Heat Exchanger

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Introduction

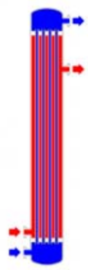
- A **heat exchanger** is a device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly contacted.
- They are widely used in petroleum refineries, chemical plants, petrochemical plants, natural gas processing, refrigeration, power plants, air conditioning and space heating.
- *One common example of a heat exchanger is the radiator in a car, in which the heat source, being a hot engine-cooling fluid, water, transfers heat to air flowing through the radiator [i.e. the heat transfer medium].*

Heat exchangers in nature

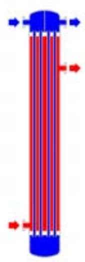
- Heat exchangers occur naturally in the circulation system of whales.
- Arteries to the skin carrying warm blood are intertwined with veins from the skin carrying cold blood causing the warm arterial blood to exchange heat with the cold venous blood.
- This reduces overall heat loss by the whale when diving in cold waters.
- Wading birds use a similar system to limit heat losses from their body through their legs into the water

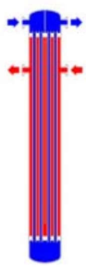
Flow arrangement

- Heat exchangers may be classified according to their flow arrangement.
- In *parallel-flow* heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side.



- In a *cross-flow* heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.
- In *counter-flow* heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is most efficient, in that it can transfer the most heat





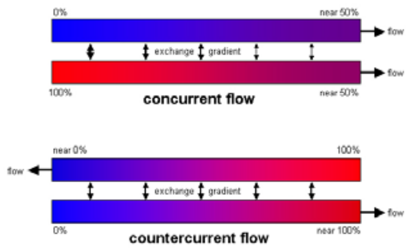
- For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger.
- The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

Countercurrent exchange

- **Countercurrent exchange** is a mechanism used to transfer some property of a fluid from one flowing current of fluid to another across a Semipermeable membrane or thermally-conductive material between them.
- The property transferred could be heat, concentration of a chemical substance, or others

- Countercurrent exchange is used extensively in biological systems for a wide variety of purposes.
- For example, fish use it in their gills to transfer oxygen from the surrounding water into their blood, and birds use a countercurrent heat exchanger between blood vessels in their legs to keep heat concentrated within their bodies.

- In biology this is referred to as a Rete mirabile. Mammalian kidneys use countercurrent exchange to remove water from urine so the body can retain water used to move the nitrogenous waste products.
- Countercurrent exchange is also a key concept in chemical engineering thermodynamics and manufacturing processes, for example in extracting sucrose from sugar beet roots.



- The diagram presents a generic representation of a countercurrent exchange system, with two parallel tubes containing fluid separated by a semipermeable or thermoconductive membrane.
- The property to be exchanged, whose magnitude is represented by the shading, transfers across the barrier in the direction from greater to lesser according to the second law of thermodynamics.

- With the two flows moving in opposite directions, the countercurrent exchange system maintain a constant gradient between the two flows over their entire length.
- With a sufficiently long length and a sufficiently low flow rate this can result in almost all of the property being transferred.

- By contrast, in the concurrent (or co-current, parallel) exchange system the two fluid flows are in the same direction.
- As the diagram shows, a concurrent exchange system has a variable gradient over the length of the exchanger and is only capable of moving half of the property from one flow to the other, no matter how long the exchanger is.
- It can't achieve more than 50%, because at that point, equilibrium is reached, and the gradient declines to zero.

Example

- In a concurrent heat exchanger, the result is thermal equilibrium, with the hot fluid heating the cold, and the cold cooling the warm. Both fluids end up at around the same temperature, between the two original temperatures.
- At the input end, we have a large temperature difference and lots of heat transfer; at the output end, we have a small temperature difference, and little heat transfer.
- In a countercurrent heat exchanger, the hot fluid becomes cold, and the cold fluid becomes hot.

- At the hot end, we have hot fluid coming in, warming further hot fluid which has been warmed through the length of the exchanger. Because the hot input is at its maximum temperature, it can warm the exiting fluid to near its own temperature.
- At the cold end, because the cold fluid entering is still cold, it can extract the last of the heat from the now-cooled hot fluid, bringing its temperature down nearly to the level of the cold input.

Counter-current exchange of heat in organisms

- Counter-current exchange is a highly efficient means of minimizing heat loss through the skin's surface because heat is recycled instead of being dissipated.
- This way, the heart does not have to pump blood as rapidly in order to maintain a constant body core temperature and thus, metabolic rate.

- When animals like the leatherback turtle and dolphins are in colder water to which they are not acclimatized, they use this CCHE mechanism.
- Counter current heat exchangers are made up of a complex network of peri-arterial venous plexuses that run from the heart and through the blubber to peripheral sites (i.e. the tail flukes, dorsal fin and pectoral fins).

- Each plexus consists of a singular artery containing warm blood from the heart surrounded by a bundle of veins containing cool blood from the body surface.
- As these fluids run past each other they create a heat gradient in which heat is transferred.
- The warm arterial blood transfers most of its heat to the cool venous blood in order to conserve heat by recirculating it back to the body core.
- Since the arteries are losing a good deal of their heat, by the time they reach the periphery surface, there will not be as much heat lost through convection.

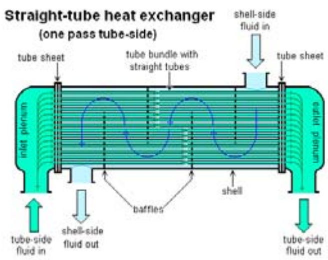
Types of heat exchangers

1. Shell and tube heat exchanger
2. Plate heat exchanger
3. Regenerative heat exchanger
4. Adiabatic wheel heat exchanger
5. Fluid heat exchanger
6. Dynamic scraped surface heat exchanger
7. Phase-change heat exchanger

1. Shell and tube heat exchanger

- A typical heat exchanger, usually for higher-pressure applications, is the shell and tube heat exchanger which consists of a series of tubes, through which one of the fluids runs.
- The second fluid runs over the tubes to be heated or cooled.
- The set of tubes is called *tube bundle*, and may be composed by several types of tubes, plain, longitudinally finned, etc.

- *They are extensively used as process heat exchangers in the petroleum-refining and chemical industries, as steam generators, condensers, boiler feed water heaters and oil coolers in power plants.*

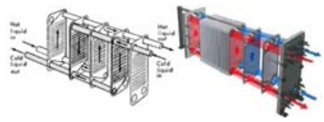


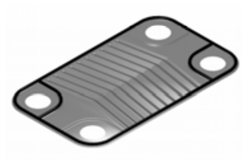
2. Plate heat exchanger

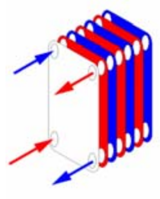
- Another type of heat exchanger is the plate heat exchanger.
- One is composed of multiple, thin, slightly-separated plates that have very large surface areas and fluid flow passages for heat transfer.
- This stacked-plate arrangement can be more effective, in a given space, than the shell and tube heat exchanger. Advances in gasket and brazing technology have made the plate type heat exchanger increasingly practical. In HVAC applications, large heat exchangers of this type are called *plate-and-frame*; when used in open loops, these heat exchangers are normally of the gasketed type to allow periodic disassembly, cleaning, and inspection.

- There are many types of permanently-bonded plate heat exchangers such as dip-brazed and vacuum-brazed plate varieties, and they are often specified for closed-loop applications such as refrigeration.
- Plate heat exchangers also differ in the types of plates that are used, and the configurations of those plates. Some plates may be stamped with "chevron" or other patterns, where others may have machined fins and/or grooves.

- *These exchangers are relatively compact and lightweight heat transfer surfaces, making them attractive for use in confined or weight-sensitive locations such as on board ships and oil production platforms.*
- *Pressures and temperatures are limited to comparatively low values because of the gasket materials and the construction.*
- *They are typically used in the food processing industry because they can be disassembled for cleaning and sterilization.*







3. Regenerative heat exchanger

- A third type of heat exchanger is the regenerative heat exchanger.
- In this, the heat from a process is used to warm the fluids to be used in the process, and the same type of fluid is used either side of the heat exchanger.
- These heat exchangers can be either plate and frame or shell and tube construction.
- *Regenerator are used extensively in electrical power generating stations for air preheating. they are also used in vehicular gas turbine power plants, in cryogenic refrigeration units and in the food dehydration industry.*

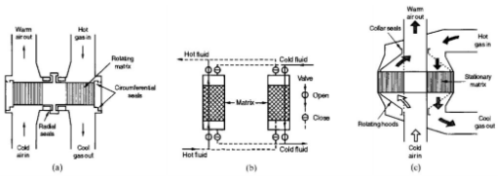


Figure 11, Regenerators: (a) rotary, (b) fixed-matrix, and (c) rotating hoods.

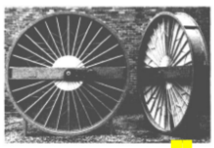


Figure 13, typical rotary regenerators or heat wheels.

4. Adiabatic Wheel heat exchanger

- A fourth type of heat exchanger uses an intermediate fluid or solid store to hold heat, which is then moved to the other side of the heat exchanger to be released.
- Two examples of this are adiabatic wheels, which consist of a large wheel with fine threads rotating through the hot and cold fluids, and fluid heat exchangers.
- This type is used when it is acceptable for a small amount of mixing to occur between the two streams.

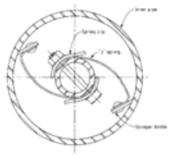
5. Fluid heat exchangers

- This is a heat exchanger with a gas passing upwards through a shower of fluid (often water), and the water then taken elsewhere before being cooled.
- This is commonly used for cooling gases whilst also removing certain impurities, thus solving two problems at once.
- It's widely used in espresso machines as an energy-saving method of cooling super-heated water to be used in the extraction of espresso.

6. Dynamic Scraped surface heat exchanger

- Another type of heat exchanger is called dynamic heat exchanger or scraped surface heat exchanger.
- This is mainly used for heating or cooling with high viscosity products, crystallization processes, evaporation and high fouling applications.
- Long running times are achieved due to the continuous scraping of the surface, thus avoiding fouling and achieving a sustainable heat transfer rate during the process.

- *The range of applications covers a number of industries including food, chemical, petrochemical and pharmaceutical.*



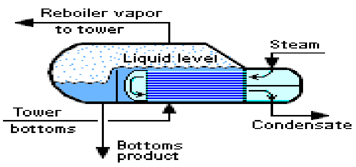
7. Phase-change heat exchangers

- In addition to heating up or cooling down fluids in just a single phase, heat exchangers can be used either to heat a liquid to evaporate (or boil) it or used as condensers to cool a vapor and condense it to a liquid. In chemical plants and refineries, reboilers used to heat incoming feed for distillation towers are often heat exchangers.
- Distillation set-ups typically use condensers to condense distillate vapors back into liquid.

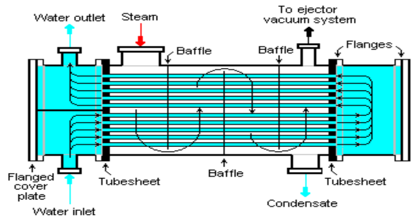
- Power plants which have steam-driven turbines commonly use heat exchangers to boil water into steam. Heat exchangers or similar units for producing steam from water are often called boilers.
- In the nuclear power plants called pressurized water reactors, special large heat exchangers which pass heat from the primary (reactor plant) system to the secondary (steam plant) system, producing steam from water in the process, are called steam generators.
- All power plants, fossil-fueled and nuclear, using large quantities of steam have large condensers to recycle the water back to liquid form for re-use.

- In order to conserve energy and cooling capacity in chemical and other plants, regenerative heat exchangers can be used to transfer heat from one stream that needs to be cooled to another stream that needs to be heated, such as distillate cooling and reboiler feed pre-heating.

- This term can also refer to heat exchangers that contain a material within their structure that has a change of phase.
- This is usually a solid to liquid phase due to the small volume difference between these states.
- This change of phase effectively acts as a buffer because it occurs at a constant temperature but still allows for a the heat exchanger to accept additional heat.
- One example where this has been investigated is for use in high power aircraft electronics



Typical kettle reboiler used for industrial distillation towers



Typical water-cooled surface condenser