Heat Transfer Equipment

From processdesign

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Basic Concept

There are three mechanisms of heat transfer: conduction, convection, and radiation. In most heat exchangers, convection will be the dominant mechanism. Conduction and radiation will generally be negligible in large heat exchangers, but radiation will be important in fired heaters.

Heat transfer across a surface by convection is given by the equation: $Q = UAF\Delta T_m$

Where: Q = heat transferred per unit time (energy/time)

U = overall heat-transfer coefficient (energy/time-area-temperature)

A = heat-exchange area (area)

F = correction factor (unitless)

ΔT_m = log mean temperature difference or the temperature driving force, (temperature)

ΔT_m is the driving force for a pure countercurrent contact pattern in a tubular system. the correction factor F is used because most heat exchangers do not implement true countercurrent contact. Design equations for heat exchangers will use generally use some form of this equation with the appropriate modifications to account for different configurations and approximations. (Towler)

Heat Exchangers

Process equipment and streams will need to be heated or cooled. One way to reduce consumption of utilities is to exchange heat between these streams. For example, if a product stream requires cooling, the excess heat can be used to preheat a feed stream that requires heating by using an appropriate heat exchanger. Here the costs of an additional heating and additional cooling unit are eliminated, and replaced by the cost of a heat exchanger. The associated utility requirements of the additional units are also eliminated and replaced by the utility requirements of operating the heat exchanger.

Traditionally shell-and-tube heat exchangers in chemical industry. Standards and codes by TEMA (Tubular Exchanger Manufacturers Association) and ASME (American Society of Mechanical Engineers)

Heat exchangers are widely seen across various types of industry, mainly for heating and cooling large processes. Depending on the process, the type and size of heat exchanger can be tailored depending on certain factors. These factors include the types of fluid that will engage in heat transfer, the phase, densities, temperatures, pressures, and various other thermodynamic properties of the fluids. Heat exchangers can save companies a lot of money by reusing the energy or heat in a waste stream and using it to heat or cool a different stream in the process that is vital. This recycling of energy saves the company a significant amount of money, as well as preserves the environment from wasting more energy (Towler and Sinnott, 2013).

There are many industries that utilize heat exchangers, including the following:

- Waste Water Management

- Oil, Gas, and Petroleum Processing

- Chemical Processing

- Cryogenic Air Separation

- Power Generation

- Refrigeration

Factors to Consider

The heat exchanger must meet certain physical requirements both to carry out the specified heat exchange and operate properly as part of a system. As such, it must provide the correct area for the specified heat exchange while maintaining a reasonable pressure drop, contain the pressure of the streams, prevent leaks between the tubes and the shell, account or thermal expansion, allow for cleaning of fouling deposits, allow for thermal expansion, and phase changes in certain applications.

It should be noted that heat exchangers rarely operate at the exact conditions specified for design. Because performance will decrease with fouling, a heat exchanger may be initially overdesigned, and after some amount of fouling, underdesigned, at which point cleaning should take place. Depending on the performance of a heat exchanger at any given time, downstream processes may be affected.

Thermal and hydraulic requirements

A certain amount of energy needs to be exchanged, and the pressure drop across the heat exchanger must be accounted for in the context of the process. It may be acceptable, or may need to be maintained using pumps. The key tradeoff in heat exchangers is the heat exchanged vs. pressure drop. More surface area can always be added, but the pressure drop may become unacceptable for downstream processes. The thermal difference in the two fluids should also be considered in picking the proper heat transfer equipment, as some materials and types of heat exchangers accept larger temperature differences while others are not as efficient.

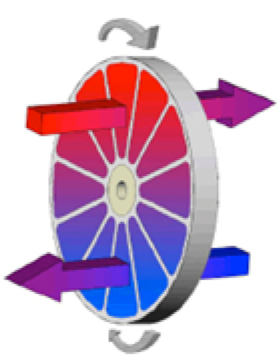


Figure 1: Turbo heat exchanger (process-heating.com)

Material compatibility

Heat exchangers must be able to maintain acceptable performance through prolonged contact in the materials with which heat is being exchanged. While regular maintenance and cleaning is unavoidable, appropriate construction materials should be chosen that are not prone to excessive corrosion or fouling. In addition, there is a certain tradeoff between costs and safety. Materials that are chosen with poor specifications to the given heat transfer application will see leakage, fouling, and possible brittleness (through temperature changes). This will lead to potential loss of material through leaks and even explosions. Material compatability is one of the most important parts in designing a heat exchanger. It is generally worth investing in a quality material that costs more upfront, as maintenance, repair, and cleaning costs will be much cheaper later on, offsetting the higher initial costs.

Operational Maintenance

Fouling on the heat transfer surface will reduce the overall heat transfer coefficient and efficiency. To maintain economical operation, the fouling will need to be periodically removed. Depending on the type of heat exchanger used, it may be disassembled and cleaned, or it will have to remain intact and be cleaned chemically, which can involve hazardous materials. Some heat exchangers are more easily disassembled and cleaned, while others are not. This trait will lead to a significant increase (or decrease) in costs. Depending on the application of the heat exchanger, it may be more vital to constantly check the amount of residue buildup in the exchanger, as this may lead to leakages, malfunctions, or explosions. There should be valves and other process controls that can monitor the current status of the exchanger, which will alert the operator to know when it is time to perform a maintenance checkup.

Figure 2: Fouled heat exchanger (regonline.com)

Environmental, health, and safety considerations and regulations

Hazards and toxicity of the streams involved must be guarded against, and safety codes must be met. Plans must be prepared to deal with leaks or failures of the heat exchanger that will minimize adverse effects. Any hazardous waste should be taken care of using proper protocol, and at the very least adhering to the guidelines of the laws in the area. However, ethics do not stop at national borders, so one must be very careful when dealing with toxic waste, especially in a populated area or ecologically rich area. Safety of the operators and workers should always be prioritized, and at no point should anyone be in any danger. If this is the case, then there needs to be a major change in the plant procedure.

Availability and cost

As with any project, the ability of the heat exchanger construction to fall within the deadlines and costs is key to the economics. Each material used to construct the heat exchanger should be properly examined for how it reacts and handles the liquids/gases that will be involved in heat transfer. There is a significant trade off between cost of material and safety. Analysis on what the required specifications in the given heat transfer application is vital to correctly identifying the correct material to use. In addition to the capital fixed costs in obtaining the heat transfer equipment, one should also analyze the variable costs. For example, the cost for the energy required to perform the proper amount of heat transfer as well as the repairing and maintaining costs of the exchanger when there is residue buildup.

Types of Heat Exchangers

Double Pipe

The double-pipe heat exchanger is one of the simplest heat exchangers utilized in industry. This exchanger's name comes from how one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first, essentially a "tube within a tube." One way to improve heat transfer is to add fins on the outside of the inner tube. This is used to improve the heat transfer of a fluid with a low heat transfer coefficient such as a viscous liquid or a gas, which is passed on the outer side.

There are two flow configurations that can be used using a double pipe heat exchanger. These are co-current flow and counter current flow.

Co-Current Flow

In co-current flow, also known as parallel flow, the two fluids that are exchanging heat are flowing in the same direction. Co-current flow is generally employed when there is less heat transfer required, as this method has a lower heat transfer coefficient. However, this flow is used much less than counter-current flow in industry, as this method is not as efficient given the capital costs used in purchasing the equipment (Mecklenburgh, 1985).

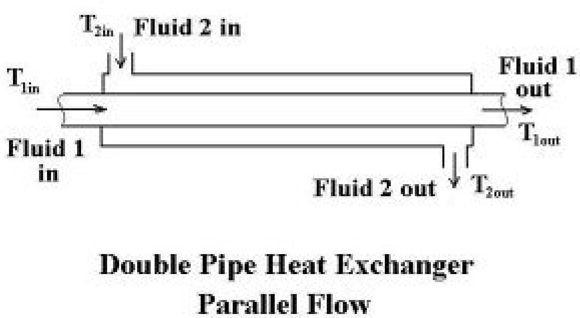


Figure 3: Double Pipe Parallel Flow (Encyclopedia.org)

Counter-Current Flow

The counter current flow mechanism is used for condensing, gas cooling, and liquid-liquid applications. Here, the fluids flow against each other in opposite directions. In the industry, counter current movement is used more often, as there is a higher rate of heat transfer. This method maximizes the temperature differences between the tube side and shell side fluids, resulting in more heat transfer and less surface area given a constant duty.

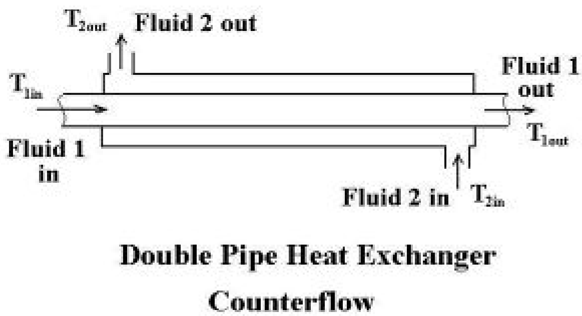


Figure 4 : Double Pipe Counter-Current Flow (Encyclopedia.org)

Table 1: Advantages and Disadvantages of Double Pipe Heat Exchangers (Leung, 2015).

Advantages	Disadvantages
Simple to operate	Higher duties see a significant increase in pricing
Relatively simple structure with large amount of heat transfer	Inspection of shell side of the tubes for damage is difficult
Easy to maintain and repair if damaged or fouling residue incurs	Having only two single flow areas leads to low fluid flow rates
Suppliers easily found globally	
High pressure and temperatures are withstanded	

Applications

Double pipe heat exchangers can withstand high pressures and temperature. They also do not have high surface area requirements, making them economically feasible for many different applications. Double pipe heat exchangers are also used where abrasive materials are present, smaller duties, and high fouling applications, such as slurries. A more common configuration of the double pipe is with modular U-tubes in a “hairpin” configuration to conserve space. Double pipe heat exchangers have lower efficiencies compared to other heat exchangers such as the shell and tube, which has led to a decline in use in industry. However, the simplicity of the double pipe heat exchanger allows its design to be studied by students much easier, and is generally the first kind of heat exchanger introduced to a student studying heat transfer.

Shell-and-Tube

A bundle of tubes is passed through a shell. Heat exchange occurs between the fluid inside the tubes (tube-side) and the fluid outside of the tubes but within the shell (shell-side). Baffles are often used to direct the flow of the shell-side fluids as well as to support the tube bundle. TEMA has set standards for construction of shell-and-tube heat exchangers as well as nomenclature for the front heads (4 types), shells (6 types), and rear heads (8 types) (Towler and Sinnott, 2013).

Three commonly used types of shell-and-tube heat exchangers are: the fixed-tube, U-tube, and floating-head type. Each has its own set of advantages and disadvantages. For example, the fixed-tube type exchanger has the simplest construction, which reduces construction cost and difficulty of routine cleaning. However, it may not be the most efficient. Meanwhile, the U-tube configuration allows more surface area inside the exchanger, but is more difficult to clean. Additionally, the flow pattern is not truly a counterflow pattern unless a longitudinal baffle is used (Type F shell). The U-tube configuration is more able to absorb the stress of thermal expansion than the fixed tube exchanger. Finally, the floating¬-head exchanger can move within the shell, which allows the exchanger to handle higher temperatures and pressures. However, it is more complex than the former two types, and thus construction can be approximately 25 percent higher for a unit of similar area (Peters et al., 2002).

The tube pitch describes the center-to-center distance for the arrangement of the tube bundle, and can be square or triangular. A larger pitch leaves more space between tubes and allows for easier cleaning, but this comes at the cost of a lower shell-side heat transfer coefficient and the need for a larger shell. A smaller pitch allows more tubes to be fit inside a given shell.

Triangular pitch allows for tighter packing of tubes in a shell. If shell-side fouling is a problem, square pitch should be used for easier cleaning. In horizontal boiling heat exchangers, square pitch should also be used to prevent vapor blanketing. Square pitch should also be used when there is a lower shell-side pressure drop (Towler and Sinnott, 2013).

The baffles lead to increased pressure drop of the shell-side fluid. However, it also improves the mixing of the fluid and increases turbulence, which leads to improved heat transfer. Again, the tradeoff between improved heat transfer and pressures drop is illustrated. The most common type of baffle is the segmental baffle. Other baffles include the disk-and-doughnut, orifice, no-tube-in-window, and triple segmental baffle.

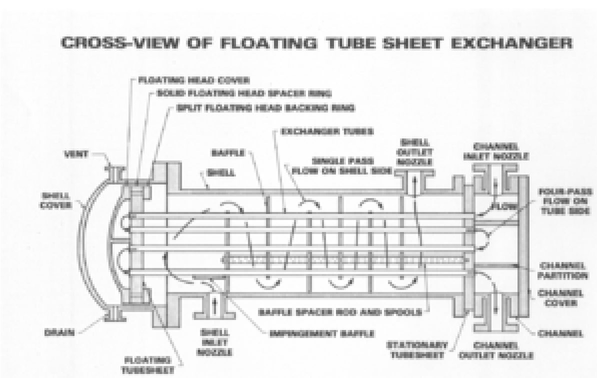


Figure 5: Shell and Tube Heat Exchanger (regonline.com)

Scraped-Surface

Crystallization systems and heat transfer involving viscous fluids, fouling may occur rapidly enough to make routine cleaning impractical. In this case, a rotating blade moves over the surface, liberating the deposited material from the surface and allowing it to exit at the bottom of the exchanger. Additionally, the motion of the blade shears the deposited product close to the wall, which results in high local heat transfer rates. Scraped-surface exchangers are generally not considered unless liquid viscosity exceeds 1 Pa•s or fouling is rapid.

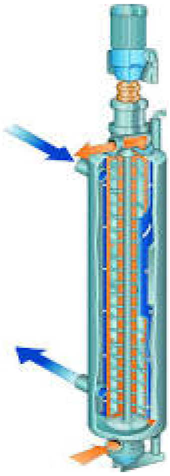


Figure 6 : Scraped-Surface Heat Exchanger (regonline.com)

Gasketed and Welded Plate

Plate heat exchangers consist of a stack of corrugated plates. The corrugation of the plates improves rigidity, controls spacing of the plates, and increases the heat-transfer area compared to a flat plate.The hot and cold streams flow countercurrently through the alternating spaces created by the plates. The modular design allows easy addition of more heat transfer area, but at a cost of increased pressure drop. Edges can be sealed with gaskets for lower pressures. Cleaning is relatively simple because the configuration can be disassembled and cleaned. For operating at higher pressures the edges can be welded. Welded-plate heat exchangers typically do not operate past 3 MPa. However, in welding the plates together, the convenience of disassembling and cleaning the modular plates is lost, and cleaning must be done chemically. Additionally, the plates are usually larger than those of the gasketed-plate exchanger to reduce the amount of welding necessary.

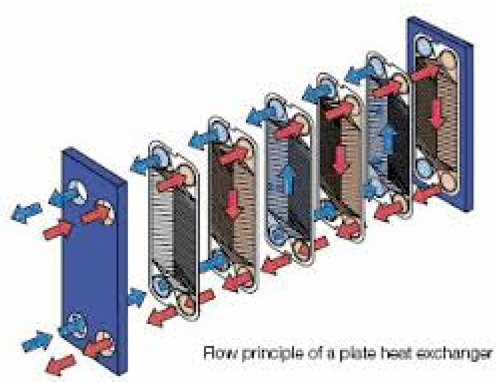


Figure 7 : Gasketed-Plate Heat Exchanger (wassertech.com)

Spiral Plate and Tube

Spiral plates are coiled to create alternating passages for the fluids. The cold fluid enters at the periphery and flows towards the center, while the hot fluid enters at the center and flows outward. Introducing the cold fluid at the periphery reduces or eliminates the need for external insulation. These heat exchangers are used for small capacities with viscous, fouling, and corrosive fluids. The end plates can be removed for cleaning the shell. However, the configuration of the tube makes the spiral plates difficult to clean.

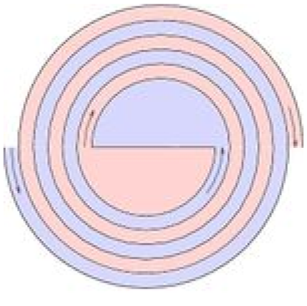


Figure 8 : Spiral Plate and Tube Heat Exchanger (regonline.com)

Plate-Fin

Plate-fin heat exchangers consist of layers of corrugated metallic sheets (fins) between flat plates to form the flow passages. The plates are sealed with metal bars on the side. Plate-fin heat exchangers can be 9 times as compact as a shell-and-tube heat exchanger, and weighs less. Can withstand design pressures up to 6 MPa in the temperature range of -270 and 800 ºC. Many different configurations of plate-fin exchangers can be used.

Plate

Plate heat exchangers utilize metal plates to perform heat transfer between two fluids. They are composed of a lot of thin metal plates compressed together by two pressure plates into a "plate pack." Fluid paths within a plate heat exchanger alternate between the plates, allowing the fluids to transfer heat in a small area without mixing. Plates are generally corrugated in order to increase the heat transfer area (surface area) and turbulence, and thus maximize the amount of heat transfer completed. Plate heat exchangers expose fluids to a larger surface area compared to a conventional heat exchanger such as a double pipe or a shell and tube. The fluids are spread out over the plates, increasing the rate of temperature change significantly. There are four types of plate heat exchangers: brazed plate, welded, semi-welded, and gasketed.

Figure 9 : Plate heat exchangers (heat-exchangers.com)

Gasketed Plate

Gasketed plate exchangers use high quality gaskets to seal plates together and protect against leakage. Maintenance and repairing costs are generally low due to the simplicity of removing the plates. Additionally, gasketed plate heat exchangers allow for increased flexibility in industrial settings, as plates can be added and removed easily to increase or decrease heat transfer as necessary (useful if fouled). Also, plates of the same type can be used in heat exchangers of the same size, so one set of backup plates can be used in all heat exchangers of the same size. Common industrial applications of this type of heat exchanger include HVAC, pharmaceutical, and dairy.

Brazed Plate

Brazed plate exchangers are generally used in refrigeration applications. They are highly resistant to corrosion due to its copper brazing and stainless steel plate composition.

Welded Plate

Welded plate exchangers have plates that are welded together, making them extremely durable and ideal for high temperatures and corrosive material. However, mechanical cleaning of plates is not an option due to the plates being welded together, so maintenance and repairing costs will be significantly higher. Common industrial applications that use this type of plate heat exchanger include hazardous liquids, process chemicals, and oil cooling.

Semi-Welded

Semi-welded exchangers show a mixture of the welded and gasketed plates. Pairs of two plates are welded together, and gasketed to other pairs of plates. Thus, one fluid path is welded while the other path is gasketed. A benefit of having this type of exchanger is that it is able to transfer more corrosive and high temperature fluids, while having the accessibility of cleaning the plates relatively easily. There is also a very low risk of fluid loss with this type of exchanger, and thus, it is recommended to use this type of heat exchanger when transferring materials that are expensive.

There are certain limitations to plate heat exchangers. Heat transfer between two liquids of large temperature differences are not very efficient, and it is generally better to use a shell and tube heat exchanger instead. There is also a possibility of high pressure loss due to turbulence created from the narrow flow channels, so applications requiring low pressure loss should not be considered (Towler and Sinnott, 2013).

Design Considerations for Plate Heat Exchangers

As with any heat exchanger type, there are several important design factors to consider when designing a plate-and-frame heat exchanger. These factors include temperature approach, pressure drop, number of passes, channel velocity, plate gap, and plate thickness, and corrugation arrangement.

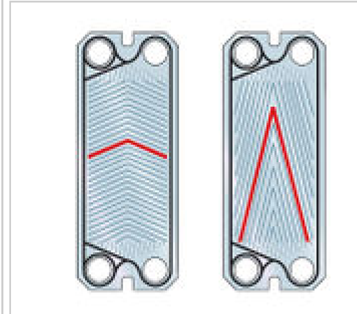
The most important factor is temperature approach. Approach temperature capabilities are better than shell-and-tube heat exchangers, with minimum approach temperatures of 1-3 F. However, it is important to note that smaller approach temperatures necessitate more plates - and thus increase cost. If the freedom to choose approach temperature exists, approach temperatures of 5-10 F are ideal for design.

Pressure drop is an important consideration, as smaller gaps in the heat exchanger result in higher pressure drops than other exchangers. Generally, the pressure drop increases with number of plates and flow rate through the exchanger, while decreasing with an increase in number of passes.

As with shell-and-tube heat exchangers, increasing number of passes decreases the pressure drop in the exchanger, allowing for the addition of heat transfer area without reaching maximum pressure drop. When considering increasing the number of passes, plate heat exchangers allow for flexibility. Odd number of passes must have opposite inlet and outlet connections, and even number passes must have same side inlet and outlet connections. However, adding another two passes only requires the addition of two "turn plates" - which are plates lacking holes on the side which is being passed.

Channel velocities are important to reduce fouling between plates. Since there is a small gap between plates, a small amount of fouling can significantly reduce heat transfer. Although increasing plate gap can lengthen the amount of time between cleanings, increasing channel velocity allows a small gap to be retained, while still increasing time between cleanings. However, channel velocities that are too high can increase the risk for a blowout. For most design applications, 1-2 ft/s allow for reduced fouling while ensuring safe operation (Peters et al., 2002).

Plate gap is exactly as it sounds - the gap between two plates. Typical gaps between plates range from 1.3 - 1.5 mm. Increasing the gap between plates reduces velocity and decreases pressure drop, but decreases heat transfer as there is more fluid that does not contact either side of the plate. Plate gap can be adjusted in industry by tightening or loosening the end bolts on the heat exchanger - although overtightening can lead to crushing, and undertightening can result in leaks.


Example of a high-theta plate (left) and a low-theta plate (right)

As with plate gap, increasing plate thickness decreases heat transfer. From heat transfer, a greater wall thickness increases resistance to heat transfer. However, when working with abrasive or corrosive fluids, thicker plates can be necessary for safety purposes.

Finally, chevron arrangement affects heat transfer. Each manufacturer configures corrugation patterns differently, with some companies offering multiple styles. In general, however, increasing the chevron angle decreases the heat transfer and the pressure drop. Therefore, altering chevron angle is another way use the trade off between heat transfer and pressure drop limitations. For the two plates shown on the right, the left plate has a high angle, and therefore higher heat transfer and higher pressure drop. Unfortunately, each company has a specific, proprietary arrangement and design of corrugation (Towler and Sinnott, 2013).

Gas-to-Gas

Gas-to-gas heat exchangers are primarily used to recover energy from combustion gases to preheat furnace air. The plain tube gas-to-gas heat exchanger is a simple countercurrent exchange through a tube bank, either in a single-pass (cross-flow) or multipass configuration (Peters et al., 2002).

Boiling and Condensing Heat Transfer

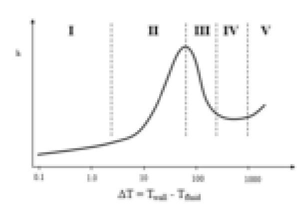
Heat transfer involving boiling liquids or condensing vapor is different from heat transfer involving constant fluid phases. Heat transfer operations that involve phase changes are typically carried out in separate units in order to account for the different physical properties of the phases.

Boiling Heat Transfer

Boilers transfer heat to boil liquids.

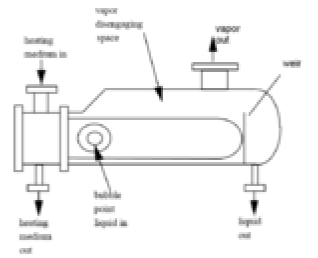
Boiling Heat Transfer Coefficient

Boiling liquids have different heat transfer regimes. I: Heat transfer with natural convection II: Heat transfer with bubbling agitation III: Heat transfer with nucleate boiling with unstable film IV: Heat transfer with stable film boiling V: Radiant Heat Transfer



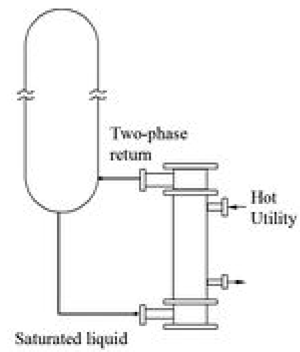
The heat transfer coefficient of a boiling liquid begins to decrease with the onset of film boiling. One method of improving the overall heat transfer coefficient is to use high-flux tubing, which utilizes a porous coating inside of tubes. It can improve boiling performance up to 10 times over a bare tube, and overall performance 2 to 5 times over a bare tube.

Kettle Reboilers



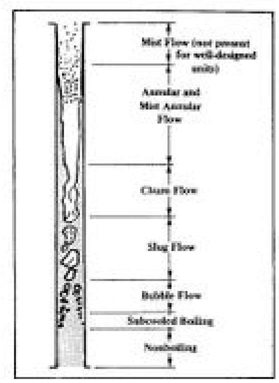
Kettle reboilers are often used as a steam generator. Pool boiling is used in kettle reboilers. In pool boiling, agitation occurs through bubbling and natural convection. The vapor-liquid separator is built-in and allows for blowdown. The weir helps to maintain the liquid level above the tube bundle. It also helps to prevent the entering bubble point liquid (distillation bottoms) from mixing with the residual reboiled liquid (exiting from the bottom). Kettle reboilers are more expensive than horizontal thermosiphons fabricated for a comparable duty.

Thermosiphon Reboilers



Thermosiphon reboilers use flow boiling. In flow boiling, agitation occurs through bubbling and forced convection at high velocities. They can be located at a height below the column sump. This allows the static head of the sump to force the column bottoms into the reboiler, which is designed for about 25 to 33% vaporization per pass. Thermosiphon reboilers can be vertical (tube-side) or horizontal (shell-side flow). Horizontal thermosiphon reboilers tend to be cheaper than vertical thermosiphons, but vertical thermosiphons are better at handling dirty fluids.

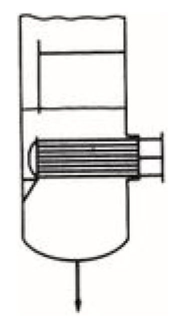
Flow is critical in a thermosiphon reboiler, and the different flow regimes will impact operation. The different flow regimes are caused by the increasing vapor/liquid ratio as the fluid passes through the thermosiphon.



Flow regimes in order of increasing vapor/liquid ratio: nonboiling < subcooled boiling < bubble flow < slug flow < churn flow < annular and mist flow < mist flow

Slug flow is unavoidable, but should be minimized. It causes noise and vibration in the thermosiphon. Annular and mist flow are also undesirable. Annular flow can be avoided by designing for less than 33% vaporization, and mist flow can be altogether avoided in well-designed reboilers.

Stab-in Reboilers



Stab-in reboilers are essentially the heat exchange tube bundle fitted inside a sump. In this case, the sump behaves in a similar capacity to a kettle reboiler, and mechanism of pooling is again pool boiling. It is important that there is enough space in the sump for good level control and to contain the entire tube bundle.

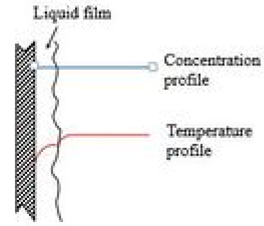
Condensing Heat Transfer

Condensing heat transfer is important because many heat transfer applications will condense the steam used as the hot stream, and often gaseous products are needed in liquid form. There are two types of condenser: total condensers and partial condensers. Both total and partial condensers need to account for the accumulation of noncondensable vapor. This can be done by venting through the top of the exchanger. The tube bundle arrangement affects overall heat transfer as well. Falling condensate from higher to lower tubes increases local turbulence and thus the heat transfer coefficient. However, condensate that collects on a tube and has yet to drain prevents the cooled heat transfer surface from contacting the vapor.

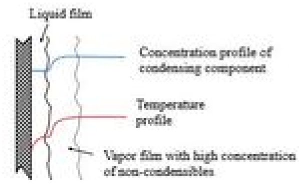
Total Condenser

In a total condenser, all the vapor that enters is condensed as a film on the heat transfer surface. The heat transfer coefficient is determined only by the thermal resistances.

Partial Condenser



In a partial condenser, not all of the vapor that enters is condensed. This allows for vapor-liquid separation. However, there will be a a vapor film with a higher concentration of high-boiling products. The heat transfer coefficient is not determined solely by the thermal resistance, but also in part by the mass transfer resistance as well. The condensable component of vapor will have to diffuse through the noncondensable component. The resistance to diffusion leads to a much lower overall heat transfer coefficient. Additionally, it complicates the calculation of heat transfer.



Heaters and Coolers

It is not always possible to couple process streams for heat-exchange. It is likely that separate heaters and coolers will have to be used in addition to a heat-exchange network for a process.

Heaters

Operating temperatures can be classified into three ranges: low (< 120C), medium (120-250C), and high (>250C). low temperature-range heaters generally tend to use condensate or steam, medium temperature-range heater tend to steam, and high temperature-range heaters tend to use fired heaters or hot oil loops (<400C)

Temperature and required heat load are important factors in selecting a heater.

Fired Heaters

Fired heaters are used for heating up to high temperatures. They are able to reach these high temperatures because they generate energy by combustion of natural gas, fuel oil, or process off-gas. Fox example, they are used to generate heat for hot oil loops or steam generators (boilers). Hot oil can be used up to 600F (35C), and fired heaters provide a way to reach those temperatures. High pressure steam, used for utilities, is approximately 480F (250C).

Because fired heaters carry out combustion, factors such as pollutant emissions and excess air feed need to be accounted for in addition to the required heat duty. Reducing emissions can incur substantial additional costs.

Common types of fired heaters include cabin heaters, U-tube heaters, and vertical cylindrical heaters.

Electric Heaters

In electric heaters, heat is generated by running electricity through wires of high resistance. Heat is exchanged with fluid passed over axially through MgO insulation. The maximum duty that is typically obtained from electric heaters is approximately 1 MW.

Advantage of electric heaters include: the ability to reach very high temperatures (up to 1200F), no cross-leakage (because only one fluid is being used), good control (because of electrical system), no site emissions (initial power generation occurring elsewhere), and applicability in cyclic operations (metal cycles are not constantly used and/or fouled). However, disadvantages of electric heaters include: both higher capital and operating costs (equipment purchase and paying for electricity), and the large voltages make them extremely hazardous if they are not properly installed, operated, and maintained.

Steam Generators

Steam is typically the primary source of heat in processes. Steam used for this purpose is generated in boilers. The heat used to generate steam comes from combustion of natural gas, liquefied petroleum gas, or heating oil (commonly #2 or #6).

Often, high-pressure steam is generated in boilers. As it moves through a plant, it can be expanded in turbines to recover energy. Most plants use more than one level of steam.

Boilers are typically sold as packaged units. The two main types are water-tube and fired-tube.

Coolers

If heat cannot be recovered directly through exchange with another process stream, high-temperature heat can still be recovered by generating steam or preheating the feed water to the boiler. This way at least some energy is recovered.

Water and air are used for most cooling applications because they are available in large quantities at minimal cost. A comparison between the two makes the tradeoffs easily apparent.

Air Coolers

Advantages of air coolers are that they do not require additional infrastructure, and air is free so that the only operating cost is the electricity for the fans. Additionally, it is easy to add extra capacity for a higher duty. However, air coolers have much lower heat transfer coefficients compared to water coolers, and as a result can take up a lot of space. They can also lead to over-cooling depending on external temperatures.

Air coolers can use forced or induced draft. In forced draft, air is pushed up through the tubes by fans, located below. In induced draft, air is pulled up through the tubes, by fans located above. Forced draft air coolers allow easier access for maintenance, and allows recirculation of air for winterizing. Induced draft air coolers have better air distribution and less air recirculation, as well as a better natural draft.

Water Coolers

Water coolers require extensive infrastructure (pipes, cooling towers, water treatment) in order to provide water for cooling. Depending on the location, cheap water is not always available, and it is expensive to add capacity to handle an increased duty. Also, fouling is a problem. However, they have much higher heat transfer coefficients than air coolers, and thus are more compact.

Refrigeration

Refrigeration is used for very low temperatures (<40C) (Towler and Sinnott, 2013).

Example Problem 1

Part a. A stream of hot fluid at $T_{h,in} = 120^oC$ flowing at $\dot{m}_h = 10\frac{kg}{s}$ needs to be cooled to $T_{c,out} = 60^oC$. Its heat capacity is $C_{p,h}2 = \frac{kJ}{kg \cdot^o C}$. A cold stream at $\dot{m}_c = 8\frac{kg}{s}$ and $T_{c,in} = 50^oC$ is available to cool it. The heat capacity of the old stream is $C_{p,c} = 3\frac{kJ}{kg \cdot^o C}$. If they are contacted in a true counter current pattern in a double tube heat exchanger with overall heat-transfer coefficient $U = 2\frac{kJ}{m^2 \cdot^o C \cdot s}$, what is the outlet temperature of the cold stream, and what is the area A needed for this heat exchange rate?

Part b. If a plate-heat exchanger were used with the same area, determine the necessary number of plates for heat transfer and ensure that the channel velocities are acceptable. Use an M10-M plate heat exchanger, with a maximum heat transfer area of 90 m^2.

Note: Assume $p_h = 1000\ \frac{kg}{m^3}$ and $p_c = 900\ \frac{kg}{m^3}$ at T_avg.

Example Problem Solution

Part a. We are trying to solve for two things in this problem: the **outlet temperature of the cold stream** $T_{c,out}$ and the **heat-exchange area** A . In order to find the outlet temperature $T_{c,out}$, we need to find the total heat transfer rate, which is equal to the amount of energy lost by the hot stream. The amount of energy gained by the cold stream is the opposite of this value. The absolute value of either will give the heat duty Q We can then relate the energy change to the temperature change using the heat capacity and mass flow rate.

$$Q = -\dot{m}_h C_{p,h}(T_{h,out} - T_{in}) = \dot{m}_c C_{p,c}(T_{c,out} - T_{c,in})$$

Plugging in values

$$1200\frac{kJ}{s} = -(10\frac{kg}{s})(2\frac{kJ}{kg \cdot^o C})(60^oC - 120^oC) = (8\frac{kg}{s})(3\frac{kJ}{kg \cdot^o C})(T_{c,out} - 50^oC)$$

We can see that $T_{c,out} = 100^oC$

Once $T_{c,out}$ is solved, we can calculate the log mean temperature driving force ΔT_m .

$$\Delta T_m = \frac{(T_{h,out} - T_{c,in}) - (T_{h,in} - T_{c,out})}{ln\frac{T_{h,out} - T_{c,in}}{T_{h,in} - T_{c,out}}} = \frac{(60^oC - 50^oC) - (120^oC - 100^oC)}{ln\frac{60^oC - 50^oC}{120^oC - 60^oC}} = 14.427$$

Plugging in our values for Q , U , ΔT_m , we can obtain the heat-exchange area A .

$$Q = 1200\frac{kJ}{s} = UA\Delta T_m = (2\frac{kJ}{m^2 \cdot^o C \cdot s})(A)(14.43)$$

From this we are able to obtain $A = 41.58m^2$

Part b. Using the area from part a, include a 10% design factor to obtain design area, DA.

$$DA = 1.10 * A = 45.73m^2$$

Next determine the size of each plate. From literature, we find that each plate has a heat transfer area of 0.24 m^2, and dimensions of 1.0 m high by 0.47 m wide. Divide design area by area per plate to determine number of plates, N.

$N = \frac{DA}{A_p} = 190.54$ plates, which rounds to 191 plates.

The number of plates seems high, but not unreasonable.

Next determine the channel velocity:

First, determine the number of hot channels and cold channels, where the number of channels, $C = \frac{N+1}{2}$

We find C = 96.

Using $\dot{m}_h = 10\frac{kg}{s}$ and $\dot{m}_c = 8\frac{kg}{s}$, we determine volumetric flow rates for hot and cold streams.

$\dot{q}_h = \frac{10\frac{kg}{s}}{1,000\frac{kg}{m^3}} = 0.01\ \frac{m^3}{s}$ and $\dot{q}_c = \frac{8\frac{kg}{s}}{900\frac{kg}{m^3}} = 8.89 * 10^{-3}\ \frac{m^3}{s}$

Determine the channel velocity by dividing volumetric flow rate per channel by the cross-sectional area through which fluid is passing, which is equivalent to the width of the plate times the distance between plates, which we will assume to be 1.5 mm.

Cross-sectional area, $A_c = 0.47m * 0.00015m = 7.05 * 10^{-5}\ m^2$

We determine that the channel velocities are as follows:

$v_{ch,h} = \frac{0.01\frac{m^3}{s}}{C * A_c} = 1.56\frac{m}{s}$ and $v_{ch,c} = \frac{8.89 * 10^{-3}\frac{m^3}{s}}{C * A_c} = 1.38\frac{m}{s}$

these velocities are slightly out of the design range of 1-2 feet per second, and are therefore reasonable but not recommended for design.

Aside: Simulation Environments to aid in plate-heat exchanger design

There are many different factors to consider when designing a plate heat exchanger. In the example problem, a few easy-to-calculate parameters were chosen. In practical application, there are several simulation packages available to aid aid in design and make designs more accurate. Aspen has design software available (developers of HYSYS) that allows for performance simulation of gasketed, welded, and brazed heat exchangers. It also can provide optimum heat exchanger configuration. (AspenTech, 2015) Xphe also has a simulation package available that allows for heat exchanger design and analysis. It also allows for different chevron angles to be specified, as well as non-newtonian fluids. (HTRI, 2015) Both programs have an extensive bank of fluids and the ability to specify an original fluid not in memory.

Conclusions

Efficient use of thermal energy is critical in chemical processes, many of which include energy-intensive separations. How heat is used has a significant impact on process economics, and it is desirable to find ways to reduce its consumption. Heat exchangers provide a way to reduce energy consumption by taking advantage of process stream conditions and coupling streams that need to be heated with those that need to be cooled. Although use of heating and cooling utilities may be inevitable, their loads can be reduced through efficient heat-exchange networks. Proper selection and design of both heat exchangers and utilities equipment is important, and is dependent on many factors. A major problem that occurs with heat exchangers is fouling. Deposits on heat transfer surfaces can lead to reductions in efficiency. Routine maintenance is important, and the ease with which this is done also play a major part in equipment selection.

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