

Basics of Mechanical Engineering-3

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Week 06

Lecture 24: Heat Exchangers and Mass Transfer

Welcome to the next lecture on Heat Exchangers and Mass Transfer. We discussed conduction, convection, and radiation modes of heat transfer in the previous lecture.

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- Mass Transfer



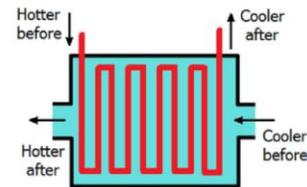
In this lecture, we will explore what heat exchangers are. There are different types of heat exchangers, such as shell and tube heat exchangers. What is a heat exchanger?

From the word itself, you can understand. There is an exchange of heat. It can be between the fluid and the surroundings. There is an exchange. The exchange can be from higher to lower temperature or lower to higher temperature.

Whatever it may be. So, heat exchangers include shell and tube heat exchangers, shell and coil heat exchangers, pipe and pipe heat exchangers, plate-type heat exchangers, boiling and condensation, boiling heat transfer, and condensation heat transfer. Finally, we will explore mass transfer.

Heat Exchanger

- A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another.
- The media may be separated by a solid wall to prevent mixing or they may be in direct contact.
- They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment.
- The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.



Heat Exchangers. As I mentioned, a heat exchanger, from the name itself, clearly indicates an exchange of temperature. A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another.

The medium can be liquid, or the medium can be air. So here, this is passed through a tube inside which a working fluid flows, right? It is passed through, and then you try to take it out through the cooler side. So here, you can pass a working fluid through, or you can try to have a working fluid outside, and the gas can be used to reduce the temperature. That is also possible.

So the working fluid can be here, or the working fluid can be here. The working fluid can be gas or liquid, and here the outside can be gas or liquid—whatever you need, it can be, right? So, this is the equipment you send cooler before. So, then you have all the fluid flowing through, then hot before. So, you start from here and push it through.

So, then when the cold air is passed by, the hot air is removed from the other side. It can be used as a heater where the hot air is blown into the room, so you get a warm effect.

The media may be separated by a solid wall to prevent mixing, or they may be in direct contact. So the working fluid can flow inside a tube, or it can be outside. They don't want these two to mix; that is why they have a tube.

The media may be separated by a solid wall. So, the pipe is a solid wall to prevent mixing, or they may be in direct contact. They are widely used in refrigeration, air conditioning, power plants, chemical plants, petroleum chemical plants, petroleum refineries, natural gas processing, and sewage treatment. Almost in every place, they use these heat exchangers. Wherever they want to exchange temperatures between the working fluid and the surroundings.

The classical example of a heat exchanger is found in an internal combustion engine (IC engine), in which a circulating fluid cools the engine by a flow of coolant through a radiator coil. Nowadays, you don't see that impact. Ten years ago, you could see when you went on a highway, after every 100 kilometers or every 200 kilometers, people used to stop their vehicles, open the radiator on a hot sunny day, and start pouring water into it. Now, they have changed the working fluid from water to an oil-based one. So here, what happens is the conductivity is reduced.

So once the conductivity is reduced, the water does not boil. In the radiator nowadays, you do not see boiling water coming out. So, the internal combustion engine, in which a circulating fluid known as engine coolant flows through the radiator coil and air is passed through the coil, cools the coolant and heats the incoming air.

Heat Exchanger



Classification of Heat Exchangers by Flow Configuration

There are four basic flow configurations:

- 1) Counter Flow
- 2) Concurrent Flow
- 3) Cross flow
- 4) Hybrids such as Cross Counter flow and Multi Pass Flow



The classification of a heat exchanger by flow configuration. There are four types of flow configurations. Counter flow, you can have concurrent flow, you can have cross flow, you can have hybrid flow, which is a hybrid between cross flow and multi-pass flow. These are different types of flow configurations. Heat exchangers: the topic itself clearly explains heat exchange.

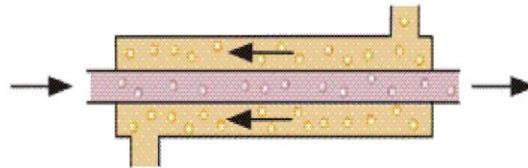
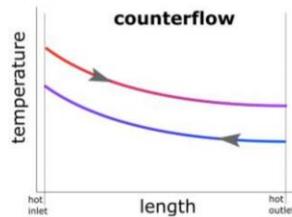
How will you achieve that heat exchange? When you have a very large surface, the heat can dissipate, or you can try to flow two different fluids in a pipe. So, this is one fluid, and the other one is fluid 2. So, wherever you have a temperature gradient (ΔT), you can try to exchange or remove heat—that is why it is called a heat exchanger.

Heat Exchanger



Counter Flow Heat Exchanger:

- In a counter flow heat exchanger, the hot and cold fluids flow in opposite directions.
- The hot fluid enters at one end, while the cold fluid enters at the opposite end, and they pass each other as they move through the exchanger.
- Notice the arrow direction in the figure for the counter flow (they are opposing).



<https://www.wattco.com/2021/06/heat-exchanger-configurations/>
<https://fastcalculator.in/process/types-of-heat-exchangers-and-their-selection/>

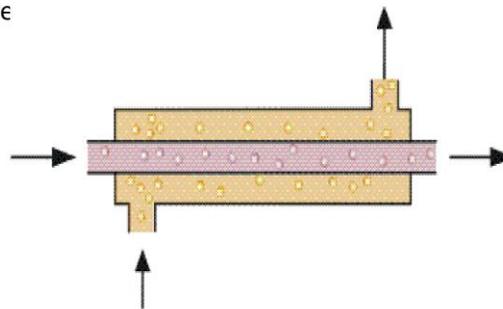
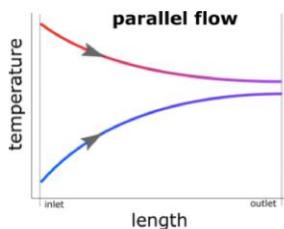


Heat Exchanger



Concurrent Flow Heat Exchangers:

- In a concurrent flow (also known as parallel flow) heat exchanger, both the hot and cold fluids flow in the same direction.
- They enter the exchanger at one end and exit at the opposite end, moving alongside each other, as indicated by the arrows in the figure



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So, counter-flow heat exchanger. As the name suggests, 'counter' means opposite, right? Counter-flow heat exchanger. In a counter-flow heat exchanger, the hot and cold fluids flow in opposite directions. So, one fluid flows here, and the other fluid flows here. If the ΔT is very small, the exchange takes a longer time.

Generally, what we do is try to reduce the temperature here and send the hot one here. But even there, you cannot have a steep ΔT . So, there has to be a small constraint on this. The ΔT need not be small, but it has to be within a range. Keep that in mind.

The hot fluid enters from one side, and the cold fluid enters from the opposite side. As they pass through, heat exchange occurs as they move. So, notice the arrow direction in the given figure. So, one direction, two directions. Fluid 1, fluid 2.

So, when you plot it on a temperature versus length graph, you can see here: this is the hot inlet, and this is the hot outlet. At the hot inlet, you will see a temperature drop as it exits the hot side. For the cold one, you see the temperature increases. The next one is called a concurrent flow heat exchanger. Concurrent means both fluids flow in the same direction.

Here, in concurrent flow—also known as parallel flow heat exchanger—both hot and cold fluids flow in the same direction. You see here it flows this way and exhausts this way. Here, it flows through this way and exhausts through this way. Here, it is fluid 1 and fluid 2. Friends, the outer can be cold and the inner hot, or the outer can be hot and the inner cold.

They enter the exchanger at one end and exit on the opposite side, one end entry and opposite side exit, moving alongside each other. So it makes doubly sure that it flows like this. As indicated by the arrow in the figure. So, entry and exit. Friends, you can also change the Q .

You can also change the flow. For example, here it is flowing at a rate of $1 Q$. So, let us set the Q rate as 1. This will flow at a Q rate of 2. Again, you can have a difference in heat exchange.

So, when you try to see parallel flow, you plot it between temperature and length. You see here, this is the inlet and this is the outlet. How does the inlet vary with respect to the outlet for hot as well as for cold? By understanding heat exchangers, these two, you will be able to appreciate the use of these heat exchangers. These heat exchangers are used in engines.

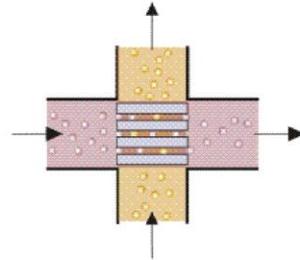
In automotive engines, in your air conditioners, in boilers, in your airplanes, in your fighter planes, you use heat exchangers. So, by going through this, I am sure you will now try to understand why these fin-like structures are given in an air conditioning unit.

Heat Exchanger



Cross flow heat exchangers :

- A cross flow heat exchanger is a type of heat exchanger in which the hot and cold fluids flow perpendicularly to each other.
- One fluid flows through a set of tubes or channels, while the other fluid flows across them at a right angle.
- This arrangement allows efficient heat transfer and is commonly used when one of the fluids changes phase, such as in air-cooled condensers or radiators.



<https://fastcalculator.in/process/types-of-heat-exchangers-and-their-selection/>

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The next one is a cross-flow heat exchanger. The cross-flow heat exchanger is a type of heat exchanger in which the hot and cold fluids—the hot and the cold—flow perpendicular to each other. One fluid flows through a set of tubes.

These are tubes or channels. This can be a tube or it can be a channel. When I try to take a cross-section, it can be like this. It can be like this channel, right? If you want to visualize the channel, it can be something like this. Okay.

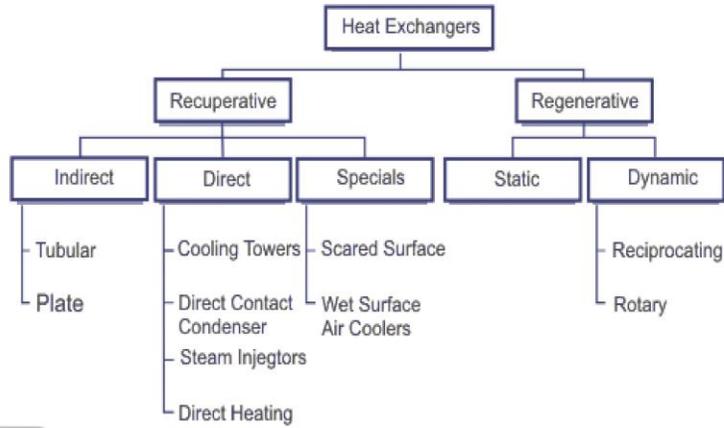
This channel can be tapered or straight. Depending on your requirements, it can have a positive taper, a negative taper, or whatever. It can also have pipes. These are pipes or tubes, right? One fluid flows through a set of tubes or channels, while the other fluid flows across them at 90 degrees—at a right angle.

This arrangement allows efficient heat transfer and is commonly used when one fluid changes phase, such as in an air-cooled condenser or radiator. When one of the fluids changes phase, it can be three-phase: liquid phase or gas phase. So it can be liquid to steam or steam to liquid.

Heat Exchanger



Classification of Heat Exchangers by Construction:

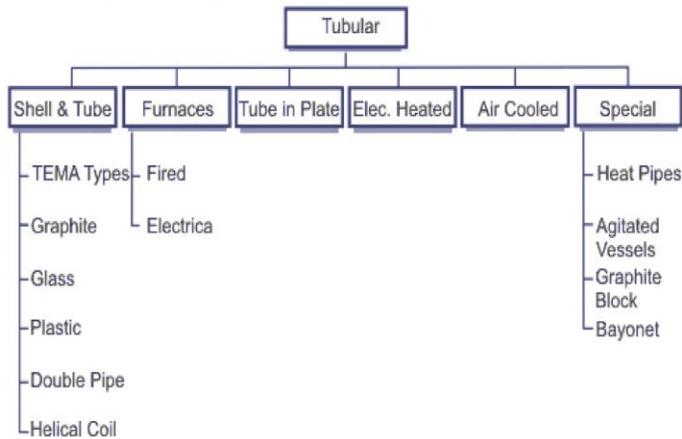


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Heat Exchanger



Classification of Heat Exchangers by Construction:

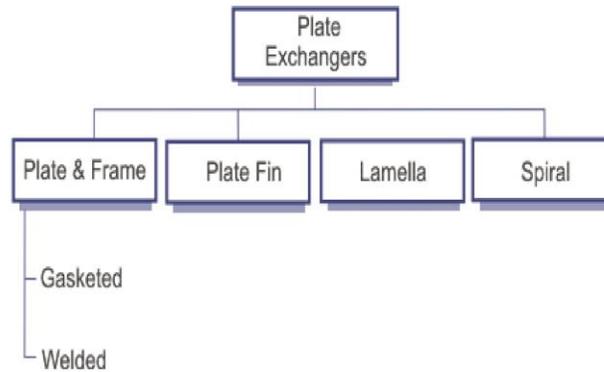


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Heat Exchanger



Classification of Heat Exchangers by Construction:



So the classifications of heat exchangers by construction can be basically classified into regenerative and recuperative. Recuperative can again be classified as indirect, direct, and special.

Regenerative can be static or dynamic. In the sub-classification of dynamic, you can have reciprocating or rotating. The regenerative heat exchanger works on the principle of a piston or in terms of a pump. So dynamic can be reciprocating or rotary. When we look at recuperative, it is indirect—tubular and plate—where direct includes cooling towers.

Cooling towers, which you see just beside the mall where there is an HVAC system, will have a cooling tower. Cooling towers, direct contact condensers, steam injectors, and direct heating. So all these things are direct. Special types are scraped surface, wet surface, and air-cooled surface, which are part of the special classification of heat exchangers. We will try to see a tubular one.

So, this is exchanged by classification. Then, we are trying to see indirect tubular. So, classification of heat exchanger by construction: tubular. You can have shell-and-tube structure, furnace structure, tube-in-plate, electric heating, air-cooled, and specialized types. In specialized types, we have heat pipes, agitated vessels, graphite blocks, and bayonet.

So, these are all special-type tubular construction heat exchangers. But shell-and-tube, tube-in-plate—these are all very common. So, plate exchangers, tube-in-plate—when you see 'plate,' we are always talking about recuperative, indirect tubular, and plate. So, plate exchangers can be plate-and-frame, plate-and-fin, lamellae, and spiral. So again, plate-and-frame can be classified as gasketed and welded.

Heat Exchanger



Classification of Heat Exchangers by Construction:

- A Recuperative Heat Exchanger has separate flow paths for each fluid and fluids flow simultaneously through the exchanger exchanging heat across the wall separating the flow paths.
- A Regenerative Heat Exchanger has a single flow path, which the hot and cold fluids alternately pass through.
- In a regenerative heat exchanger, the flow path normally consists of a matrix, which is heated when the hot fluid passes through it (this is known as the "hot blow").
- This heat is then released to the cold fluid when this flows through the matrix (the "cold blow").



So, the recuperative heat exchanger has separate flow paths for each fluid, and fluids flow simultaneously through the exchanger, exchanging heat across the wall separating the flow paths. So, basically, it is separated by a flow path for each fluid, and the fluids flow simultaneously through the heat exchanger, exchanging heat across the walls. Regenerative heat exchangers have a single flow path—separate flow paths here—but it has a single flow path, which hot and cold fluids alternately pass through. In regenerative heat exchangers, the flow path normally consists of a matrix. In regenerative types, they have a flow path normally consisting of a matrix, which is heated when the hot fluid passes through.

It is known as a hot blow. The heat is then released to the cold fluid when this flows through the matrix. That is called a cold blow. So, you have a hot blow and a cold blow in regenerative heat exchangers. This is a typical shell-and-tube heat exchanger, which consists of a series of tubes.

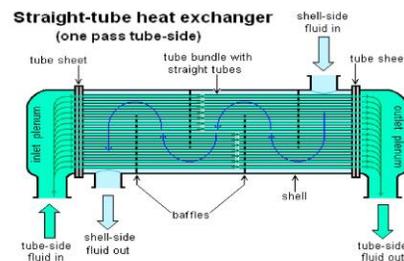
So, these are tubes—small ones—these are all tubes. These are kept inside a shell.

Shell and Tube Heat Exchanger



Shell and tube heat exchangers consist of a series of tubes.

1. One set of these tubes contains the fluid that must be either heated or cooled.
2. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required.
3. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc.
4. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C).
5. This is because the **shell and tube heat exchangers are robust due to their shape.**



https://www.researchgate.net/figure/Schema-of-a-shell-and-helical-tube-heat-exchanger_fig1_299417471

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If you see a boiler, it will look like this. So, this will be assuming that this is the shell of the boiler. This is a boiler. So, here, this is the thickness of the shell. This is a shell. When you take a cross-section, this is the shell, right? Inside the shell, you will see several tubes, right? This is a front view.

This is a side view. You will see tubes. These tubes have to be held in position. That is done by baffles. A baffle is a plate with several holes in it.

The pipes will pass through the baffle. If you see here, from here to here, it passes and tries to hold these pipes. Then from here to here, it holds them. It tries to hold the pipes in a regular position. This is held by baffles: shell tube baffle, right.

Then you will see there is a shell-side fluid in. There is a fluid that goes through, and then there is a fluid that goes through the pipes. The shell-side fluid in can be air or water. Inside the tube, it can again be air, water, or any other fluid. The tube-side fluid in goes this way, and from here to here, when it flows through, it tries to exchange heat with the shell-side fluid in. This straight tube heat exchanger works on the principle of one pass. One set of these tubes contains fluid that must be either heated or cooled.

So anything can flow through the fluid. The working fluid condition can be anything. The second fluid runs over the tubes that are being heated or cooled. So the tube on top of the

tube, whatever goes. So it can be heated or cooled to either provide heat or absorb the required heat.

The set of tubes is called a tube bundle. So there are many tubes. So each of them is called a bundle and can be made up of several types of tubes: plain, longitudinal, fin, etc. So it can be plain, straight, or in a serpentine pattern also. So we can have many things.

The shell and tube heat exchangers are typically used for high-pressure applications where we talk about 30 bar, and temperatures can go up to 260 degrees Celsius. This is basically used in thermal power plants. This is because the shell and tube exchangers are robust due to their shape. So these pressures—30 bar inside a cylinder—are not a big deal, and a 260-degree Celsius cylinder. Operation is also not a big deal when using a steel material.

Shell and Tube Heat Exchanger



Applications and uses:

The simple design of a shell and tube heat exchanger makes it an ideal cooling solution for a wide variety of applications.

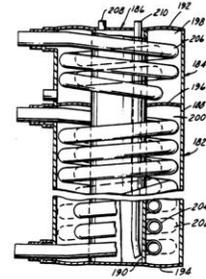
- One of the most common applications is the cooling of hydraulic fluid and oil in engines, transmissions and hydraulic power packs.
- With the right choice of materials they can also be used to cool or heat other mediums, such as swimming pool water or charge air.
- One of the big advantages of using a shell and tube heat exchanger is that they are often easy to service, particularly with models where a floating tube bundle (where the tube plates are not welded to the outer shell) is available.



Shell and Coil Heat Exchangers



- The shell and coil heat exchangers are constructed using circular layers of helically corrugated tubes placed inside a light compact shell.
- The fluid in each layer flows in the opposite direction to the layer surrounding it, producing a crisscross pattern.
- The large number of closely packed tubes creates a significant heat transfer surface within a light compact shell.
- The alternate layers create a swift uniform heating of fluids increasing the total heat transfer coefficient.
- The corrugated tubes produce a turbulent flow where the desired feature of fluctuating velocities is achieved.



https://www.researchgate.net/figure/Schema-of-a-shell-and-helical-tube-heat-exchanger_fig1_299417471

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So the application of this, this is what I said, baffle. So in the baffle, you will see all the tubes that are attached. So this can be in, and this can be out. The simple design of shell and tube exchangers makes them an ideal cooling solution for a wide variety of applications. One of the most common applications is the cooling of hydraulic fluid and oil in engine transmissions and hydraulic power packs, wherever they use this shell and tube type heat exchanger.

With the right choice of material, they can be used to cool or heat through mediums such as swimming pool water or charge air. So you can try to do anything. One of the biggest advantages of using shell and tube heat exchangers is that they are often easy to service, particularly with models where a floating tube bundle is available. For example, after a period of time, the tube can be choked. The fluid on the top, which flows, can deposit salts on it.

So it is also required to do maintenance. So shell and tube type exchangers are very easy for it. So the shell and coil, this is shell and tube. The next one we are doing is shell and coil. Coil is, it goes around.

So there is a fluid in the center. There is a coil. So you can see the fluid, and then there is a coil. The Shell and a coil heat exchanger are constructed using circular layer of helical corrugated tubes placed inside a light compact shell. And friends, when we try to talk

about the coil whatever is there and on top of the coil if you try to have. Suppose, let us assume this is a coil. So now what we can do is we can also have projections on these coils.

So what is the advantage of these projections? These projections are going to have a larger surface area on the coil. So there is going to be more heat extracted from the fluid through this coil. So you can have rivets which are welded short and are welded on top of the coil. So the fluid in each layer flows in the opposite direction to the layer surrounding it, producing a crisscross pattern.

So, a crisscross pattern. The large number of closely packed tubes create a significant heat transfer surface within a tight, compact shell. Friends, this heat exchange, if it has to happen, you can always have a heat exchanger. But the size of the heat exchanger is also very important because many times these heat exchangers will be attached to a moving body. If it is for a static one, the sizes don't matter.

But if it is placed inside an automobile, if it is placed inside a car for AC, right, or if it is placed inside a rocket which goes. So, there the compaction is also very important. So, light compact shells are very important. The alternate layers create a swift, uniform heating of fluid, increasing the total heat transfer coefficient. So, the swift, uniform heating of the fluid.

So, you have to go here when the heat exchange happens; you should remember the things we studied for convection. The fluid is flowing on top of it. The thickness of the fluid plays a role. There can be a vortex which is created. So, all these things can take place.

So, the other thing is the corrugated tube. The corrugation is you have a surface area increase. Corrugation is this. The corrugated tubes produce a turbulent flow where the desired feature of the fluid velocities is achieved. So, the laminar flow is disturbed when you have undulations on the surface. So that creates turbulence, and there is heat exchange.

Shell and Coil Heat Exchangers

- The shell and coil design is the perfect choice whenever high heat transfer rates, compact design and low maintenance costs are high priorities.

Other benefits include:

- **High Performance:** the unique coil arrangement has a large heat transfer area meaning high heat transfer coefficients.
- **Compact and Lightweight:** closely packed tubes makes our shell and coil exchangers compact and lightweight. Small footprint makes it easy to install where space is limited and hard to access.
- **Low Maintenance Costs:** corrugated tube design produces a high turbulent flow, which reduces deposit build-up and fouling. This means longer operating cycles between scheduled cleaning intervals.

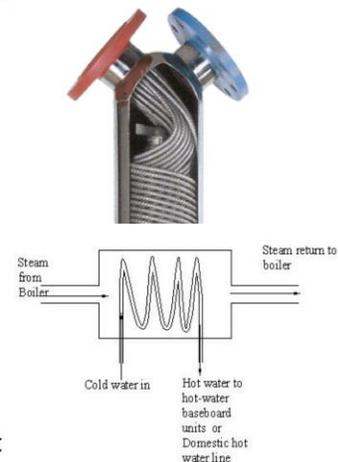
So the shell and coil design is the perfect choice wherever high heat transfer rate, compact design, and low maintenance cost are priorities. So the benefits are going to be high performance, compact and lightweight, and low maintenance cost, which are the advantages of the shell and coil type heat exchanger. The installation cost is very low.

Shell and Coil Heat Exchangers

- Low Installation Costs:
- Higher Temperature Differentials:
- Flexible Designs
- Low Pressure Drop:

Shell and Coil Applications:

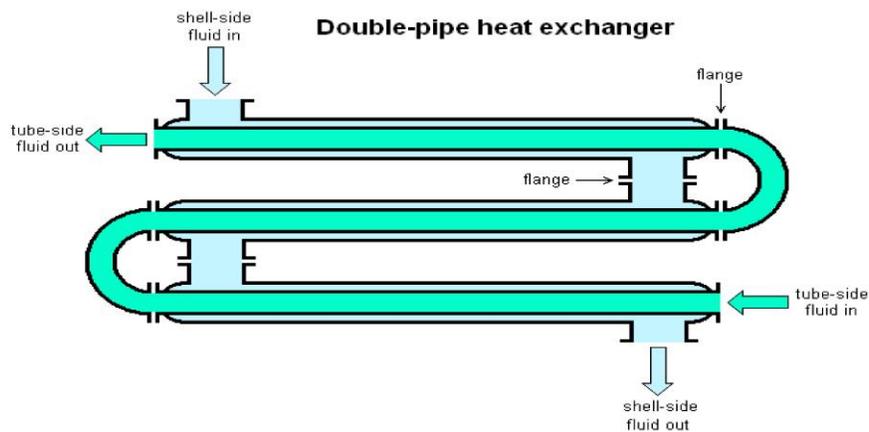
- Heating Systems
- Chilled Water Systems
- Ground Water Systems
- Residential Use
- District Heating Systems: heating systems that distribute heat from one or more heating sources to multiple buildings.



So this is a typical one. You can see red is hot and the cold one is blue. So then you can see the coil which goes around. High temperature differentials can be achieved. Flexible design and low pressure drops are also seen. The shell and coil applications are finding many uses in heating systems, chilled water systems, groundwater systems, and residential use.

We extensively use shell and coil heat exchangers. So this is steam from a boiler which goes through it. The steam returns to the boiler. From the boiler, the steam returns to the boiler, and here there is cold water which is passed. There is heat transfer happening.

Pipe in Pipe Heat Exchanger



<https://www.zwimerequipment.com/blog/what-is-a-double-tube-heat-exchanger/>



So then it is Pipe-in-Pipe Heat Exchangers. So pipe-in-pipe is, you have a shell-side fluid which flows inside a pipe. Then there is a pipe inside, which is called the tube-side flow out and tube-side flow in. So this is shell-side fluid in, shell-side fluid out. And these pipes are held between flanges. So you have a flange to hold it.

Pipe in Pipe Heat Exchanger



- A Double Pipe Heat Exchanger is one of the simplest forms of Shell and Tubular Heat Exchanger.
- Here, just one pipe inside another larger pipe. To make a Unit very Compact, The Arrangement is made Multiple Times and Continues Serial and Parallel flow.
- One fluid flows through the surrounded by pipe and the other flows through the annulus between the two pipes.
- The wall of the inner pipe is the heat transfer surface. This is also called as a hairpin Heat Exchanger.
- These are might have only one inside pipe, or it may have multiple inside tubes, but it will forever have the doubling back feature shown.
- In some of the Special Cases the Fins also Used in Tube side.



So, double-pipe heat exchangers are one of the simplest forms of shell-and-tube heat exchangers. Here, it's just one pipe inside another large pipe. There is only one pipe. One pipe inside another large pipe.

To make a unit very compact, the arrangement is made multiple times in continuous series and parallel flow. One fluid flows through the pipe, and the other flows through the annulus between the two pipes. So the wall of the inner pipe is the heat transfer surface. This is called a hairpin heat exchanger.

Pipe in Pipe Heat Exchanger

Disadvantages:

- There are significant disadvantages however, the two most noticeable being their high cost in proportion to heat transfer area.
- and the impractical lengths required for high heat duties.
- They also suffer from comparatively high heat losses via their large, outer shells.



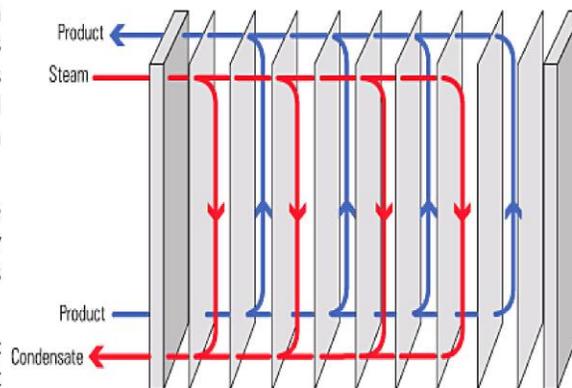
<https://www.sinoprettech.com/What-Is-Plate-Type-Heat-Exchanger-id45674586.html>

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The major disadvantages of pipe-in-pipe heat exchangers are, the two most noticeable being the high cost in proportion to the heat transfer area.

Plate Type Heat Exchanger

- A plate heat exchanger consists of a series of thin corrugated metal plates between which a number of channels are formed, with the primary and secondary fluids flowing through alternate channels.
- Heat transfer takes place from the primary fluid steam to the secondary process fluid in adjacent channels across the plate.
- Figure shows a schematic representation of a plate heat exchanger.



<https://www.sinoprettech.com/What-Is-Plate-Type-Heat-Exchanger-id45674586.html>

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Plate Type Heat Exchanger. These plate-type heat exchangers can be seen in room heat exchangers, which we use during winter days. A plate-type heat exchanger consists of a series of thin, corrugated metal pipes. These are plates. So this consists of thin, corrugated metal plates. These are all corrugated, and between them, a number of channels are formed, with the primary and secondary fluid flowing through them. So, this is a product that comes out, and this is the steam that goes. The primary and secondary fluids flow through them alternatively.

The heat exchange takes place from the primary fluid to the secondary fluid in the adjacent channel across the plate. The figure shows a schematic representation of the heat pipes.

Plate Type Heat Exchanger



- The plate heat exchanger consists of a specific number of plates arranged between the pressure & the fixed frame.
- The plates are having corrugations with different designs which increase the total surface area for the heat exchange.
- The plates are movable within the frame and rest on the carrying bar on the top and the bottom of the frame.
- The plates are arranged in pairs which are opposite of each other forming a honey comb pattern when viewed sideways.
- The plate corrugations promote fluid turbulence and increase the heat transfer.

It consists of a number of plates arranged between the pressure and fixed frame. The plates have corrugations with different designs, which increase the total surface area for heat exchange. The plates can be static or movable, depending on the arrangement, to achieve the desired benefits.

Plate Type Heat Exchanger

- The fixed and the pressure plate are supported by the supporting column.
- The plates are fitted with each other with gaskets which seal the material from coming out sideways as well as through the holes on the plates.
- The steam heat exchanger market was dominated in the past by the shell and tube heat exchanger, whilst plate heat exchangers have often been favoured in the food processing industry and used water heating.
- However, recent design advances mean that plate heat exchangers are now equally suited to steam heating applications.

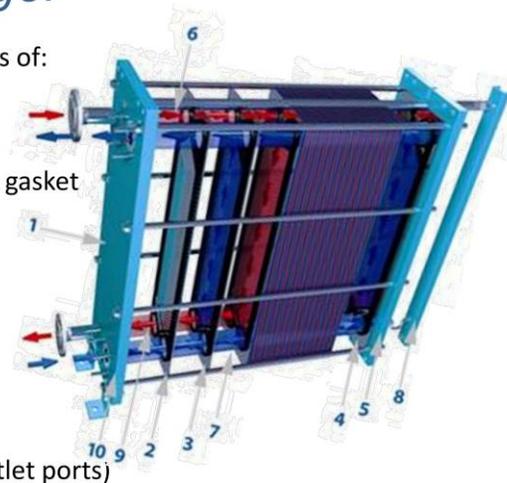
Applications of Plate type Heat Exchanger

- Power generation applications
- In food, Dairy and brewing industries
- Refrigerants in cooling systems

Plate Type Heat Exchanger

A Plate type Heat Exchanger (as shown) comprises of:

1. Fixed pressure plate
2. Start plate
3. Thermoline heat exchanger channel plate with gasket
4. End plate
5. Movable pressure plate
6. Upper carrying bar
7. Lower carrying bar
8. Support column
9. Tightening bolt
10. Stud bolt or flanged connection (fluid inlet/outlet ports)



The fixed and pressure plates are supported by the supporting column. The plates are fitted together with gaskets, which seal the material from leaking outside as well as through the holes of the plates. The applications of plate-type heat exchangers include power generation, food, dairy, and brewing industries. Refrigerants in cooling systems also use plate-type heat exchangers. So this is a typical plate-type heat exchanger.

You can have moving pressure plates, an upper carrying bar, and a lower carrying bar. The upper carrying bar and lower carrying bar are to guide them.

Boiling and Condensation



- Boiling and condensation are essential phase-change processes in thermodynamics, involving the transformation between liquid and vapor states.
- Boiling occurs when a liquid is heated to its saturation temperature, leading to the formation of vapor bubbles within the liquid or on a heated surface.
- It plays a vital role in heat transfer systems like boilers and evaporators, especially in the nucleate boiling regime where heat transfer is highly efficient.
- On the other hand, condensation is the process where vapor cools and changes back into liquid, releasing latent heat in the process.
- It typically occurs on cooler surfaces and can happen in the form of film condensation, where a continuous liquid layer forms, or drop-wise condensation, which offers better heat transfer.



Boiling and condensation. Boiling and condensation are essential phase-change processes. Boiling is from liquid to gas. Condensation is from gas to liquid. Boiling and condensation are essential phase-change processes in thermodynamics, involving the transformation between liquid and vapor states. Boiling occurs when a liquid is heated to its saturation temperature, leading to the formation of vapor bubbles within the liquid or on the heated surface. That is why, when you try to heat a pan, you put water or milk in it. When you heat it from the bottom, you will see vapor bubbles forming on the top.

So the liquid is heated to its saturation temperature leading to the formation of a vapor bubble within the liquid or on a heated surface. It plays a vital role in heat transfer system like boiler and evaporator especially in the nucleating boiling regime where heat transfer is highly efficient. So, you should understand this point. The heat transfer system, like boilers and evaporators. Especially in the nucleated boiling regime, when there is a nucleated boiling regime is there, it tries to vapor comes and then it tries to do a high heat transfer.

On the other hand, condensation is a process where vapor cools and changes back to liquid, releasing latent heat in the process. If you go back to solidification, latent heat plays a very important role. It typically occurs on cooler surfaces and can happen in the form of film condensation, where a continuous liquid layer forms. It typically occurs on cooler surfaces and can happen in the form of film condensation. So, what happens is when you have the relative humidity very high and you have a pipe in which you are passing cold air.

What happens? This relative humidity air comes and hits the cold air pipe and tries to form; it tries to condense. Droplets get condensed, and once the droplets get condensed, they form a film. It typically occurs on a cold surface inside a room and can happen in the form of film condensation, where a continuous liquid layer is formed, or dropwise condensation happens, which offers better heat transfer. So here, heat transfer is because of the nucleate boiling regime, and here it is because of the film condensation or dropwise condensation.

Boiling Heat Transfer

- **Evaporation** occurs at the liquid–vapor interface when the vapor pressure is less than the saturation pressure of the liquid at a given temperature.
- **Boiling** occurs at the solid–liquid interface when a liquid is brought into contact with a surface maintained at a temperature sufficiently above the saturation temperature of the liquid.

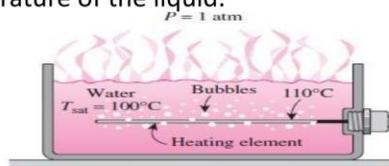


FIGURE 10-2
Boiling occurs when a liquid is brought into contact with a surface at a temperature above the saturation temperature of the liquid.



FIGURE 10-
A liquid-to-vapor phase change process is called *evaporation* if it originates at a liquid–vapor interface and *boiling* if it occurs at a solid–liquid interface.

solid-liquid interface. Where the liquid is brought in contact with the surface maintained at a temperature sufficiently above the saturation temperature of the liquid.

So you see here, this is the pan. So here you have a heater which is used, an immersion heater rod. So the solid-liquid interface, when the liquid is brought in contact with the surface at a temperature sufficiently above the saturation temperature of the liquid, boiling happens. So these are all boiling bubbles formed; boiling happens. When you talk about evaporation, the vapor pressure must be less than the saturation pressure of the liquid.

Boiling Heat Transfer



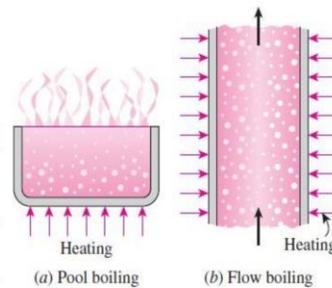
- Boiling heat flux from a solid surface to the fluid

$$\dot{q}_{\text{boiling}} = h(T_s - T_{\text{sat}}) = h\Delta T_{\text{excess}} \quad (\text{W/m}^2)$$

$$\Delta T_{\text{excess}} = T_s - T_{\text{sat}} \quad \text{excess temperature}$$

Classification of boiling:

- Boiling is called pool boiling in the absence of bulk fluid flow.
- Any motion of the fluid is due to natural convection currents and motion of the bubbles under the influence of buoyancy.
- Boiling is called **flow boiling** in the presence of bulk fluid flow.
- In flow boiling, the fluid is forced to move in a heated pipe or over a surface by external means such as a pump.



FIGURE

Classification of boiling on the basis of the presence of bulk fluid motion.



So the boiling heat flux from a solid surface to a liquid can be derived or obtained by this formula.

$$\dot{q}_{\text{boiling}} = h(T_s - T_{\text{sat}}) = h\Delta T_{\text{excess}} \quad (\text{W/m}^2)$$

$$\Delta T_{\text{excess}} = T_s - T_{\text{sat}} \quad \text{excess temperature}$$

The classification of boiling can be done as it is called pool boiling in the absence of bulk fluid flow. There is a pool boiling effect. Any motion of the fluid is due to the natural convection current and the motion of the bubbles under the influence of buoyancy. Under the influence of buoyancy, this is there. The boiling is called flow boiling in the presence

of a bulk fluid flow. In the absence of a bulk fluid flow, it is called pool boiling. This is pool boiling.

In the absence of bulk fluid flow, it is called pool boiling. When there is flow happening, it is called flow boiling, where the presence of bulk fluid is flowing. So this is the difference between pool boiling and flow boiling. Friends, these are very important. In flow boiling, the fluid is forced to move in a heated pipe over a surface by external means such as a pump. The fluid is allowed to move through pressure, right? So, this is called flow boiling and this is called pool boiling.

Boiling Heat Transfer



Subcooled Boiling:

- When the temperature of the main body of the liquid is below the saturation temperature.

Saturated Boiling:

- When the temperature of the liquid is equal to the saturation temperature.

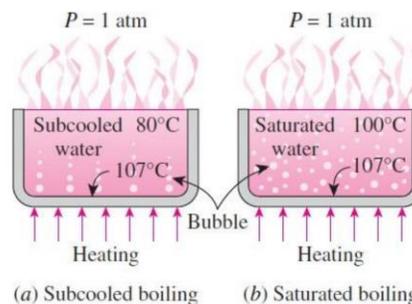


FIGURE 10-4

Classification of boiling on the basis of the presence of bulk liquid temperature.



There is something called sub-cooled boiling and saturated boiling. Sub-cooled boiling is when the temperature of the main body of the liquid is below the saturation temperature. It is called sub-cooled boiling.

So, when the temperature at the base is 107 degrees Celsius and the liquid is around 80 degrees Celsius, it is called super-cooled boiling. The atmosphere is 1. Saturated boiling is when the temperature of the liquid is equal to the saturation temperature. So, here, saturation temperature is very important. So, we saw what is pool boiling, what is flow boiling, what is subcooled boiling, and what is saturated boiling. Friends, these are very important because you have to choose the regime through which heat transfer can happen.

Boiling Heat Transfer

Pool Boiling:

- In pool boiling, the fluid is not forced to flow by a mover such as a pump.
- Any motion of the fluid is due to natural convection currents and the motion of the bubbles under the influence of buoyancy.

Boiling Regimes And The Boiling Curve:

$$\dot{q}_{\text{boiling}} = h(T_s - T_{\text{sat}}) = h\Delta T_{\text{excess}}$$

Boiling takes different forms, depending on the

$$\Delta T_{\text{excess}} = T_s - T_{\text{sat}}$$

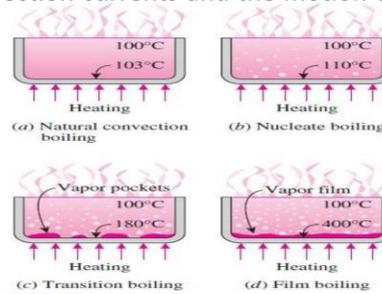
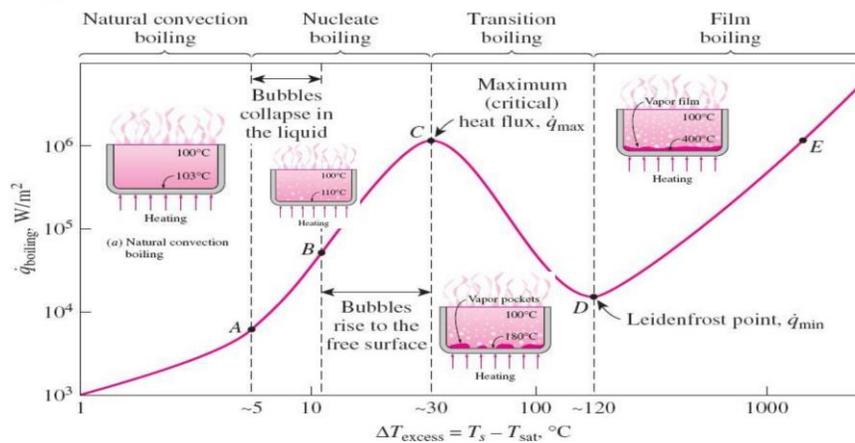


FIGURE Different boiling regimes in pool boiling.

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Boiling Heat Transfer



Typical boiling curve at 1 atm pressure

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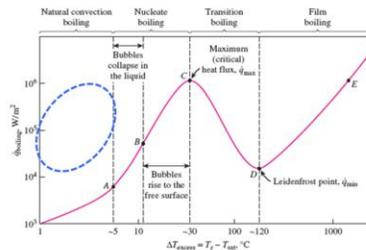
So, when we go a little deeper into pool boiling, in pool boiling, the fluid is not forced to flow by a mover such as a pump. So, it is static, like in a pressure cooker where water is filled. Any motion of the fluid is due to natural convection here.

Boiling Heat Transfer



Natural Convection Boiling (Region A–B)

- In the first region (A–B) of the boiling curve, the liquid is heated slowly, and the surface temperature is only slightly higher than the saturation temperature (usually by 1–5°C).
- This regime is termed natural convection boiling, although technically, no actual boiling (bubble formation) takes place yet.



Natural convection currents and the motion of the bubbles are under the influence of buoyancy. So, under buoyancy, they can go up. So, q_{boiling} is nothing but it is expressed as $h \times dT_{\text{excess}}$. So, boiling takes different forms depending upon the T_s . Here, it is natural convection. And here, it is nucleate boiling. And here, it is transition boiling.

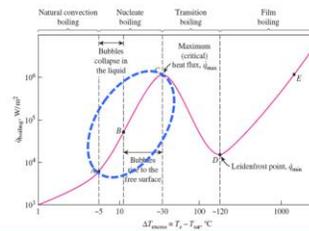
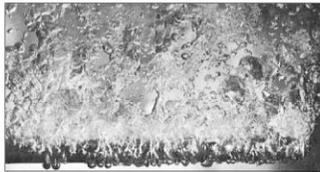
And here, it is heat and thin-film boiling. So, you see here how many different types of boiling we have seen. We have seen pool boiling, forced boiling, supercooled boiling, and saturated boiling. Then, we saw natural convection boiling.

Boiling Heat Transfer



Nucleate Boiling (Region B–C)

- When the surface temperature increases to a moderate excess temperature (typically 5–30°C above saturation), the system enters the nucleate boiling regime.
- This is the most efficient and highly desirable regime for boiling heat transfer.
- Here, vapor bubbles form at discrete nucleation sites on the heated surface, grow, and detach to rise through the liquid.
- The departing bubbles induce strong liquid mixing and turbulence, which significantly enhances convective heat transfer.



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Then nucleate boiling, where the temperature is slightly high, so there is nucleation of bubbles forming. Nucleated boiling, then we will try to have transition boiling, and finally, we will have film boiling. So, all these things are different types of boiling that can happen. So, if you try to draw a boiling heat transfer, you can try to have four major regimes. So, one is called natural convection boiling. So, where the q boiling (W/m²) you can see, and ΔT exceed, which you can see in terms of temperature.

So, here it is 1. ΔT we are seeing, right? We are seeing ΔT . So, 5, 10, 30, 100, 120, and 1000, right? So, when it goes between 1 to 5, and when the watts, q boiling, let us assume it is 10 to the power 4. So then, watt per meter square, you can see a point A. So, in point A, you can see that here the bubbles are getting formed.

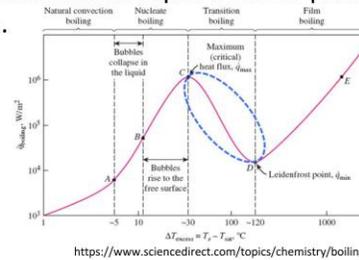
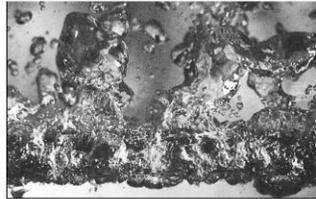
So then, the bubbles collapse in the liquid, which is happening here till B. So then, the bubbles will try to rise to the free surface from B to C.

Boiling Heat Transfer



Transition Boiling (Region C–D)

- Beyond point C, further increase in surface temperature causes the onset of transition boiling, represented by region C–D.
- This is a highly unstable and inefficient regime where heat transfer decreases despite the rising surface temperature.
- The heat flux drops steeply due to the formation of intermittent vapor films or pockets that temporarily blanket portions of the heated surface.



At C, there is a transition boiling. So, the maximum critical temperature heat flux will be q_{max} at this point. Then, after this transition boiling, there will be a drop. There will be a drop.

So here, the vapor pockets are forming up to D. Then D is the Leidenfrost point, q_{min} , which is there before it goes to E. So you can see natural convection happening up to 5 here. That is ΔT_{excess} . Then C happens up to 30, where nucleate boiling is occurring. So first, it just goes like natural convection. Next, the bubbles are forming.

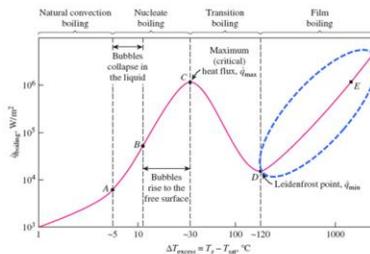
The formed bubbles rise from the bottom to the top. Then, once they rise to the top, transition boiling occurs from there. It falls down. The q boiling falls down. So the vapors go up.

Boiling Heat Transfer



Film Boiling (Region D–E)

- When the surface temperature rises significantly above the Leidenfrost point (often 200°C+ for water), a continuous and stable vapor film forms over the entire surface.
- This marks the onset of film boiling (Region D–E). The vapor layer, being a poor thermal conductor, acts as an insulating barrier between the surface and the bulk liquid.



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Then the vapors form a film. So film boiling happens. This figure is very important, friends. This is a typical curve at only one atmosphere pressure you can observe. If you change the atmospheric condition, the entire thing changes.

So the natural convection is region A to B. In the first region A to B of the boiling curve, the liquid is heated slowly, and the surface temperature is only slightly higher than the saturation temperature. So, which is by 1 to 5 degrees. So, there is this regime of natural convection boiling, although technically no actual boiling takes place; the bubbles are getting formed. Then between B to C, when the surface temperature increases to a moderate excess temperature, the system enters the nucleated boiling regime. So, 30 degrees more if it increases.

So, that is what we said: 30 degrees, right? 10 degrees to 30 degrees. This is the most efficient and highly desirable region for boiling water. So it is B to C. This B to C is the most required regime. The vapor bubbles form at discrete nucleation sites. They are not forming at continuous sites.

They form here, here, here, here. Discrete nucleation sites on the heated surface grow and detach to rise into the liquid. So the boiling vapor will happen here. Then they will all move up. The departed balloon induce strong liquid mixing and turbulence, when it goes to the top and then it bursts, which significantly enhances the convective heat transfer.

Then from C to D, you can see here, this is called transition boiling. Beyond point C, the further increase in temperature causes the onset of boiling, representing the regime C to D. So here, the onset of transition boiling happens. This is a highly unstable and inefficient region where the heat transfer decreases despite the temperature increase. So here, the heat transfer decreases despite the temperature increase. The heat flux drops steeply due to the formation of intermittent vapor films or pockets that temporarily blanket the heated surface. So here in this transition boiling, what happens?

The temperature continues to rise. Now, the vapor forms a jacket on top of it. So, the heat flux drops steeply due to the formation of intermittent vapor films or pockets that temporarily blanket portions of the heated surface. Then in D to E, whatever is temporary forms a regime. When the surface temperature increases significantly above the Leidenfrost point, a continuous and stable vapor film is formed entirely.

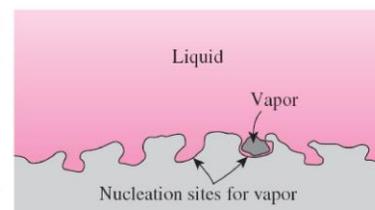
So here, the vapor film is not continuously formed. Here, if you see there, the vapor film is not continuously formed. It forms here and there. But here in film boiling, it is completely formed. And that's the vapor, being a poor thermal conductor, acts as an insulating barrier between the surface and the bulk liquid. And here, the Q increases. So, the enhancement of heat transfer in pool boiling is very important.

Boiling Heat Transfer



Enhancement of Heat Transfer in Pool Boiling

- The rate of heat transfer in the nucleate boiling regime strongly depends on the number of active nucleation sites on the surface, and the rate of bubble formation at each site.
- Therefore, modification that enhances nucleation on the heating surface will also enhance heat transfer in nucleate boiling.
- Irregularities on the heating surface, including roughness and dirt, serve as additional nucleation sites during boiling.
- The effect of surface roughness is observed to decay with time.



FIGURE

The cavities on a rough surface act as nucleation sites and enhance boiling heat transfer.

The rate of heat transfer in the nucleate boiling regime—this is liquid, this is vapor—these are nucleate sites for vapor, as you can see. The rate of heat transfer in the nucleate boiling regime strongly depends on the number of active nucleation sites on the surface and the rate of bubble formation at each site. Therefore, modifications that enhance nucleation—these are nucleation sites—on the heated surface will also enhance heat transfer. So, liquid, vapor—this is vapor, and these are nucleate sites.

Therefore, modifications that enhance nucleation on the heating surface will also enhance heat transfer in the nucleate boiling regime. Irregularities on the heating surface, including roughness and dirt, will all be potential nucleation sites. The effect of surface roughness is observed to decay over time.

Boiling Heat Transfer



Flow Boiling:

- In flow boiling, the fluid is forced to move by an external source such as a pump as it undergoes a phase-change process.
- It exhibits the combined effects of convection and pool boiling.
- External flow boiling over a plate or cylinder is similar to pool boiling, but the added motion increases both the nucleate boiling heat flux and the maximum heat flux considerably.
- The higher the velocity, the higher the nucleate boiling heat flux and the critical heat flux.
- Internal flow boiling, commonly referred to as two-phase flow, is much more complicated in nature because there is no free surface for the vapor to escape, and thus both the liquid and the vapor are forced to flow together.

So, flow boiling—these are all part of pool boiling. Now, we will try to understand what flow boiling is. In flow boiling, the fluid is forced to move by an external force, such as a pump. So, all these things we saw earlier were part of pool boiling, because here we observed different types, right? Pool boiling, flow boiling. Now, we will try to—we saw what pool boiling is, and we saw all the regimes of pool boiling. Natural convection, nucleate phase, transition, and film boiling.

Now, when we go to forced boiling or flow boiling, the fluid is forced to move by an external source such as a pump as it undergoes a phase change process. It exhibits a combined effect of convection and pool boiling. External flow boiling over a plate or a cylinder is similar to pool boiling, but the additional motion increases both the nucleate boiling heat flux and the maximum heat flux considerably. So, the higher the velocity, the higher is the nucleate boiling. So, if you keep pumping it very fast, the nucleate boiling heat flux will also be very high.

Boiling Heat Transfer

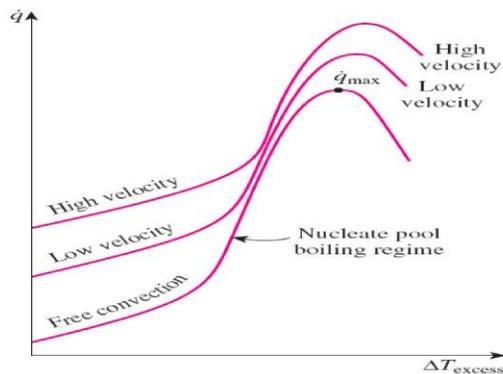
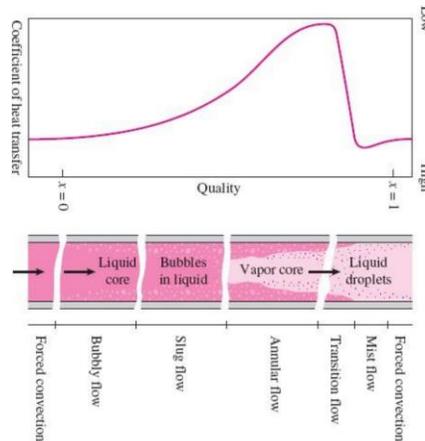


FIGURE
The effect of forced convection on external flow boiling for different flow velocities.

Boiling Heat Transfer

- The two-phase flow in a tube exhibits different flow boiling regimes, depending on the relative amounts of the liquid and the vapor phases.
- Note that the tube contains a liquid before the bubbly flow regime and a vapor after the mist-flow regime.
- Heat transfer in those two cases can be determined using the appropriate relations for single-phase convection heat transfer.



The internal flow boiling is commonly known as two-phase flow. It is much more complicated in nature because there is no surface for the vapor to escape, and thus both the liquid and vapor are forced to flow through. So, this is called flow boiling. So here, you can see what is the q dot. What is q dot?

We saw here q dot boiling in watts per meter squared. So q dot is here, and this is ΔT in terms of excess. ΔT is the temperature difference in excess. Free convection you can see here. It moves from here, and then there is a slope here, and then it hits a q max.

So, this slope is nothing but the nucleated pool boiling regime happening in this region. Then it hits a maximum. So, when we move at low velocity, this is free convection, pool boiling, and this is flow boiling. At low velocity and high velocity, you can see here that Q_{max} increases and it is getting shifted. The effect of forced convection on external flow, boiling at different flow velocities, is shown in this figure.

The two-phase flow in a tube exhibits different flow boiling regimes depending on the relative amount of liquid and vapor phases present. So, it is the volume fraction. So, I have a liquid number of bubbles present, which is the volume fraction. Note that the tube contains liquid before the bubbly flow regime and vapor after the mist flow regime. So, you can see here forced convection; you are flowing it. Then you see here the liquid core,

where the liquid is in the core and the bubbles are on the surface. Then you can see bubbles in the liquid.

So now, there are more bubbles in the— So, the volume fraction of bubbles They are all here touching the surface. Now they are all through the surface. Now, what has happened?

These bubbles get coagulated and form a vapor. So here it was a liquid core. Then it gets converted into a vapor core. And then finally it gets converted into a liquid drop. Note that the tube contains a liquid.

Before the bubbly flow regime and the vapor after the mist flow regime. The heat transfer in those two cases can be determined using an appropriate relationship with a single phase. So here it is forced convection leading to bubbly flow. Then it is slug flow. Then it is annular flow.

Annular means it is ring-like. So annular flow, and then finally it transitions into a mist flow, and forced convection comes out here. So the start—this is what they say before the mist. Note the tube contains a liquid before the bubbly flow regime and a vapor after the mist flow regime after this. So you can see the coefficient of heat transfer. The coefficient of heat transfer is very high in the transition region and then it falls down.

Condensation Heat Transfer



- Condensation occurs when the temperature of a vapor is reduced below its saturation temperature.

Film condensation

- The condensate wets the surface and forms a liquid film.
- The surface is blanketed by a liquid film which serves as a resistance to heat transfer.

Dropwise condensation

- The condensed vapor forms droplets on the surface.
- The droplets slide down when they reach a certain size.
- No liquid film to resist heat transfer.
- As a result, heat transfer rates that are more than 10 times larger than with film condensation can be achieved.

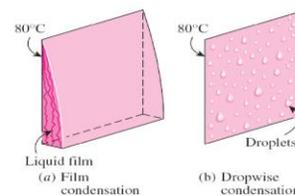


FIGURE 10-20
When a vapor is exposed to a surface at a temperature below T_{sat} , condensation in the form of a liquid film or individual droplets occurs on the surface.

So, condensation heat transfer. Condensation occurs when the temperature of a vapor is reduced below its saturation temperature. We have seen this point. The film condensation—so, till now, it was boiling. Now, we are trying to see condensation. Boiling was the heated side. Condensation was the vapor-to-liquid side.

Condensation Heat Transfer

- Liquid film starts forming at the top of the plate and flows downward under the influence of gravity.
- δ increases in the flow direction x
- Heat in the amount h_{fg} is released during condensation and is transferred through the film to the plate surface.
- T_s must be below the saturation temperature for condensation.
- The temperature of the condensate is T_{sat} at the interface and decreases gradually to T_s at the wall.

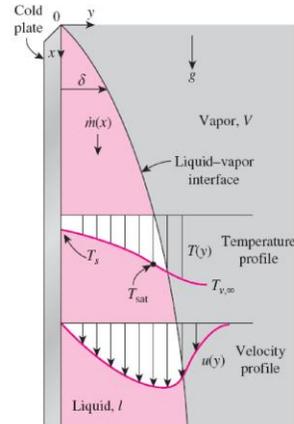


FIGURE
Film condensation on a vertical plate.



The condensate wets the surface and forms a liquid film. The surface is blanketed by a liquid film, which serves as a resistance to heat transfer. So, this is like a liquid film getting formed.

This is a plate. So, you can see a film which is getting formed. So, if you see the side view, it is something like this. This is a film. The dropwise condensation—film means it is continuous.

Dropwise means at certain points, there is a nucleating site, and the droplet starts here. The condensed vapor forms droplets on the surface. The droplets slide down when they reach a certain size. The droplet, what happens? The droplet also grows.

After a certain heaviness, the droplet, it tries to fall down. So the droplet slides down when they reach a certain size. So the droplet also grows from small, little larger, little larger, little larger, little larger it grows. So then after a certain time, the weight is high, so it rolls down. No film is formed in the drop-wise condensation.

As a result, the heat transfer rate that has more than 10 times larger than the film condensation because it forms, the surface area is there, so the volume of the droplet is there, so it tries to also evaporate. It also evaporates and then it goes away. So it has, droplet condensation has more efficiency, more heat transfer rate. So, if you see that this is a cold plate and then this is a film which is getting formed. So, if we try to draw the temperature profile and velocity profile, so you can see the liquid which is flowing from here.

The liquid film starts forming at the top of the plate and flows downward under the influence of gravity. So, it is flowing down by gravity. Delta increases in the flow direction. Delta increases; the film thickness keeps increasing along the flow direction. The heat in the amount HFG is released.

The heat is released during the condensation and is transferred through the film to the plate. So, from here to here, there is a release of heat. The T_s must be below the saturation temperature for the condensation to happen. So, T condensation to happen. The temperature of the condensate is T_{sat} at the interface, and it keeps decreasing gradually to T_s . From T_{sat} , it goes to T_s at the valves.

Mass Transfer



- Mass transfer is the study of the transfer of a component in a homogeneous mixture from one phase to another coexisting phase, or within the same phase from a region of high concentration to low concentration.
- Transfer of a component from one phase to the another is due to the difference of chemical potential (μ) of a component in the coexisting phases.
- The direction of mass transfer is from higher chemical potential to lower chemical potential.
- If $\mu_i^\alpha > \mu_i^\beta$, component i transfers from α to β phase.
- Chemical potential (μ) is a conceptual property.
- It can be expressed in terms of measurable properties such as mole fraction, concentration, pressure, vapor pressure etc.



<https://www.mr-cfd.com/services/fluent-modules/mass-transfer/>

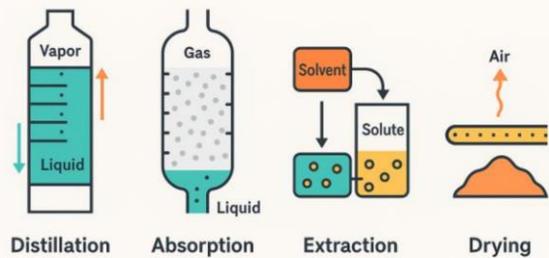
Mass Transfer: till now, what we studied was heat transfer—heat temperature T_1 to T_2 , T_2 to T_1 , and other things. Mass transfer is the study of the transfer of components in a homogeneous mixture from one phase to another coexisting phase or within the same phase from a regime of higher concentration to a lower concentration. Till now, we saw heat transfer; now, we are going to study mass transfer. The transfer of components from one phase to another is due to the difference in the chemical potential μ . So, it is like osmosis—the chemical potential μ of the component in the coexisting phase.

The direction of mass transfer is from higher chemical potential to lower chemical potential. Where μ_α is greater than μ_β , the components transfer from α to β phase. The chemical potential is a conceptual property. It can be expressed in terms of measurable properties such as mole fraction, concentration, pressure, vapor pressure, etc.

Mass Transfer



- The importance of mass-transfer operations in chemical engineering is profound.
- There is scarcely any chemical process which does not require either a preliminary purification of raw materials or a final separation of products from by-products, and for these, mass-transfer operations are commonly used.
- Frequently, the separations constitute a major part of the costs of a process.
- Examples for Mass Transfer Operations:
Absorption, Distillation, Extraction, Drying.



So mass transfer plays a very important role. In processing industries, this plays a very important role. The importance of mass transfer operations in chemical engineering is profound. So there is scarcely any chemical process that does not require either a preliminary purification of raw materials or a final separation of products from byproducts. And for these, mass transfer operations are commonly used where they talk about the chemical potential. Frequently, separation constitutes a major part of the

process cost. So there can be two types: preliminary purification of the raw material, whatever it is—extraction—and then the final product you subtract.

So the processes which use mass transfer, like distillation: the liquid gets heated up, vapor is formed, the vapor condenses, and then you get a liquid out.

Mass Transfer

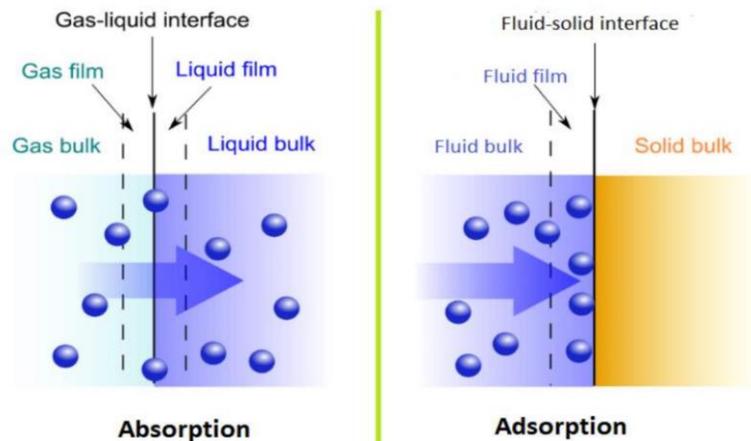


- **Absorption:** removal of H_2S from natural gas by absorption with monoethanolamine or diethanolamine solutions.
- **Stripping:** removal of oxygen from water (for use with electronic material processing) by contacting with a nitrogen gas.
- **Distillation:** (i) separation of benzene and toluene from a solution of benzene-toluene, (ii) fractionation of petroleum crude oil.
- **Extraction:** (i) removal of adipic acid from water using diethyl ether, (ii) removal of mercaptants from naphtha by NaOH solution.
- **Adsorption:** (i) removal of odor / color from materials, using activated carbon, (ii) removal of moisture from air using silica.



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Mass Transfer



Absorption of solutes happens in the bulk of the liquid. Adsorption of solutes happens on the surface of the solid.



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Next one is gas absorption. The gas is passed through, and then you have absorption. These absorbents absorb whichever impurities are present, and the pure gas is released. Then the next one is extraction.

The liquid we add is a solvent, so it gets mixed, and then from the solvent, you try to separate the solute. And then finally, drying in air occurs, which is also a mass transfer. So, I go back; mass transfer is the study of the transfer of a component in a homogeneous mixture from one phase to another coexisting phase. Phases can be alpha, beta, liquid, or solid, within the same phase from a region of higher concentration to lower concentration. So, the phenomena observed are absorption. Removal of H₂S from natural gas by absorption with monoethanolamine and diethanolamine solutions is a mass transfer.

Stripping: removal of oxygen from water by contact with nitrogen gas is stripping. Distillation: we can separate benzene and toluene from a solution of benzene and toluene, and fractional distillation of crude oil is also mass transfer. Extraction: removal of adipic acid from water using diethyl ether, removal of mercaptans from naphtha by NaOH solution. Adsorption: absorption and adsorption. Removal of odor, color, and other materials using activated carbon. Silica gel is also an adsorption process. So, you have a gas. This is a gas bulk.

Then you have a gas film which is formed. Then this is a gas-liquid interface. Then you will have a liquid film. And then you have a liquid bulk. This is called absorption.

Gas, liquid, absorption. This is adsorption. Adsorption happens only on the surface. So you have a solid bulk. You have a fluid bulk.

So there is a film formed, and there is a sitting here. For example, a majority of the coating is done by adsorption. A majority of the tablets which are coated with color are done by adsorption. So it is done by fluid flow. They do it by fluidized bed, but that's a different story.

Mass Transfer

$$N_A = k\Delta C A = k(C_A - C_A^*)$$

Where,

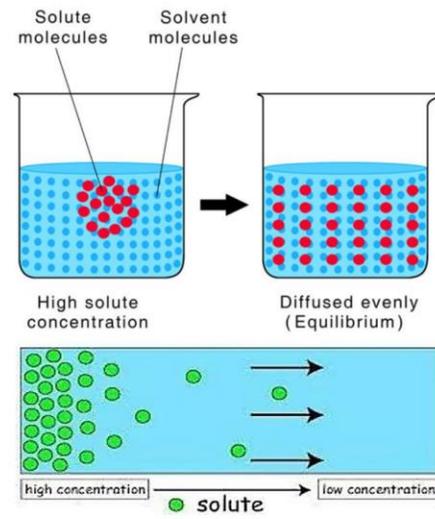
N_A = mass transfer flux of component A, mol/(area.time)

k = mass transfer coefficient

C_A = bulk concentration of A

C_A^* = equilibrium concentration of A

- There are various forms of concentration measures, such as mol/ltr, partial pressure, mole fraction, mole ratio, etc.



So this is the mass transfer where gas-liquid interface is there, and gas-solid interface is there. Gas-liquid interface, absorption, adsorption on the surface.

$$N_A = k\Delta C A = k(C_A - C_A^*)$$

So Here, N_A is the mass transfer flux of a component A, and k is the mass transfer coefficient. C_A is the bulk concentration of A, and C_A^* is the equilibrium concentration of A. So, there are various forms we can use to talk about concentration: moles per liter, partial pressure, mole fraction, and mole ratio. So here, you have solute molecules, and these are all solvent molecules. They get diffused and form this. This is diffused evenly and at equilibrium. So then, here, what is there is you have a higher concentration and a lower concentration. Here, you have a solute through which it tries to move.

Mass Transfer



Diffusion- Fick's first law:

- Diffusion is the process by which molecules, ions, or other small particles spontaneously mix, moving from regions of relatively high concentration into regions of lower concentration.
- The molar flux (mol/area.time) due to diffusion of a constituent A relative to the average velocity of all constituents, is given by Fick's first law as

$$\text{Molar flux} = -D_{AB} \frac{\partial C_A}{\partial z}$$

- D_{AB} = diffusivity or diffusion coefficient of component A in B
- C_A = concentration of A
- z = distance Fick's first law is applicable to steady state system.



So here, the mass transfer is dictated by Fick's first law of diffusion. Diffusion is a process by which molecules, ions, or other small particles spontaneously mix, moving from a region of higher concentration to a lower concentration. So, this is given by the formula:

$$\text{Molar flux} = -D_{AB} \frac{\partial C_A}{\partial z}$$

Suffix AB is diffusivity or the diffusion coefficient of component A in B. Then, C_A is the concentration of A, Z is the distance fixed. The first law is applicable to a steady-state system Z . So, this is the diffusion coefficient. It is almost like k times A; if you see the thermal conductivity formula, it is almost the same.

Mass Transfer



Hydrogen diffusion into a metal:

- This process can be described with either a mass transfer coefficient (k), or a diffusion coefficient (D_{AB}).
- The description with a diffusion coefficient correctly predicts the variation of concentration with position and time, and so is superior.
- Whereas, the description with mass transfer coefficient predicts the variation, only with time.



So here, some examples are hydrogen diffusion into metals. This process can be described with either a mass transfer coefficient K_a or a diffusion coefficient D_{AB} . The description with the diffusion coefficient correctly predicts the variation of concentration with position and time.

So, the hydrogen embrittlement is there, whereas the description of the mass transfer coefficient predicts the variation only with time. So, this is very important. The description with the diffusion coefficient K correctly predicts the variation of concentration with position and time. Whereas, when you describe with the diffusion coefficient, the mass transfer predicts the variation only with respect to time. So, one tells with position, the other talks with time.

To Recapitulate



- State and explain the Heat Exchanger and its types.
- State the characteristics of a Shell And Coil Heat Exchanger?
- Explain the working of a Pipe In Pipe Heat Exchanger.
- State and Explain the Plate Type Heat Exchanger.
- Discuss the phenomena of Boiling and Condensation with their types.
- Explain the Boiling Heat Transfer process in details.
- What is the Condensation process?
- Define and explain the Mass Transfer and its types.



So, friends, in this lecture, we went through what a heat exchanger is and what the different types of heat exchangers are. We saw in detail shell and coil heat exchangers, pipe-in-pipe heat exchangers, and plate-type heat exchangers—how they work. Then, we discussed boiling, different types of boiling, pool boiling, flow boiling, and then we saw condensation. Then, we saw different modes of heat transfer in boiling, followed by various types of condensation processes. And finally, we discussed mass transfer. Mass transfer is very important. When we look at coatings, adsorption, absorption, and distillation, mass transfer plays a very important role.

As far as chemical engineering is concerned, mass transfer is a very important topic because it deals with movement from a higher concentration to a lower concentration.

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These are the references we have used throughout this lecture.

Thank you very much.