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Revision Memo

1/05 Added paragraph describing Tower Heat Exchangers (section 4.3)

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1 SCOPE

This section presents information concerning the common types of unfired heat exchangers and their applications. Usually exchangers are specifically designed and fabricated for each service; very little heat exchange equipment can be purchased off the shelf. Design of exchangers is completed using computer tools, with Heat Transfer Research, Inc. (HTRI) programs used through Hextran (Simulation Sciences, Inc.) being the recommended approach. Hand calculations are presented in later sections to allow heat transfer calculations of the common types of heat exchangers. To ensure the purchase of an exchanger meeting design requirements, the designer normally completes a heat exchanger data sheet giving the specific requirements for the unit. These requirements are a combination of calculated results and plant or end-user requests. The recommended data sheet for shell-and-tube heat exchangers can be found in API Standard 660.

The calculation methods, both computer and hand calculation, are explained in the sections which follow. Certain items, such as exchanger type, tube length and size, and material preference are usually supplied by the end-user. If the end-user has no specific requirements, economics should dictate the unit chosen.

2 REFERENCES

2.1 DESIGN PRACTICES

DPs [IX-B](#) through [IX-L](#)

DP XV [Safety in Plant Design](#)

2.2 INTERNATIONAL PRACTICES

- IP 6-1-1 TEMA Type Shell-and-Tube Heat Exchangers
- IP 6-2-1 Double Pipe and Multitube Hairpin Heat Exchangers
- IP 6-3-1 Brazed Aluminum Heat Exchangers
- IP 6-4-1 Air-Cooled Heat Exchangers
- IP 6-5-1 Plate and Frame Heat Exchangers

2.3 OTHER REFERENCES

Standards of the Tubular Exchanger Manufacturer's Association (TEMA)
 API Standard 660, Shell-and-Tube Heat Exchangers for General Refinery Service
 API Standard 661, Air-Cooled Heat Exchangers for General Refinery Services
 API Standard 662, Plate Heat Exchangers for General Refinery Services
 Heat Transfer Research Incorporated (HTRI), Design Manual Vol. 1 & 2
 EMRE, *Refinery Construction Materials Manual*, Manual No. EETD 028

2.4 COMPANY TECHNICAL REPORTS

Extended Surface Heat Exchanger Tube Retrofits for Light End Condensers and Reboilers, ER&E Report No. EE.147E.82.
Survey of Tube-Side Heat Transfer Enhancement Techniques, ER&E Report No. EE.20E.83.
Plate and Spiral Heat Exchangers - A New Approach for Cost Effective Heat Transfer, ER&E Report No. EE.54E.83.
A Review of New Techniques for On-Line Heat Exchanger Cleaning, ER&E Report No. EE.92E.83.
Enhanced Nucleate Boiling Tubes: New Technology for Improved Heat Exchanger Design, ER&E Report No. EE.57E.84.
Fire Safety of Plate Heat Exchangers, ER&E Report No. EE.47E.87.
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Fouling in Heat Exchangers: New Developments, ER&E Report No. EE.92E.89.

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Plate Heat Exchangers: Extending the Range of Applications within Exxon, ER&E Report No. EE.80E.90.

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Spiral Heat Exchangers: A Technology Update, ER&E Report No. EE.100E.91.

Field Date Analysis of SPIRELF On-Line Cleaning Devices for Shell-and-Tube Heat Exchangers, ER&E Report No. EE.2E.94.

Wet Surface Air-Cooled Heat Exchangers and Evaporative Coolers, ER&E Report No. EE.16E.94.

Field Applications of Double Enhanced Tubes in Shell-and-Tube and Air-Cooled Heat Exchangers, ER&E Report No. EE.108E.94.

A Typical Mechanical Specification and a Guide for the Safe Application of Gasketed Plate-and-Frame Heat Exchangers, ER&E Report No. EE.18E.95.

Successful Application of Brush-and-Basket Heat Exchanger Tube Side On-Line Mechanical Cleaning Technology at The Baytown Refinery, ER&E Report No. EE.25E.95.

Enhanced Heat Transfer in Stratco Sulfuric Acid Alkylation Reactors, ER&E Report No. EE.96E.96

Exxon Application of the Wet-Surface Air-Cooled Heat Exchanger Technology, ER&E Report No. EE.50E.97

Field Performance Analysis of a Packinox Welded Plate Heat Exchanger, ER&E Report No. EE.45E.98

A Scoping Tool for Application of Enhanced Heat Transfer Technologies, ER&E Report No. EE.142E.99

3 DEFINITIONS AND DESCRIPTIONS

Heat transfer equipment is usually specified both by type of construction and by service. The following terminology is in general use throughout the industry for specifying the service of a unit.

Aftercooler - Aftercoolers are used to cool the discharge from the final stage of a compressor to partially remove condensable vapors.

Chiller - A chiller cools a fluid using a refrigerant to a temperature below that obtainable using ambient air or cooling water as the heat sink. Common refrigerants are ammonia, propane, ethylene and propylene; chilled water or brines are less frequently used.

Condenser - A condenser is a unit in which a process vapor is totally or partially converted to liquid. The heat sink is usually a utility such as cooling water, but can be another process stream. Generally the term "surface condenser" refers specifically to shell-and-tube units used for the condensation of low pressure exhaust steam from steam turbines or engines. In the vacuum pipestill, the overhead condenser is generally referred to as the primary condenser; sometimes the term surface condenser is used instead, to indicate a tubular exchanger rather than a barometric (direct-contact) condenser. A "direct contact condenser" refers to a unit in which the vapor is condensed by direct contact heat exchange with droplets of the heat sink fluid (usually water).

Cooler - A cooler exchanges heat between a single-phase process stream and water or air.

Evaporator - An evaporator is an exchanger specifically designed to concentrate water solutions by vaporizing some of the water.

Exchanger - In the broad sense, an exchanger is any item of unfired heat transfer equipment whose function is to change the total enthalpy of a stream. The term "heat exchanger" also conveys this meaning. In the specific (and more usual) connotation, an exchanger transfers heat between flowing process streams.

Feed / Effluent Exchangers - These exchangers are used to heat cold feed to a reactor by using the heat available from effluent of the same reactor. These exchangers operate with a close temperature approach to maximize heat recovery. In many instances, allowable pressure drop is specified as a combined feed side and effluent side pressure drop.

Heater - This is a broad classification for heat transfer equipment that adds enthalpy (usually without change of phase of the cold fluid) to a stream using a utility as a source of heat. The utility can be steam, a vapor heat transfer fluid such as Dowtherm, or a liquid heat transfer fluid such as Exxon Caloria, Mobiltherm, or other hot oil. Occasionally, a process stream of relatively large heat content is used as a utility; examples are the compressor discharge in a heat pump and the effluent stream of high temperature process reactors.

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Intercooler - Intercoolers are used to cool the discharge from one stage of a compressor before it goes to the next stage of the compressor. They are needed to maintain the discharge temperature within acceptable limits in compression services with a high compression ratio. Intercoolers increase volumetric efficiency of the compressor and partially remove condensable vapors.

Knock-Back Condenser - Knock back condensers are also known as dephlegmators or reflux condensers. The design of a knock back condenser is the reverse of the falling-film evaporator. The hot fluid being condensed enters at the bottom of the vertically mounted exchanger, flows up the exchanger, and is partially condensed. The condensed portion flows downwards and exits at the bottom of the exchanger while the portion that does not condense exits at the top. It is important to have gravity controlled laminar flow on the condensing side to prevent entrainment of the liquid in the vapor and to allow the two phases to separate because entrainment can result in unsteady or pulsed flow. Knock-back condensers may be shell-and-tube, air-cooled, spiral, or plate-fin type exchangers. The importance of a knock-back condenser is that it performs separation duties as well as heat transfer. Throughout the exchanger mass transfer occurs between the liquid moving in one direction and vapor moving in the other. This mass transfer results in fractionation of the fluid where the liquid and vapor outlet streams will have different compositions. As knock-back condenser it is used on top of distillation towers to serve as an overhead condenser. As a reflux condenser it is used on top of separators to recover any condensables in the vapor space before waste gases are incinerated. As a vent condenser it is used in steam systems to recover the condensate.

Overhead Condenser - Overhead condensers condense vapors from the top of a column. They can be partial or total condensers.

Pumparound Coolers - Pumparound coolers cool a side stream from an intermediate tray of a distillation column. The side stream or pumparound, after it has been cooled, is returned to another tray in the distillation column. A part of the pumparound may be drawn as side stream product.

Reboiler - A reboiler is a vaporizer that provides latent heat of vaporization to the bottom (generally) of a fractionation tower. Some reboilers return only vapor to the tower, referred to as "kettle reboilers", and others return mixed phase by either natural circulation, referred to as "thermosiphon reboilers", or forced flow, referred to as "pumped reboilers". Kettle reboilers are normally more expensive than other types of reboilers but tend to be the easiest to operate. Kettles have a distinctive shape in which the ID of the shell can be much larger than the tube bundle in order to separate the liquid and vapor phases at the outlet. See [DP IX-E](#) for further discussion on reboilers.

A "cascade reboiler" heat integrates two towers by using the overhead of a hotter tower to reboil the bottoms of a colder tower.

Thermosiphon reboilers are the most common type. Horizontal thermosiphons with vaporization on the shellside are commonly used in the refining industry, while vertical units with intube vaporization are favored in chemical plants. Flow on the boiling side of a thermosiphon reboiler is achieved by of the density difference between the inlet liquid and the exiting two-phase mixture. Sufficient liquid head must be provided on the inlet side to overcome the pressure drop in the piping and the exchanger.

Forced circulation reboilers use a pump to force the boiling medium through the exchanger. This type of reboiler is infrequently used because of the added cost of pumping the reboiler feed and reduced reliability due to pump failure, but may be required to overcome hydrostatic head limitations or circulation problems.

A "heat pump" is applied in some special applications where the overhead vapor is first compressed; the heat obtained by cooling / condensation of the overhead vapors is then used to reboil the tower bottoms. In such cases, the designer will often use enhanced heat transfer tubes to reduce the overall temperature difference required to produce vaporization. A reduced temperature difference requires less compression of the overhead vapors and can make the system cost effective. An example of such an application is in a propane-propylene fractionator.

Recycle Cooler - Recycle coolers are used to cool compressor discharge before it is recycled to the compressor suction and are also called surge coolers or antisurge coolers. Recycling is necessary to stop compressor surge in centrifugal compressors. In reciprocating compressors the recycle is used for capacity control. Recycle coolers allow continued compressor operation after unit shut down.

Steam Generators (Waste Heat Boilers, Heat Recovery Steam Generators, Flue Gas Coolers) - Steam generators are a special type of vaporizer used to produce steam. When the source is excess heat from process, these units are referred to as Waste Heat Boilers. When the heat source is the exhaust gas from a turbine or CO boiler; these units are referred to as Heat Recovery Steam Generators, also known as HRSG, or Flue Gas Coolers. Similar to reboilers, steam generators can be kettle, pump-through, or thermosiphon. Both pump-through and thermosiphons require a separate steam drum to disengage steam from water.

Superheater - A superheater heats a vapor, above its saturation temperature.

Vaporizer - A vaporizer is an exchanger that converts liquid into vapor. This term is sometimes limited to units handling liquids other than water.

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4 TUBULAR HEAT EXCHANGERS

4.1 TYPES AND APPLICATIONS

When designing a heat exchanger, one must first determine the type of exchanger to use. The following paragraphs outline the fields of application of the major types of tubular type heat exchangers used by ExxonMobil and by the petroleum industry, in general. A summary of the exchanger types is given in [Table 1](#).

4.2 SHELL-AND-TUBE HEAT EXCHANGERS

This is the most common type of exchanger. It consists of a tube bundle enclosed in a cylindrical casing called a shell. [DP IX-C](#) defines the nomenclature used for shell-and-tube exchangers, and a detailed discussion of this exchanger type.

There are two basic types of shell-and-tube exchangers. The first is the fixed tube sheet unit, in which both tube sheets are fastened to the shell and the tube bundle is not removable. In this type of construction, differential expansion of the shell and tubes due to different operating and non-operating conditions may require the use of an expansion joint or a packed joint.

The second type of shell-and-tube unit has one restrained tube sheet, called the stationary tubesheet, located at the channel end. Differential expansion problems are avoided by use of a freely riding floating tube sheet at the other end or the use of U-tubes. This design may be used for single or multiple pass exchangers. The tube bundle is removable from the channel end, for maintenance and mechanical cleaning.

Listing the above variations in shell-and-tube heat exchangers in order of increasing life-cycle cost for low to moderate pressure levels gives:

1. Fixed tube-sheet (single pass tubeside).
2. U-tube.
3. Floating tube-sheet (called "floating head" unit).
4. Fixed tube-sheet with an expansion joint or a packed joint with a floating tube sheet.

Shell-and-tube exchangers are designed and fabricated according to the standards of the Tubular Exchanger Manufacturers Association (TEMA). These standards are modified by the American Petroleum Institute (API) Standard 660, and the ExxonMobil International Practice **IP 6-1-1**. TEMA Standards list three standard mechanical classes of exchanger construction: R, C and B. Of these, we prefer Class R, although C may be used. Equipment fabricated in accordance with the requirements of Class R will adequately meet the heavy-duty service requirements of refinery units.

4.3 TEXAS TOWER EXCHANGERS

Texas Towers are large, vertical Shell & Tube heat exchangers, TEMA type CET. They have a single pass on the tube side and require an expansion joint in the tail-pipe, but the low pressure drop that can be obtained in a single pass unit helps achieves greater efficiency. Typical size is 60 to 80 inches (1500 to 2000 mm) in diameter with tubes up to 80 ft (25 m) long. Because they can provide a very large amount of heat transfer surface area in one shell and because flows are true counter-current they are a very good fit in Feed vs Effluent service. A typical Feed vs Effluent service using a Texas Tower can be found in the SCANfiner or CCR Reformer units. The reactor feed is normally on the tubeside because it enters as a two-phase mixture that will be vaporized and superheated. A distributor plate is used to prevent uneven flow distribution at the tubeside inlet. On the shell side, the effluent comes in all vapor and leaves partially condensed. Acoustic vibration can be a concern on the shell side, and the design could incorporate deresonating baffles. Typically, a double segmental baffle, NTIW, helical baffle or rod-baffle design is used. Approach and pinch temperature in the exchanger are important design criteria. A hot end approach of 90 to 100 F (30 to 40 C) can be achieved but the design pinch temperature in the exchanger shall not be less than 35 F (2 C). It is preferable that one exchanger be used for the Feed/Effluent because of the possibility of "liquid lock" when 2 parallel exchangers are used. In most cases a Texas Tower exchanger is in hot hydrogen service, with the incoming Effluent temperature in the range of 700 to 1000 F (400 to 550 C). If H₂S is present, 1 1/4 or 2 1/4 Cr - 1/2 Mo material will be required at the hot end with high alloy cladding, but Carbon Steel may be used at the cold end. Although the design should allow for bundle removal, the number of flanged joints should be kept to a minimum to avoid potential sources for leaks. Also note that the tube to tubesheet joints are welded.

4.4 AIR-COOLED HEAT EXCHANGERS

An air-cooled heat exchanger consists of one or more fans and one or more heat transfer bundles mounted on a frame. The bundles typically consist of high-finned tubes unlike low-finned tubes used in some shell-and-tube exchangers. The hot fluid passes

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through the tubes which are cooled by air supplied by axial fans. The choice of an air cooled condenser over water-cooled shell-and-tube exchanger depends on economics, considering onsite and offsite initial investment and operating costs.

In general, air-cooled heat exchangers should be considered for use in locations where pollution laws set strict effluent water requirements, where expansion of a once-through cooling water systems would be required, or where the nature of cooling water causes frequent plugging or corrosion problems. Air-cooled heat exchangers are frequently used to remove high level heat, with water cooling used for final "trim" cooling. Process fluid temperature to the trim-cooler should be limited to approximately 280°F (140°C) to prevent salt deposition, accelerated fouling and corrosion of the tubes.

Air-cooled heat exchangers can be used to provide emergency cooling. With the fan off, natural convection will allow an air-cooled unit to cool at about 15 to 35% of design duty, depending upon the temperature of the process fluid and ambient conditions. Air-cooled exchangers operating in cold climates may require steam heating or hot air recirculation to reduce the possibility of the process fluid freezing or solidifying. Design considerations for air-cooled exchangers are discussed in [DPIX-I](#).

Air-cooled heat exchangers occupy relatively large plot areas. Therefore, they are frequently mounted over pipe racks, drums, and other exchangers (for safety considerations, see [DP XV](#)). When considering this type of installation, one should check the heat losses from surrounding equipment, to determine if there is an effect on the air inlet temperature to the air-cooler.

4.5 DOUBLE-PIPE AND MULTITUBE HAIRPIN EXCHANGERS

Double-pipe and Multitube Hairpin exchangers consist of one or more pipes or tubes inside a pipe shell and often have two straight lengths connected at one end to form a U or "hairpin" ([DP IX-H](#)). The inner tube may be bare or finned with longitudinal fins welded the whole length of the tubes (different than the Integral or Low Fin). Fins may be cut and twisted to increase turbulence in laminar flow applications. Fin-tube bundles with greater than 7 tubes may be difficult to clean because of the longitudinal fins. Double-pipe exchangers can be easily dismantled for cleaning by removing a cover at the return bend, disassembling both front-end closures, and withdrawing the tube bundle from the rear. These exchangers are available as manufacturer's standard units, reducing their cost.

Hairpin exchangers permit true counter-current or true co-current flow, which may be of particular advantage when very close temperature approaches or very wide temperature ranges are required. In addition, because of their relatively small diameters, these exchangers are well suited for high pressure applications. Hairpin sections have been designed for up to 2,400 psig [16,550 kPa(g)] on the shellside and up to 15,000 psig [103,500 kPa(g)] on the tubeside. Metal-to-metal ground joints, ring joints, or confined O-rings are used in the front-end closures at lower pressures. For extremely high pressures [above 1000 psig or 6900 kPa(g)], use an all welded construction or consult the Heat Transfer Equipment Section of EMRE for experience with closure devices.

Commercially available single tube double-pipe sections range from 2 in. through 6 in. (50 to 150 mm) pipe size shells with inner tubes varying from 1/2 in. to 4-1/2 in. (12 to 114 mm) pipe size. Double-pipe exchangers are typically economically justifiable if the equivalent shell and tube surface area required is less than about 400 sq ft (40 sq m).

Multitube exchangers typically contain up to 750 tubes within the outer pipe shell made of 4 in. to 30 in. (100 to 760 mm) pipe. Multitube exchangers may be manufactured with over 1000 tubes in a 36 in. (915 mm) shell for special applications. The tubes, which may be either bare or finned (low fin), are available with outside diameters of 5/8 to 1.25 in. (16 to 32 mm).

5 TUBULAR EXCHANGER ENHANCED HEAT TRANSFER TECHNOLOGIES (EHT)

Use of Enhanced Heat Transfer (EHT) technologies in new or replacement tubular heat exchangers can often reduce costs, improve reliability, and facilitate debottlenecking. More than 25% of the heat exchangers in a refinery or chemical plant are suitable candidates for some form of EHT technology. Additional benefits of reduced holding volumes of hazardous fluids and reduced fouling also result in safety and environmental credits.

Often combinations of heat transfer enhancement, for example enhancement of both the shell and tube sides of tubular exchangers, can result in further economic savings. Some examples of the ways enhancement can result in capital or operating cost incentives are:

- Replacing an existing bundle with an EHT technology bundle to obtain greater heat duties (debottlenecking) while retaining the existing shell, piping, structure, and foundation.
- Using fewer heat exchangers to perform the same duty that would be required with traditional technology, reducing initial investment cost and plot space.
- Using a EHT bundle in place of traditional design technology, to reduce fouling and maintain the exchanger on-stream for a longer time between cleanings.

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- Gaining energy credits by using lower pressure steam or higher temperature refrigerant, resulting in closer temperature approaches than are possible with traditional technology (especially important for chillers and product coolers).

The results of recent R&D work have included reports that explain the value of EHT and describe numerous field applications (see [REFERENCES](#)). These reports provide characteristics and limitations, screening calculation procedures, summaries of ExxonMobil experience, and suggested potential applications.

The following paragraphs discuss ten EHT methods which are most commonly found in shell-and-tube exchangers. However, some of these technologies can be applied in other tubular type exchangers such as double-pipe, multitube, and air-cooled heat exchangers. The enhancement technologies discussed are all commercially available, proven devices.

For an initial screening, [Figure 1](#) is a logic diagram to help determine if an EHT technology is applicable under a given set of conditions. The figure is applied by starting with the specification sheet conditions for the traditional equipment (e.g., shell-and-tube) and following the logic diagram. Once an EHT technology is identified, one of the following descriptions can be reviewed to determine if the application should be pursued further. [Figure 2](#) details the process undertaken to determine if double heat transfer enhancement techniques may yield even greater economies. Listing of current applications of enhancement methods at ExxonMobil sites are available in the references.

5.1 INTEGRAL-FIN TUBES (IFT)

Integral-Fin Tubes, also known as low fin tubes ([DP IX-G](#)) have extended external heat transfer surface area in the form of short fins ranging in density from 11 fins per in. (fpi) to 40 fpi (430 to 1575 fins/m) and in height from 0.030 to 0.059 in. (0.75 to 1.5 mm). [Figure 3](#) is a sketch of an IFT. Although IFTs are not a new technology, significant advancements have expanded their applicability. The most important advances are their availability in a wide range of alloys and new fin designs with improved heat transfer characteristics.

A major advantage of IFT is that they can be used in debottlenecking schemes by retubing an existing tube bundle. For example, the replacement of bare tubes in a water-cooled condenser provides 2.5 or more times the condensing surface area while retaining the same shell, piping, structure, and insulation. This advantage can be best utilized when the shellside resistances (heat transfer and fouling) significantly control the overall coefficient. On the other hand, in shell-side condensing applications, a high surface tension will prevent good drainage of the condensate from the fin groove thus making the IFT partially ineffective. These effects should be investigated with the recommended heat exchanger design tools described in [DP IX-K](#). If finned tubes look promising for a particular application, check local experience or refer to the Heat Transfer Equipment Section at EMRE for the most recent experience base.

Tube external (shell-side) integral fins are produced in two major types. The first type, the most common, are circumferential fins which circle around the tube. These fins may be used in most types of services, including sensible heat transfer, boiling, and horizontal condensing service. Another fin type includes longitudinal fins formed axially along the tube. These fins are employed in vertical condensing services.

There is not a single, general answer to the question of whether finned tubes are susceptible to fouling. Research and experiences (some within ExxonMobil for more than 20 years) have shown that there are types of fouling for which finned tubes foul less and are easier to clean than bare tubes. In other cases, usually where a foulant forms between the fins, and expands during formation, (the fouling causing damage to the tubes) the IFT becomes ineffective.

Another consideration is the effect of IFT on tubeside pressure drop. When tubes are manufactured with integral fins, the outside diameter of the finned section is made equal to or slightly less than the outside diameter of the bare tube end. Therefore, the height of the fin will require a reduction of the inside radius of the tube and/or the tube wall thickness under the fin. If the wall thickness is maintained, the inside radius must be reduced by the fin height, which increases the tubeside pressure drop and heat transfer for the same flowrate. These effects must be checked by the engineer to ensure design constraints can still be met. Typically shell-side pressure drops are only slightly affected by the addition of finned tubes.

Integral fins may also be placed on the inside surface of the tubes, and are typically a spiral ridge (rib) that resembles rifling in a gun barrel. This spiral ridge increases tubeside turbulence, resulting in an increased heat transfer coefficient, because of an increase in fluid mixing, reducing boundary layer effects. IFTs for the bottom section of a vertical thermosyphon are sometimes used to reduce the subcooled boiling zone of the tube. The heat transfer increase is at the cost of increased tubeside pressure drop. Various manufacturers supply tubes that are finned on both the shell and tubeside for additional enhancement of heat transfer. These tubes are called double enhanced tubes and are shown in [Figure 4](#).

In finned tube applications where metallurgy has been upgraded, a reduced wall thickness under the fin may be allowable. In such cases, it is important to check the effect of the thinner wall on tube bundle vibration.

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Finned-tube technology can also be combined with one of the non-integral tubeside enhancements described in this section. The combination of technologies (e.g., IFT with TP or OMC in condensers) can sometimes be cost effective when a technology by itself would not be cost effective.

5.2 NUCLEATE BOILING TUBES (NBT)

Enhanced Nucleate Boiling Tubes (NBT) have a specially prepared surface containing cavities (nucleation sites) that can reduce the vaporizing side heat transfer resistance by up to a factor of 10. The surface can be manufactured in a number of ways, including coating and mechanical deformation. [Figure 5](#) shows examples of several of these tubes. The reduced boiling heat transfer resistance provides the opportunity to operate the exchanger with a lower heating medium temperature or to debottleneck existing equipment with a bundle retrofit.

NBT are only effective in the nucleate boiling regime; see [DP IX-E](#). Cases of film boiling or complete dryout do not benefit from NBT. For example, a large temperature difference [greater than 50°F (28°C)] between the two heat transfer fluids can often result in film boiling conditions with hydrocarbons. The use of NBT has no effect on pressure drop.

The NBT technology, like the IFT technology described earlier, can benefit from the use of double enhancement in cases where the boiling side heat transfer is not controlling. For example, double-enhanced tubes have been used in thermosiphon reboilers. Where the vertical up-flow boiling tubeside was enhanced by NBT and the shellside condensation by external fins. [Figure 6A](#) shows a tube with an internal coating boiling enhancement and external fluted condensing enhancement. [Figure 6B](#) shows a tube with external nucleate boiling T-fins and an internal spiral ridge to enhance condensation or sensible heat transfer. Tubes are also available with a tubeside spiral ridge and a shellside nucleate boiling coating.

5.3 TURBULENCE PROMOTERS (TP)

Turbulence Promoters are tubeside devices that mix the tubeside flow either across the entire tube cross section or only near the tube wall (see [Figure 7](#)).

The improved mixing or turbulence provided by TP increases the tubeside heat transfer coefficient 1.5 to 3 times over that of bare tubes at the same flowrate. Along with the heat transfer enhancement is a corresponding increase in friction factor resulting in additional pressure drop. The magnitude of the pressure drop increase depends on whether the flow is laminar or turbulent and the type of enhancement device. The pressure drop increase corresponding to a 1.5 to 3 times increase in heat transfer is approximately 3 to 10 times that of bare tubes. Typically the best heat transfer gain vs. pressure drop is achieved in initially laminar or transition flow. TP technology benefits are further augmented when used with an IFT.

Extremely viscous fluids typically flow in the laminar regime. The turbulence promoter mixes the fluid limiting the thickness of the boundary layer at the wall and increasing heat transfer. TP in viscous fluid services, called static mixers, have been used by ExxonMobil sites in fluids with viscosities up to 6×10^5 cP.

Cases that would benefit from TP technology alone are mainly in heat exchangers where the tubeside heat transfer is controlling. This is often true in exchangers where the process fluid is heated by a steam source, where fouling is a problem because of temperature-sensitive fluids, or where turndown conditions. It is important to ensure proper material selection so that the TP device does not fail during operation.

5.4 ON-LINE MECHANICAL CLEANING DEVICES (OMC)

On Line Mechanical Cleaning devices are used on the tubeside of a shell and tube bundle to prevent or minimize fouling deposition. Since fouling resistance often represents 30% or more of the surface area required in a heat exchanger design, the OMC technology can be used to design smaller exchangers. These technologies can be applied to retrofit or new designs.

Three types of on-line mechanical cleaning devices are considered here: The first is the Brush-and-Basket technology, in which brushes are cycled in both directions inside the tubes. The second is the Oscillating Wire, in which a loosely fitting wire is suspended from one or both ends of the tube; the wire contacts the tube wall as a result of fluid-induced motion and thereby minimizes the fouling layer. The third is the Recirculating Balls technology, in which sponge rubber balls continuously circulate through the tubeside of the exchanger. Brush-and-Basket on-line cleaning systems allow mechanical cleaning of heat exchanger tubes without removing the exchanger from service. [Figure 8](#) is a diagram of a Brush-and-Basket system in a shell-and-tube exchanger. Mechanical cleaning is achieved by using the motion of the process fluid itself to drive brushes through the tubes. The brushes, made of stainless steel or a polymer, scrape the tube walls as they travel, removing foulant that has collected. The flow through the tubeside of the exchanger is reversed, at intervals determined by the rate of fouling, to drive the brushes back and forth through the tubes. The flow reversal process is achieved using either an external piping valve or a flow reversing channel box. The

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brushes are held outside the tube ends by baskets fitted to the end of the tubes. This system can only be applied to exchangers with straight tubes.

The ability of the brushes to maintain the tubeside at clean condition is valuable in reducing both energy consumption and maintenance. This technology was first developed for cooling water services. ExxonMobil has employed a brush-and-basket system in benzene stripper feed/effluent service at the Baytown Refinery. This system has allowed the exchanger to operate without fouling in a service that fouled plate-and-frame exchangers in a matter of weeks. Brush-and-Basket on-line cleaning systems are applicable where heat transfer is controlled by tubeside fouling or where tubeside fouling reduces run length.

Oscillating wires are coiled wire inserts placed into the tubes of shell-and-tube heat exchangers. The motion of the process fluid through the tube and around the wire causes the wire to vibrate or oscillate. This motion helps to prevent the formation of foulant on the inside surface of the tube.

Two versions of this technology are commercially available. ExxonMobil has had successful experiences with both, but it is important that complete fluid description and all operating cases be considered. [Figure 9A](#) is an oscillating wire called SPIRELF that is suspended between two ends of each tube. [Figure 9B](#) shows a second technology, TURBOTAL, consisting of a rigid, rotating wire that is installed and suspended from only the inlet end of each tube.

These technologies have been applied in only single-phase liquids, mostly in crude preheat and hydrofining feed applications. After initial screening the manufacturer will perform a detailed analysis to determine if the desired results may be achieved with the insert. These tube inserts will result in additional pressure drop through the tubeside of the exchanger. The pressure drop increase in typical services is 2.5 to 3 psi (17 to 21 kPa) per tube pass. The turbulence created by the wire inserts has been seen to result in an increase in tubeside heat transfer coefficient, although this increase is difficult to quantify. In ExxonMobil applications internal heat transfer coefficient increases between 1.5 and 1.8 times the bare tube value have been seen.

Recirculated balls are rubber balls inserted into a water stream upstream of the tubeside of an exchanger. These balls move with the flow into the exchanger and in the process of moving through the tubes remove foulant. A catcher system removes the balls from the water stream after they exit the exchanger.

Only cooling water service can be considered for this technology because the recirculated balls are not compatible with hydrocarbon streams. The life of the recirculated balls can be significantly reduced if hydrocarbon leakage occurs into the cooling water stream. [Figure 10](#) shows a sketch of a system installation. This technology is now regularly used in large power plant surface condensers to minimize the effects of cooling water fouling.

5.5 ROD-BAFFLE EXCHANGERS (RBE)

Rod-Baffle Heat Exchangers as licensed by Phillips Petroleum differ from traditional baffled shell-and-tube heat exchangers in that RBE baffles consist of sets of rods, that produce longitudinal shellside flow, [Figure 11](#). This baffle configuration results in very low pressure drop and eliminates the tendency for tube vibration. Reduced pressure drop is a result of the removal of the segmental baffles, which increase the number of flows across the tube bundle. Tube vibration is not likely because the unsupported tube span length is reduced and the flow is all longitudinal.

Test results for an exchanger with single-phase flow showed that the RBE had approximately 80% of the heat transfer but only 15% of the pressure drop compared to the same flow through a double-segmental baffle bundle. RBE bundles are approximately 10% more costly than conventional segmental bundles and they can be installed in a TEMA exchanger in debottlenecking cases; however RBE bundles can only be used in 90° or 45° layouts.

5.6 NON-SEGMENTAL BAFFLE EXCHANGER

Non-segmental baffle exchangers operate similar to RBEs. As shown in [Figure 12](#), these baffles support tubes using a thin plate arrangement forming an "egg-crate" type design. Both in-line and staggered tube layouts may use this design.

5.7 HELICAL BAFFLE EXCHANGERS (HBE)

Helical-Baffle Heat Exchangers differ from traditional segmental baffled shell-and-tube heat exchangers in that HBE are constructed of baffles at an angle to the flow as shown in [Figure 13](#). These baffles force the shellside flow to move spirally through the exchanger. This design reduces the stagnant areas that create increased fouling in conventionally baffled exchangers. This baffle design cuts the maximum unsupported tube length in half because all the tubes are supported by each baffle in its quarter, drastically reducing flow induced vibration. The licensor, ABB LUMMUS claims that this baffle design increases the heat transfer rate over pressure drop ratio, results in smaller exchanger size over conventional baffle designs.

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5.8 TWISTED-TUBE EXCHANGERS (TTE)

Twisted tubes, as supplied by Brown Fintube Co., have an oval cross section that twists along the tube length, as shown in [Figure 14](#). There is contact between each adjoining row of tubes once each twist revolution, allowing the bundle to be constructed without conventional baffles. The contact points between tubes reduce the unsupported span length to the length of a revolution, under 3 in. (75 mm), and eliminates flow induced tube vibration. The twist of the tubes allows the shellside fluid to flow between the tubes of the bundle in a counterflow arrangement. Because tubes are in contact with each other, significantly more tubes can be packed, in same size bundle, than a conventional baffled tube bundle; as much as 40% more tubes in a bundle with 3/4 in. (19 mm) tubes on 1 in. (25.4 mm) pitch. Although the main advantages of twisted tubes are no vibration and more tube surface in same size bundle, the manufacturer also claims that increased heat transfer coefficients are attained due to the increased turbulence, particularly on the tubeside.

Tubes are welded to the tubesheet without roller expansion. Insertion of twisted tube bundles into exchanger shells is also identical as that for bare tube bundles. Twisted tubes are available in many of the same materials as bare tubes, including carbon steel, stainless steel, and copper alloys.

6 OTHER EXCHANGER TYPES

This section covers the application of other types of heat exchangers used within the petrochemical industry besides the more conventional tubular exchanger types. These other types are included in the summary provided by [Table 1](#).

6.1 BRAZED PLATE-FIN HEAT EXCHANGERS

Brazed plate-fin heat exchangers are made up of a stack of metal sheets with corrugated fins between sheets and sealed off on two sides by channels or bars to form a flow passage. All components are welded together by a brazing process in a vacuum furnace or a salt bath (see [DP IX-J](#)). Plate-fin exchangers are extremely compact and their counter or crossflow designs allow a cross between the outlet fluid temperatures. A single plate-fin heat exchanger can replace several shell-and-tube exchangers and handle more than two different fluids simultaneously. Typically plate-fin exchangers are used in cryogenic services. The most common material of construction is aluminum with maximum design conditions of approximately 1450 psig at 150°F [10,000 kPa(g) at 65°C] and with a maximum design temperature of 400°F (200°C). Brazed stainless steel plate-fin exchangers are available with maximum design conditions of 725 psig [5,000 kPa(g)] and 1200°F (650°C). Currently brazed stainless steel plate-fin exchangers are only available with areas equivalent to a 3,000 ft² (280 m²) shell-and-tube exchanger. Brazed plate fin exchangers, regardless of material, cannot be mechanically cleaned. Plate-fin type exchangers are commonly used in ethylene plants and LPG applications.

Several applications involving brazed plate fin heat exchangers, called "core-in-a-drum" heat exchangers ([Figure 15](#)), have been investigated for debottlenecking applications. This style looks attractive as a substitute for some kettle reboiler exchangers where the tube bundle is replaced with a plate fin pack. The plate fin core contains the heating fluid on one side while the other fluid flows on the other side and throughout the kettle.

6.2 PLATE TYPE HEAT EXCHANGERS (PHE)

Plate type exchangers ([DP IX-L](#)) consists of a number of parallel flow channels, formed by adjacent metal plates that are either welded or separated by gasket material around the perimeter of each plate. The plates can be formed from a variety of metals, but typically are made of stainless steel. The manufacturing process presses the plates into a corrugated shape that is different for each plate type and is proprietary to each manufacturer. The corrugations (sometimes called ribs or chevrons) both increase the mixing of the flow stream and add strength and support to the plate. The flow channel width between adjacent plates ranges from 0.05 to 0.25 in. (1.27 to 6.35 mm) and the ribs of adjacent plates have contact points with each other at regular intervals. PHEs can be designed for true counterflow because the hot and cold flow streams pass through adjacent channels over the entire length of the exchanger. This design allows closer approach temperatures than are possible with conventional shell-and-tube exchangers. The assembly of PHE facilitates mechanical cleaning and allows the addition or removal of plates to increase or decrease the heat transfer surface area of the exchanger.

The main advantages of PHE are their compact size and high heat transfer effectiveness that allow a reduced number of units, smaller space and, for offshore platforms, and reduced weight. They are especially attractive in cost when the equivalent shell-and-tube exchanger would require an alloy shell or tubes. The minimum recommended construction material for all types of PHEs and welded PHEs is Type 304 stainless steel. PHEs are presently operating in such liquid-liquid services as heat recovery loops, chemical process coolers and heaters, oil platform applications, and seawater cooling. Partially welded PHEs make good applications in product coolers using cooling water.

Gasketed plate-and-frame exchanger ([Figure 16](#)) - In this type the plates are sandwiched together by an outside frame with tie rods that provide uniform sealing of the plate-gaskets. The plates are 0.02 to 0.04 in. (0.6 to 1 mm) thick. The size of the individual This information is considered CONFIDENTIAL and shall not be released to or discussed with any persons except (a) employees of ExxonMobil Affiliates who have an appropriate research agreement with ExxonMobil Research and Engineering Company, EMRE, and (b) consultants, contractors, or employees of third parties with whom proper secrecy agreements have been executed with EMRE or such ExxonMobil Affiliates. ExxonMobil Research and Engineering Company

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plates ranges from a minimum of approximately 0.5 ft x 1.5 ft (0.15 m x 0.46 m) to as large as 4 ft x 10 ft (1.220 m x 3.05 m). Plate-and-frame exchangers have heat transfer surface areas ranging from 5 to 13,000 ft² (0.5 to 1210 m²).

The maximum temperature and pressure limits on a gasketed PHE are approximately 450°F and 350 psia [230°C and 2400 kPa(a)]. However, ExxonMobil experience indicates that designs operating at less than 300°F and 250 psia [150°C and 1700 kPa(a)] result in the most successful applications.

The use of plate-and-frame heat exchangers in services containing particulate matter is limited by the physical size of the particulate that can flow between the plates. Wide gap plate-and-frame heat exchangers are manufactured by Mueller in the USA, GEA in Germany, and Alfa-Laval in the U.S. and Sweden, to address this problem of large particulate fouling. These exchangers will handle particulates up to 0.5 in. (12 mm) in diameter through the use of thicker gaskets separating the plates and reduced contact between the plates. The thicker gaskets reduce the maximum design pressure and temperature of these exchangers below those of a typical gasketed plate-and-frame heat exchanger.

Gasketed PHEs with flammable fluids must meet ExxonMobil fire safety standards given in EE.47E.87, Fire Safety of Plate Heat Exchangers. One manufacturer produces a fire protection cover that has been tested to withstand a totally engulfing spill-type fire for one hour.

Partially or fully welded plate heat exchanger - A development on the gasketed plate-and-frame exchanger is the partially or fully welded plate exchanger. Gaskets on one or both sides of the plate are replaced by a weld in this type. The partially welded PHE is supported by a frame similar to the gasketed PHE, but the fully welded type may not be in a frame depending on the type and manufacturer. The welded channels of the exchanger may contain more corrosive fluids or fluids at higher temperatures and pressures than gasketed exchangers. The construction of the welded plate exchanger greatly reduces the possibility of incorrect assembly and increases the fire resistance of the unit. The disadvantage of conventional welded PHE is that they cannot be mechanically cleaned due to the sealed flow channels. The totally welded form of the technology has raised the application pressure and temperature limits to over 500°F and 500 psia [260°C and 3450 kPa(a)]. [Table 2](#) summarizes the specifications of the four general types of welded plate heat exchangers.

Alfa-Laval manufactures two types of fully welded PHE. The Alfa-Rex may have one side welded, to maintain mechanical cleaning ability on the other, or both sides may be welded. The Rolls-Laval, pictured in [Figure 17](#), incorporates the plates and frame of the exchanger into a single seamless block, allowing for a leak proof design and added structural strength. This exchanger has larger pressure capacities, up to 7250 psig [50,000 kPa(g)], and higher temperature limits, up to 750°F (400°C). The Rolls-Laval is currently only available in titanium and has a very high cost.

A crossflow PHE comprised of a fully welded plate pack enclosed by endplates offers the advantages of both fully welded and gasketed exchangers. This exchanger may be mechanically cleaned upon disassembly of the frame, but each flow channel is welded to allow higher operating temperatures and pressures and the use of more corrosive fluids. This type of exchanger contains gaskets to allow disassembly of the endplates, but these gaskets are similar to those of shell-and-tube exchanger girth flanges. These exchangers are rated for a maximum temperature of 750°F (400°C) and pressure of 450 psig [3100 kPa(g)]. The Compabloc exchanger, shown in [Figures 18A](#) and [18B](#), is an example of this type of PHE. Compabloc exchangers have been used in Sulfinol, MEK and seawater service.

All welded plate exchangers designed for feed-effluent service where relative pressure differences between the two fluids are small can be placed inside a cylindrical pressure vessel ([Figure 19](#)). This vessel allows construction of the plate pack to contain the differential pressure between the two streams, while the vessel is designed to contain the pressures of one of the streams. Plate exchangers designed in this manner may be used in higher pressure services than plate exchangers not contained in an external pressure vessel. The ability to achieve a large temperature cross between the outlet temperatures of the fluids in the exchanger further increases the usefulness of these exchangers in feed-effluent service. Heat exchange areas up to 110,000 ft² (10,000 m²) can be reached using a single welded-plate exchanger. Manufacturers of exchangers placed in pressure vessels include PACKINOX and SECATHEN.

6.3 SPIRAL HEAT EXCHANGERS (SHE)

The spiral heat exchanger, also called a spiral plate heat exchanger, has many of the same heat transfer characteristics as the plate heat exchanger. The SHE, shown in [Figure 20](#), is composed of two spirally wound heat transfer channels separated by welded studs. Every other adjacent SHE heat transfer channel is welded together at the edge to form the flow channels of the exchanger. Two covers and gasket material is used to seal the flow channels that are not welded closed. A leak around the gasket results in short circuiting of the fluid in the exchanger, but does not result in fluid mixing between the hot and cold streams. This construction allows access for inspection and cleaning to each side of the exchanger by removing one of the end covers. The SHE design allows much higher temperature limitations than are possible with a PHE, and may be used in highly fouling services because of the cleaning action of the single flow path.

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The SHE can be manufactured from several types of weldable metals, but the most common material used is mild steel. The size of a SHE ranges from 0.8 to 7.5 ft (250 to 2300 mm) in diameter with channel widths (length) ranging from 4 to 90 in. (100 to 2300 mm). Exchangers at the upper end of this diameter range require special methods of end cover attachment. These dimensions result in exchangers with heat transfer area ranging from approximately 5 to over 7000 ft² (0.5 to 650 m²) in a single unit. The plate material from which the SHE is made ranges in thickness from 0.06 to 0.625 in. (1.5 to 16 mm) and the flow channel spacing between adjacent spiral members ranges from 0.2 to 1.5 in. (5 to 38 mm). Spacer stud density between the spiral plates can be varied depending on pressure and mechanical cleaning requirements. Studs can be arranged in line for easier mechanical cleaning or totally removed for heavy fluids containing solids, which may be blocked by the studs.

There are three basic geometries of SHE manufacture, shown in [Figure 21](#). The geometry of Type I is a close approximation of pure counter or co-current flow pattern. This type gives the highest heat transfer effectiveness and is most often used for sensible to sensible heat transfer. The typical application is counter-current with the cold fluid starting at the outer edge and spiraling inward and the hot fluid starting at the center and spiraling outward. This configuration allows close temperature approaches between the exchanger fluids and a cross between fluid outlet temperatures. SHEs of Type II and III produce spiral flow on one side of the exchanger and crossflow on the other. The crossflow portion is used for condensation or vapor flow because of the reduced pressure drop and increased flow area. However, the crossflow type does not have the high heat transfer effectiveness of the full counterflow, Type I design. Type III SHEs combine aspects of both Type I and II SHEs to allow subcooled condensate. The initial spiral of the exchanger is of Type II with the hot fluid condensing in axial flow and the coolant in spiral flow. The final spirals of the exchanger are of Type I with the hot fluid being subcooled in spiral flow and the coolant in spiral flow.

Maximum temperature and pressure limits on SHEs are approximately 750°F (400°C) and 150 psig [1000 kPa(g)]. However, with special gasketing, bolting, and design, SHEs are operating successfully at greater than 2000°F (1100°C) and 300 psig [2000 kPa(g)]. Studless SHEs are limited to low pressure applications, a maximum of 75 psig [520 kPa(g)].

The maximum flow rates for the spiral vary with the particular type of geometry (I, II, or III). For spiral flow on both sides (Type I), the approximate maximum flow rate is 30,000 ft³/hr (850 m³/hr) for liquid, and 300,000 ft³/hr (8500 m³/hr) for vapor. For crossflow on one side (Types II and III), the approximate maximum flow rate is 700,000 ft³/hr (20,000 m³/hr) for liquid and 18 x 10⁶ ft³/hr (510,000 m³/hr) for vapor.

Spiral exchangers are compact exchangers extending their usefulness to those applications where weight is a concern, for example, exchangers mounted on structures. Type I SHEs are used in liquid to liquid, slurry, condensing and gas cooling services. They can be mounted with the centerline axis of the spiral horizontal or vertical. Type II and III SHEs are used as condensers, reboilers, and gas heaters and are normally mounted with the spiral centerline axis vertical. Other advantages of SHEs include a high heat transfer area to volume ratio, full access for inspection, and small servicing space (as compared to a shell-and-tube exchanger). Disadvantages include difficulty to repair in the field, no ability to expand for higher duty or flowrates, and poor life in cycling duties (more than 5 cycles per day).

6.4 MISCELLANEOUS TYPE HEAT EXCHANGERS

The following exchanger types are used only under special process or material conditions. Therefore, they are not discussed in detail in this manual. For further information concerning these types of exchangers, consult the Heat Transfer Equipment Section at EMRE. When exchangers of this type are required, they are normally duty-specified rather than designed. The design is left to the vendors who supply these specialized types of equipment.

Bayonet Type

Generally, a fixed tubesheet exchanger with a bayonet type element consisting of an outer and inner tube. The inner tube simply supplies the fluid to the annulus between the outer and inner tubes, with the heat transfer occurring only through the outer tube. Frequently, the outer tube is an expensive alloy material and the inner tube is carbon steel.

Bayonet type heat exchangers are useful when there is a high temperature difference between shellside and tubeside fluids, since all parts subject to differential expansion are free to move independently. Cost per square foot for these units are relatively high, since only the outer tube transfers heat to the shellside fluid. A frequent application of the bayonet type heat exchanger is vaporizing low temperature boiling fluids such as propane with steam. Also this type of unit is sometimes inserted into tanks and process vessels for heating and cooling purposes.

Cascade Coolers

A cascade cooler has a series of tubes mounted horizontally, one above the other. Cooling water from a distributing trough drips over each tube and then to a drain. Generally the hot fluid flows counter current to the water. Cascade coolers are used only where the process fluid is highly corrosive, such as in sulfuric acid cooling. These units are also called as trombone coolers, trickle coolers, or serpentine coolers. When built in larger sizes this type of coolers are referred to as "Wet-Surface Air-Coolers."

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