The deviations from a uniform metal temperature can be evaluated by using a more detailed (layer-by-layer) analysis, taking into account heat being transferred by metal conduction between non-adjacent layers.

8 RECOMMENDED GOOD PRACTICE

8.1 THERMAL STRESSES WITHIN BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGERS

8.1.1 Introduction

As with any pressurised heat exchanger, stresses in each component of a brazed aluminium plate-fin heat exchanger must be maintained within allowable limits. Pressure loads, externally applied loads (e.g. piping forces and moments), and thermally induced loads produce stresses which must be maintained within permissible limits to prevent component damage or failure.

Manufacturers design each brazed aluminium plate-fin heat exchanger for the intended design pressure loads; users are provided with details of allowable external loads that may be exerted on the exchanger. A margin above the stresses created by these loads is made available by the manufacturer for thermally-induced loads which may occur in service. In this section the mechanism by which thermal stresses are induced is explained.

Recommendations are given for the measures to be taken in the operation of brazed aluminium plate-fin heat exchangers so that the overall combined stresses remain within allowable limits during standard and non-standard operating conditions.

8.1.2 Failure Mechanism

The components of a brazed aluminium plate-fin heat exchanger are relatively close and rigidly connected in all directions to each other. As a result, conditions which generate large local metal temperature differences in and between the components of its structure, will cause significant thermal stress in these components.

Local metal temperature differences result from the components, or portions of the components, warming or cooling at different rates in response to a thermal input (change). These differences produce a transient differential expansion or contraction within or between the components; mechanical restraint to these thermally-induced structural movements results in thermal stress in the components. If the local metal temperature differences are large, the combined thermally-induced stresses and other stresses from imposed loads can exceed the yield stress and possibly the ultimate stress of the material.

Temperature differences between adjacent parts of a heat exchanger, having the potential to produce significant thermal stresses, can arise from:

1. Continuously unsteady operating conditions: for example, large flow fluctuations; unstable flow in boiling channels; inadequate plant control systems.
2. Transient operating conditions: for example, start-up; shut-down; plant upsets; deriming; cool-down and warm-up; etc.

An example of the creation of thermal stress is illustrated by the quick opening of a valve. If this action allows a significant quantity of cold fluid with a high thermal capacity to enter a warm heat exchanger, then those parts of the heat exchanger which can lose heat rapidly will contract quickest. The finning in the region of the inlet port would thus contract more quickly than the side bars on either side of the port; tensile thermal stress would be created within the fins and compressive stress in the side bars. These stresses will diminish as temperature differences decrease and thermal equilibrium is restored. Thermally-induced failures can also occur in other components of a heat exchanger apart from the fins. The next most susceptible component is the parting sheet.

Continuously unsteady operating conditions, as described above, can generate cyclic stresses exceeding the yield strength, and failure by fatigue may result.

During transient operating conditions, if the combined stresses exceed the ultimate tensile strength of the material, components may fail.

8.1.3 Recommendations

To reduce the possibility of component damage or failure during the operational conditions described above, the following recommendations are made:

1. Limit the pressure and external loads to those allowed (stated) by the manufacturer.
2. As with any heat exchanger, bring the brazed aluminium plate-fin exchanger to or from operating or derime conditions slowly to avoid excessive thermal stress. This is of particular importance when introducing a liquid or two-phase stream due to the heat capacity of the stream and its ability to transfer heat rapidly to or from the components. Recommended rates for start-up and shut-down, cool-down, warm-up, deriming, etc. are presented in Chapter 4.
3. Limit the temperature differences between adjacent streams at any point in the heat exchanger to those recommended in Chapter 5 or by the manufacturer. Temperature differences recommended in Chapter 5 are general to all brazed aluminium plate-fin heat exchangers. Other recommendations may be provided by the manufacturer when supplying a heat exchanger for a particular application.
4. Exercise particular care in applications where a liquid is totally vaporised within the heat exchanger. Boiling to total dryness can produce large temperature differences and also induce flow instabilities. The manufacturer's recommended allowable temperature differences for these applications must be strictly adhered to. Also, the design of the process plant must ensure that stable flow occurs.
5. Design and operate the plant equipment and piping connected to the heat exchanger to prevent flow excursion and instabilities (for example, intermittent slugging of liquid to the exchanger). This is particularly important with boiling streams.
6. Limit cyclic or frequently repeated temperature fluctuations of any stream to ±1°C per minute.

8.1.4 Summary

Brazed aluminium plate-fin heat exchangers are robust exchangers which are very tolerant of large steady-state stream-to-stream temperature differences. Being relatively compact and rigid structures, brazed aluminium plate-fin heat exchangers are susceptible to damage if subjected to transient or continuously unsteady operating conditions which produce excessive thermal stressing. Excessive thermal stressing can be avoided by following the precautions (recommendations) outlined above, thus helping to ensure long life of the heat exchanger.

8.2 FOULING AND PLUGGING OF BRAZED ALUMINIUM PLATE-FIN HEAT EXCHANGERS

8.2.1 Fouling

Fouling is generally not encountered for processes in which brazed aluminium plate-fin heat exchangers are traditionally used: air separation; hydrocarbon separation and liquefaction of gases.

In the case where a degradation of thermal performance is observed with little or no change in pressure drop of the product, fouling may be suspected.

Recommended actions are as follows:

8.2.1.1 *Prevention*

Before deciding on the use of brazed aluminium plate-fin heat exchangers, the fluid conditions have to be examined for the presence of solids, foreign particles forming deposits during operation of the heat exchanger, especially in low temperature regions.

It is important also to consider fouling that may arise from contaminants in the process fluids. A typical example is the use of seal oil with refrigerant streams, which could deposit as a solid film on the fin surfaces and reduce the thermal performance of the heat exchanger.

WARNING: GASES CONTAINING TRACES OF NO_x MUST NOT BE USED: NO_x WILL ACCUMULATE IN THE CRYOGENIC PORTION OF THE EQUIPMENT. EXPERIENCE HAS SHOWN THAT SUCH PRODUCTS CANNOT BE REMOVED FROM THE INTERIOR OF THE EQUIPMENT AND MAY SUDDENLY EXPLODE DURING WARMING UP OF THE PLANT.

8.2.1.2 *Remedial action*

If the liquid/solid transformation of the fouling agent is reversible with temperature, changing the operating conditions of the heat exchanger and thus warming up the fouled zone may be sufficient to eliminate the deposits.

In cases where this technique is not effective, solvent cleaning may be used. Brazed aluminium plate-fin heat exchangers can be modified or designed to incorporate solvent injection system thus allowing flushing of the contaminated surfaces.

8.2.2 Plugging

Plugging is defined as being the obstruction of fin channels inside a brazed aluminium plate-fin heat exchanger as a result of solid particles having entered the unit.

The effect of plugging on a brazed aluminium plate-fin heat exchanger may be very serious for its thermal performance since, generally, the plugging medium will not be distributed evenly to all passages, and uniformly within the width of the passages and will thus cause severe maldistribution. Simultaneously, the pressure drop of the plugged stream will increase significantly.

WARNING: IN THE CASE OF EXTREMELY SEVERE PLUGGING, THE SAFETY ASPECTS OF THE PLANT MUST BE CONSIDERED.

8.2.2.1 *Prevention*

Plugging of brazed aluminium plate-fin heat exchangers can be prevented by following these recommended actions.

- The end closures of brazed aluminium plate-fin heat exchangers should always be maintained during manufacture until the connection of nozzles or flanges to the plant pipework.
- The cleanliness of the connecting pipes should be checked to make sure that rust, debris, dust, etc. can not enter the heat exchanger.
- Filters on the feed streams should be installed at any location where there is a possibility of contaminating the process fluid. Recommendations are provided by manufacturers as to the mesh size, and filter types, etc., depending upon maintenance considerations, for specific applications. A mesh size of 177 microns (80 Tyler) is capable of covering most applications

8.2.2.2 *Remedial action*

Should the heat exchanger be significantly plugged for any reason (absence of filter, wrong cleaning procedure of plant pipework, failure of filtering equipment, etc.), the consequences on both the thermal and pressure drop performance will be obvious.

The plugged stream can generally be identified quickly and corrective action be planned to be taken during a shut-down of the plant.

The mechanical methods to remove plugging from a brazed aluminium plate-fin heat exchanger require the use of an air or nitrogen gas discharge from the exchanger:

- Either back-blow the plugged stream, having installed a bursting disc at the inlet and pressurising up to the rupture of the disc.

  (This operation has to be repeated until no particles are observed being discharged).
- or install a special "deplugger" at the outlet of the heat exchanger, made of a volume of air under pressure and a quick-opening valve, to produce a shock wave inside the heat exchanger core.

In the case of severe plugging, a deplugging action may be undertaken on every passage, having connected the "deplugger" successively to each individual passage.

The use of a solvent and gas bubbling uses the bubbles generated inside the liquid which fills the structure, and these provide the mechanical energy to dislodge the particles.

8.3 CORROSION

Brazed aluminium plate-fin heat exchangers are satisfactorily used in many processes without experiencing corrosion problems. However, as with any heat exchanger, when corrosion is possible, caution must be exercised both on the choice of process fluids and the environment to which the brazed aluminium plate-fin heat exchanger is exposed. Purchasers/operators should contact the manufacturer to determine the best course of action to avoid corrosion problems.

WARNING: CAUTION MUST BE EXCERCISED BOTH IN THE CHOICE OF PROCESS FLUIDS AND THE ENVIRONMENT TO WHICH HEAT EXCHANGERS ARE EXPOSED WHEN CORROSION IS POSSIBLE.

8.3.1 Process Environments Containing Water

The corrosion processes due primarily to water or which involve water as one of the contributors will stop or be unable to start in those portions of the brazed aluminium plate-fin heat exchangers which are operating below the freezing point of water. This may not be 0°C due to water purity variations and supercooling phenomena. Above the freezing point, for example during de-riming, consideration must be given to other factors. Water service can be grouped into 3 categories:

8.3.1.1 *Water service in neutral environments*

Brazed aluminium plate-fin heat exchangers can be used extensively in the processing of many materials containing water provided the water is and remains relatively neutral in character while within the exchanger (pH of 6 to 8) even in the presence of halides. The compatibility of the aluminium heat exchanger with a process stream containing neutral water can be affected by factors such as the degree of heavy metals contained within the process stream and deposit formation.

For example, aluminium heat exchangers used together with copper and its alloys, or with other heavy metals such as iron, nickel and lead, should be avoided unless an inhibitor is used to protect the aluminium heat exchanger components. The pitting corrosion resulting from the use of process streams containing heavy metals is usually less severe when the soluble ions of these heavy metals are decreased. Consequently, the presence of heavy metals in acidic or neutral water service process streams in conjunction with aluminium plate-fin heat exchangers will be more detrimental than in alkaline process streams. Austenitic stainless steels are very acceptable for use in combination with aluminium plate-fin heat exchangers in neutral water service process streams.

8.3.1.2 Water service in acidic environments

Aluminium alloys commonly used in heat exchangers are resistant to acidic process streams or local acidic conditions in the 4.5 to 6.0 pH range. However, an inhibitor should be used in this pH range if heavy metals or halides are present in the process stream. Below a pH of 4.5, corrosion can initiate by breakdown of the protective oxide film and by galvanic coupling between components or areas of the aluminium heat exchanger and other more noble metals in the process equipment. Structurally significant corrosion can result from direct chemical conversion of the exposed nascent aluminium after the protective oxide has broken down. As is the case with neutral environments, the formation of deposits can change both the environmental conditions at which corrosion begins and the severity of the attack once the corrosion begins.

8.3.1.3 Water service in alkaline environments

Aluminium heat exchanger alloys have excellent corrosion resistance in mildly alkaline environments (pH of 8 to 9). An alkaline process stream may discolour the surface of the aluminium components, but this darkening of the surface is only superficial and will not effect the structural or operational integrity of the heat exchanger. The use of Aluminium Plate-Fin Heat Exchangers in more severe alkaline environments (pH > 9) should be done only after a very careful analysis and consideration of the chemical process streams involved. Other factors such as process and impurity concentrations and temperatures within the operating environment to which the equipment will be subjected also need to be given some consideration.

To summarise, the pH value should remain between 4.5 and 8.5 and the presence of halides and heavy metal ions should be avoided.

8.3.2 Process Environments Containing Mercury

In general, mercury will not react with aluminium unless it is allowed to exist in contact with the heat exchanger in its liquid state and there is water present. If these conditions exist within a heat exchanger, then mercury contamination can result in problems. This attack is most severe when coupled with another corrosion process.

Another possible problem resulting from mercury in the process stream affects aluminium alloys that contain a high level of magnesium. A rapid reaction of mercury with a magnesium-based secondary phase within the aluminium can take place in the absence of water. If features are not designed into the equipment to address this problem and conditions are conducive, mercury corrosion cracking can occur and propagate at substantially lower levels of stress than that required if mercury were not present.

Many brazed aluminium plate-fin heat exchangers are able to operate successfully with fluids containing mercury by using precautions that are available. Purchasers can remove mercury from the feed gas with commercially available systems. Operators may also use special shutdown procedures (nitrogen blanketing) to restrict moisture and avoiding, for metallurgical reasons, elevating temperatures above 100°C for long periods, for example during de-riming operations.

Manufacturers can offer several options when mercury service is specified. Design features can eliminate the build up or pocketing of mercury. Often it is possible to avoid the use of susceptible alloys. When those choices are not possible, precautions are available either to isolate or protect the high-magnesium containing alloys from mercury attack.

8.3.3 Atmospheric or Environmental Corrosion

Aluminium plate-fin heat exchangers will generally not suffer to any structurally appreciable extent from atmospheric corrosion. Slight cosmetic corrosion may result if the exchangers are left outside in a humid environment with temperature changes that result in condensation of the humidity on the aluminium surfaces.

Extra precautions should be taken if the exchangers are exposed to an environment containing appreciable quantities of salt spray or salt air, for example, during extended open storage at site locations in coastal areas or during ocean transport. In the case of ocean freight without seaworthy packing; e.g. transport of exchanger batteries, it is recommended that, immediately after arrival on site, all surfaces be washed with water with a chlorine content < 25 ppm. Manufacturers should be contacted regarding the detailed procedures to be used to wash the core. After washing, all surfaces need to be dried thoroughly.

Since it is difficult to insure the leak tightness of any heat exchanger insulation system it is important that safety systems which use water to control fire hazards do not expose the heat exchangers to sea, brackish or other forms of salt water. This water could become trapped between the heat exchanger insulation and the heat exchanger metal surfaces resulting in corrosion of the exposed surfaces. Even tap water can result in corrosion under these conditions, and manufacturers should be contacted regarding procedures to be used to dry the cores.

8.3.4 Other Services

There are many possible service environments for satisfactory operation of brazed aluminium plate-fin heat exchangers. Not all corrosion risks are addressed in this guideline. If there is uncertainty about the fluid and/or process conditions, contact the manufacturer for specific advice.

Notation

		SI	IMPERIAL
A	Effective heat transfer surface of a passage or layer	m^2	ft^2
A_d	Designed or estimated overall effective heat transfer surface	m^2	ft^2
A_r	Required overall effective heat transfer surface	m^2	ft^2
A_1	Primary heat transfer surface of a stream	m^2	ft^2
A_2	Secondary heat transfer surface of a stream	m^2	ft^2
B	Defined by Equation (13), Chapter 7	-	-
C	Coefficient, defined by Equation (14), Chapter 7	W/m^3K	Btu/ft^2 F
C_p	Specific heat	J/kg K	Btu/lb F
d_h	Hydraulic diameter of passage	m	ft
f	Fanning friction factor	-	-
F	Force	N	lb
G_m	Mass flux/velocity of a stream	kg/m^2s	lb/ft^2 hr
h	Fin height	mm	in
H	Stacking height of a core	mm	in
j	Colburn factor for a finned passage	-	-
K	Expansion/contraction/turning loss coefficient	-	-
l_p	Passage length	mm	in
l_s	Serration length or distance between crests on herringbone fins	mm	in
L	Core length	mm	in
$LMTD$	Logarithmic mean temperature difference	K	F
M	Moment	Nm	lb ft
MTD	Mean temperature difference	K	F
n	Fin density	m^{-1}	in^{-1}
p	Fin pitch	mm	in
Pr	Prandtl number	-	-
Q	Overall heat duty; heat to be transferred	W	Btu
r	Fouling resistance	m^2K/W	ft^2F hr/Btu
s	Distance between the extreme bolts in a given plane	mm	in
t	Fin thickness	mm	in
U	Overall heat transfer coefficient between streams	W/m^2K	Btu/hr ft^2F
V	Volume of heat exchanger or exchangers	m^3	ft^3
W	Width of core	mm	in
X	Required clearance distance	mm	in

Greek

		SI	IMPERIAL
α_l	Coefficient of linear expansion at average temperature	m/m K	ft/ft F
α_o	Effective heat transfer coefficient of a stream	W/m^2K	Btu/hr ft^2F
α	Heat transfer coefficient of a stream	W/m^2K	Btu/hr ft^2F
β	Defined by Equation (11), Chapter 7	-	-
γ	Defined by Equation (12), Chapter 7	-	-
ΔP	Overall pressure drop	N/m^2 (Pa)	lb/in^2
ΔT	Local temperature difference between warm and cold streams	K	F
ΔT_R	Temperature range at support	K	F
η_1	Passage fin efficiency for single banking	-	-
η_2	Passage fin efficiency for double banking	-	-
λ_m	Thermal conductivity of fin material	W/m K	Btu/hr ft F
ρ	Density of stream	kg/m^3	lb/ft^3
ϕ	Unperforated fraction of fin	-	-

Subscripts

c	Cold stream	w	Warm stream
i	Section	x,y,z	Direction

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