UNIT SEVEN
HEAT FLOW (THERMODYNAMICS)

Special Terms

Thermodynamics: The science dealing with the generation and flow of heat, and the relationship between heat and other forms of energy (chemical, mechanical, and electrical).

Sparger: A perforated pipe or other container used for releasing gas in the form of small bubbles into liquid.

Heat Exchanger: A device used to transfer heat from one fluid to another.

Shell-and-Tube Heat Exchanger: The most common variety of heat exchanger used in process plants. It consists of a number of tubes inside a cylindrical vessel called a shell. One fluid flows inside the tubes, the other outside the tubes but within the shell.

Tubeside: Within the tubes of a shell-and-tube heat exchanger.

Shellside: Outside the tubes, but within the shell, of a shell-and tube heat exchanger.

Steam Trap: A device that automatically permits liquids to drain from a line, but prevents the exit of steam.

Condensate: The material formed when vapor is cooled and changed, or condensed, into liquid.

Dowtherm: A specialized liquid with a high boiling point. It is used in a heat exchanger to transfer heat to other materials.

Nozzle: An opening in a vessel to which a pipe can be connected; a part which directs the flow of liquid when connected to a hose.

Countercurrent: A kind of flow in which two liquids move in directions opposite to each other. When both move in the same direction, the flow is said to be *cocurrent*.

<u>Condenser</u>: A heat exchanger used for cooling vapor and condensing into liquid.

<u>Laminar Flow</u>: The smooth flow in a pipe in which the fluid in the pipe's center moves at the highest speed and the fluid near the pipe's walls moves at the lowest speed.

<u>Turbulent Flow</u>: A flow that is agitated, rather than smooth, and contains swirls and eddies.

<u>Reynolds Number</u>: A mathematical technique for predicting the transition between laminar and turbulent flow in a pipe.

Vocabulary Practice

1. Define *thermodynamics.*
2. What is a *sparger?*
3. What is a *heat exchanger* used for?
4. Describe a *shell-and-tube heat exchanger*.
5. What does *tubeside* mean?
6. What is the *shellside* of a heat exchanger?
7. What does a *steam trap* do?
8. What is *condensate*?
9. What is *Dowtherm*? What is it used for?
10. What is a *nozzle*?
11. What is meant by *countercurrent*? What is its opposite?
12. What is a *condenser* used for?
13. Describe *laminar flow*.

14. How does *turbulent flow* differ from laminar flow?

15. What is the *Reynolds number* used for?

Heat Flow (Thermodynamics)

In almost any chemical process plant, materials are constantly being heated or cooled. This is done for a variety of reasons. As we have seen in the previous unit, it is often necessary to heat viscous materials in order to make them flow easily. Another reason for heating is to melt solids, or to change liquids into vapors by boiling them. Chemicals may be heated to increase the speed of a chemical reaction or to make it occur at all. A handy rule known to most chemical engineers is that a 10^{o}C increase in temperature will approximately double the rate of most reactions. But some chemical reactions give off heat as they occur; such materials generally require cooling if the reaction is to be properly controlled. Cooling is also required to change, or condense, vapors into liquids and to freeze liquids into solids.

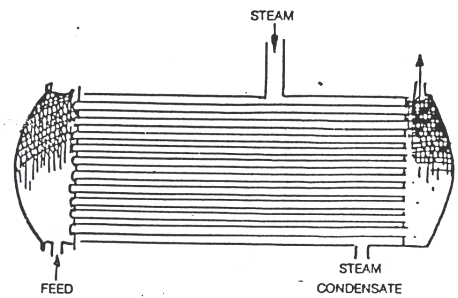
In many reactions the temperature influences the products being formed. Consequently the temperature must be controlled so that the materials remain at the temperature that produces the highest yield of the most desired product.

The science concerned with the generation and transfer of heat is called ***thermodynamics;*** this subject is emphasized in every chemical engineer's education. In almost all chemical process plants, heat is generated by the burning of fossil fuels – coal, oil, or natural gas. The heat given off by the burning fuel may be used directly, but most often it is used to generate steam which is piped to the place where heat is needed.

The easiest way of heating a liquid with steam is to bubble the steam directly into the liquid. For example, steam can be supplied to a pipe immersed in the liquid; a number of small holes are drilled in the pipe to allow the steam to escape in small bubbles. Such a device is called a ***sparger.*** The bubbles of steam rise up, transferring heat to the liquid and mixing it at the same time. During this process, some or all of the steam condenses into water, which remains in the liquid being heated. Consequently, this kind of heating, called direct injection of steam, can be used only if the pressure of condensed water is not a problem.

In most cases, direct injection of steam is impossible; the steam and the liquid to be heated must be kept separate. To heat the liquid without direct contact, a piece of equipment called a ***heat exchanger*** is used; it has a barrier of some solid material between the heating medium and the material to be heated. Many varieties have been invented, but by far the most common type is the ***shell-and-tube heat exchanger*****.**

The material to be heated may be ***tubeside*** (passed through the tubes), with the steam ***shellside*** (outside the tubes). It is possible to have steam on the tubeside and the other material on the shellside, but this is uncommon. Usually the steam is on the shellside so that it condenses on the outside of the tubes. The resulting water falls to the bottom of the shell where it is allowed to pass out of the heat exchanger by means of a special device called a ***steam trap***. This is designed to permit the escape of ***condensate*** (water condensed from the steam) while trapping the steam (preventing it from escaping).



Shell-and-Tube Heat Exchanger

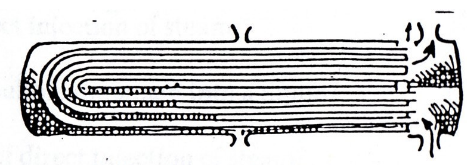
At normal atmospheric pressure, water boils at 212°F (100°C) and its steam is at the same temperature. If the pressure is increased, the boiling point of the water (and the temperature of the steam being produced) rises. To use high-temperature steam, it is necessary to design and build all equipment to withstand the high pressure associated with the high temperatures. High-pressure equipment is expensive. Sometimes, to provide high temperatures without having to deal with high pressures, chemical engineers use special heat-transfer liquids for heating. These are materials that remain liquid at much higher temperature than water. Two common heat-transfer liquids are known as Dowtherm A and Dowtherm E. (***Dowtherm*** is a trademark of the Dow Chemical Company, which manufactures and markets the products). Dowtherm A is a mixture of two chemicals: diphenyl and diphenyl oxide. It boils at about 450°F (230°C). Dowtherm E is o-dichlorobenzene, which boils at about 300°F (130°C). Some mineral oils are also sold for use as heat-transfer liquids at temperatures ranging to about 600°F (315°C), but most tend to deteriorate if kept at high temperatures for a long time. (The Dowtherm materials are very stable, even after many years of use at high temperatures.)

If a material is to be cooled, a shell-and-tube heat exchanger can also be used. The cooling medium is normally water, chilled water, or cold brine. As mentioned earlier, brine (a solution of salt in water) is used because it freeze at a lower temperature than pure water. Sometimes liquids are cooled by circulating them through pipes exposed to the atmosphere; this is called an air-cooled heat exchanger. The cooling process is speeded if a fan is used to blow cool air rapidly over the tubes.

When a shell-and-tube heat exchanger is used for cooling, the material to be cooled may be either on the tubeside or the shellside, with the cooling medium on the other side. If one of the two liquids is more corrosive than the other (brine, for example, can be corrosive) it is usually on the tubeside. The tubes can then be made of a corrosion-resistant material, with a cheaper material for the shell. If a corrosive material is used on the shellside – in contact with both the inner surface of the shell and the outer surface of the tubes – both the tubes and shell must be able to withstand corrosion.

It is possible to operate shell-and-tube heat exchangers in either the horizontal or vertical position, but horizontal exchangers are most common. When steam is used for heating, it is always introduced through the upper opening, or ***nozzle***, in the shell, so that the lower opening can be used for draining condensate. If a pool of condensate builds up in such an exchanger (usually due to a malfunctioning or wrongly sized steam trap) and submerges some of the tubes, the heat transfer suffers because condensing steam transfers heat more rapidly than does hot water. When a liquid is used on the shellside, it is always introduced through the lower nozzle and withdrawn through the upper nozzle. In this way the engineer can be assured that the exchanger remains full, with liquid surrounding all the tubes.

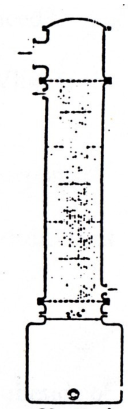
Shell-and-tube heat exchangers are so widely used that they are available as stock items from many manufacturers. There are a number of standard designs used throughout the industry. These are detailed in a publication of the Tubular Exchanger Manufacturers Associa-tion (TEMA) and are therefore called the TEMA Standards. However, no group of standard exchangers could fulfill all needs, so many exchangers are custom designed and manufactured. The size of the shell-and-tube heat exchanger needed for any particular job depends mainly on the amount of heat to be transferred and the volume of fluid to be handled. The calculations are learned in college by most chemical engineers, but computer programs now do them automatically.



Shell-and-Tube Heat Exchanger

Although most heating is done with steam or heat-transfer liquid such as Dowtherm, other liquids may also be used as the heating medium. This is most commonly done when there is one liquid stream in a plant that needs to be heated and another that needs to be cooled. Passing both streams through the same heat exchanger will accomplish both objectives simultaneously. When a heat exchanger is used with liquids on both the tubeside and the shellside, the two liquids are usually made to flow in opposite directions; this is known as ***countercurrent*** flow. If both materials flow in the same direction the flow is called ***cocurrent***.

Sometimes a heat exchanger is designed to chill the vapors of a substance and condense it into a liquid. A special exchanger of this kind is called a ***condenser*** because of the way it is used, although it is not too different from any other exchanger.



Vertical

When used as condensers, shell-and-tube heat exchangers are often mounted vertically.

When a fluid flows in a pipe, it moves fastest at the center of the pipe and slowest at the wall because of friction between the pipe and the flowing fluid. When fluid flows relatively slowly, there can be a fairly thick layer of fluid near the pipe wall that hardly moves at all. This condition is known as ***laminar flow***, and makes for poor heat transfer because the static layer of fluid near the wall acts as a resistance to the movement of heat. When fluid is flowing rapidly, swirls and eddies are set up that reduce the thickness of the static layer near the pipe wall, and thereby decrease the resistance to the movement of heat – or increase the rate of heat transfer. This kind of agitated flow is known as ***turbulent flow***.

The speed at which laminar flow changes to turbulent flow was investigated early in this century by an experimenter named Osborne Reynolds. He worked out a relationship, known as the ***Reynolds number*** that helps to determine the transition from laminar to turbulent flow. The Reynolds number is found by multiplying the inside diameter of the pipe by the fluid velocity and the fluid density, and then dividing by the fluid viscosity. The units used for the variables are selected so that all the units cancel out; hence, the Reynolds number is known as a dimensionless number. (For example, diameter in centimeters, velocity in centimeters per second, density in grams per cubic centimeter, and viscosity in grams per centimeter-second.)

When the Reynolds number is less than 2,100, flow is always laminar. When it is above 4,000, flow is always turbulent. Between Reynolds numbers of 2,100 and 4,000, the flow may be either laminar or turbulent, depending on conditions at the entrance of the pipe and on the distance downstream from the entrance.

Discussion

1. What are some of the reasons for heating materials in chemical process plants?

2. What are some reasons for cooling materials?
3. What is the simple rule that relates temperature to rate of reaction of chemicals?
4. How is heat usually obtained in process plants?
5. Describe heating by direct injection of steam.
6. What might be used to bubble the steam into a liquid?
7. What is a disadvantage of direct injection of steam?
8. What is a heat exchanger used for?
9. What is the most common type of heat exchanger?
10. What is the difference between the tubeside and the shellside of a shell-and-tube heat exchanger?
11. How is condensed steam usually removed from a heat exchanger?
12. At what temperature does water boil under atmospheric pressure? What is the temperature of the steam produced?
13. How can the temperature of steam be increased? What is the disadvantage of doing this?
14. What materials, besides steam, are used for heating purpose?
15. What liquid is usually used for cooling in shell-and-tube heat exchanger?
16. Describe an air-cooled heat exchanger.
17. Why is it desirable to use a corrosive material on the tubeside of a tubular exchanger rather than on the shellside?
18. Are shell-and-tube exchangers usually mounted in the horizontal or vertical position?
19. Is steam usually introduced through the upper or lower nozzle of an exchanger's shell? Why?

20. Is cooling liquid normally introduced through the upper or lower nozzle of a shell-and-tube heat exchanger? Why?
21. What would you call a heat exchanger that is designed to condense a vapor?
22. Describe the difference between laminar and turbulent flow.
23. What is the name of the relationship that enables an engineer to predict whether flow is likely to be laminar or turbulent?

Review

A. Choose any chemical process with which you are familiar and discuss at what stages of the process materials have to be heated and what stages they have to be cooled.

B. Complete the following sentences with the proper word or phrase.

1. In a shell-and-tube heat exchanger, liquid outside the tubes is said to be on the ________________
2. A ____________________ is an opening on a vessel to which a pipe can be connected.
3. When fluids are flowing _______________________, they are moving in opposite directions.
4. A ___________________ automatically permits condensate to leave but does not permit steam to leave.
5. If the flow in a pipe is __________________, heat transfer will be better.
6. A _____________ may be used to bubble gas into a liquid.

7. A material made by the Dow Chemical Company, called ________________, is used as a heat transfer liquid.

8. An engineer studies ______________________ to learn about the flow of heat.

9. The _______________________ is used to predict the transition between laminar and turbulent flow.

10. The __________________ heat exchanger is the most common type used in process plants.

11. A ____________________ is a heat exchanger used to change vapor into liquid.