CHAPTER – 1

Heat Transfer

Syllabus:

Heat transfer, overall heat transfer coefficient, sources of heat, steam and electricity as heating media, determination of requirement of amount of steam / electrical energy, steam pressure, boiler capacity, heat exchangers.

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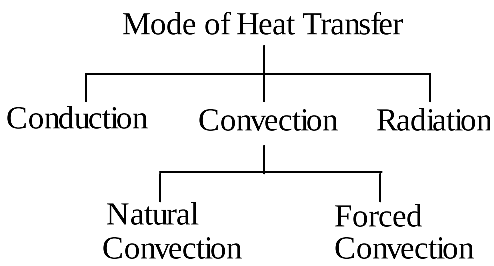
1. Classification of heat flow process

When two objects at different temperatures are brought into thermal contact, heat flows from the object at higher temperature to the object at lower temperature. The mechanisms by which the heat



may flow are (i)conduction, (ii)convection and (iii)radiation.

1.1 Conduction

When heat flow through a body without any observable motion of matter, the type of heat flow is called conduction.

Mechanism :

In metallic solids, thermal conduction results from the unbound electrons (which is similar to the electrical conductivity).

In solids that are poor conductor of heat and in liquids the heat is conducted by the transport of momentum of the individual molecules along the temperature gradient.

In gases the conduction occurs by the random motion of the molecules, so that heat is "diffused" from hotter regions to the colder ones.

Examples:

Heat flow through the brick wall of a furnace or the metal wall of a tube.

1.2 Convection

When heat flows by the transfer of matter, the type of heat flow is called convection.

In this case the heat flows by actual mixing of warmer portions with the cooler portions of the same material. Convection is restricted to the flow of heat in fluids (i.e. gas and liquids). Heat flows through fluid by both conduction and convection and it is difficult to separate the two methods because of the eddies set up by the change of density with temperature.

Examples

Transfer of heat by the eddies of turbulent flow and by the current of warm air from a room heater flowing across the room.

Natural and forced convection

The forces used to create convection currents in fluids are two types.

1.2.1 Natural convection:

When a fluid is heated the warmer part becomes lighter than the cooler part. Due to this difference in density the cooler (higher density) fluid moves down wards and the warmer (lighter density) move upwards and thus forming convection current. Thus heat is transferred with mass. This method of heat transfer is called natural convection.

1.2.2 Forced convection:

If the current (or movement of fluid) is caused not by the density difference but by some agitator or by some mechanical devices then the type of heat flow associated with it is called forced convection.

1.3 Radiation

When heat is transferred through the space by electromagnetic waves the type of flow of heat is called radiation heat flow.

Characteristics

- Any solid body at any temperature above absolute zero radiates energy.
- This radiation is an electromagnetic phenomenon and takes place without the necessity of any medium.
- When radiation is passing through empty space, it is not transformed into heat or any other form of energy nor it is diverted from its path. If the radiation falls on a matter the radiation energy

will be transmitted (i.e. pass through the matter), reflected or absorbed. Only the energy that is absorbed is converted into heat energy.

The approximate range of wavelengths for infra-red radiation (or heat rays) is 0.8 to 400 μm.

In industries, most of the cases, the thermal radiation corresponds to wavelengths from 0.8 to 25 μm.

1.3.1 The Black Body

Not all substances radiate heat at same rate at a given temperature. So a theoretical hot body is defined, which is called ‘black body’.

Definition: A ‘black body is defined as that body which radiates maximum possible amount of energy at a given temperature.

Example: An enclosed space is kept at a constant temperature. If the inside of the space is viewed through a tiny hole (so that negligible amount of energy leaked from inside) then the inside of the space may be called a black body.

Practical example. In practice, a convenient black body is made from a tube of carbon plugged at both ends with a small observation hole at the center of one end.

Industrial example. The inside of furnace at completely uniform temperatures, viewed through a small opening, is a black body. The interior of the furnace and all the objects within the furnace can also be considered black bodies.

Rates of radiation

The amount of energy radiated from a body can be expressed by Stefan-Boltzmann law

$$q = \varepsilon\, b\, A\, T^4.$$

where

q = energy radiated per hour (BTU/hr)

A = area of radiating surface (sqft)

T = absolute temperature of the radiating surface ^{0}R (Rankine) = t ^{0}F + 460

For black bodies the value of b = $0.174 \times 10^{-8} \dfrac{Btu}{hr\ ft^2\ {}^0R^4}$

ε = emissivity of the body

No actual body radiates quite as much as the black body.

- The emissivity is a fraction less than 1 and is the ratio of the energy emitted by the body in question to that emitted by a black body at the same temperature.
- When a radiant energy falls on a cooler body either the energy is *reflected* or *transmitted* or *absorbed*. The fraction of the radiation energy falling on a body that is absorbed is represented by α, the *absorptivity*, which is always less than 1. If the reflected energy can be neglected then the energy absorbed by any body is equal to the radiation falling on it.
- It can be shown that the absorptivity of a given substance at a given temperature and its emissivity at the same temperature must be equal.

That is, $\varepsilon = \alpha$

Since the ε of a black body is 1 hence the α of the black body will also be equal to 1. Therefore the black body absorbs all the radiation falling on it – an important property of black body.

- The value of α for a given surface at a given temperature varies some what with the wavelength of the radiation involved. To avoid complication due to this, the concept of *gray body* has been introduced. The *absorptivity* of a gray body at a *given temperature* is constant for all wavelengths of radiation.
- When a small black body of area A and temperature T_2 is completely surrounded by a hotter black body of temperature T_1, the net amount of heat transferred from the hotter body to the colder body is, therefore the algebraic sum of the radiation from the two bodies, so that Stefan's law may be written for this case as

$$q = b\,A\,(T_1^4 - T_2^4)$$

CONDUCTION

The basic law of heat transfer by conduction can be written in the form of the rate equation:

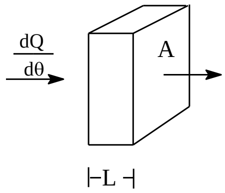
$$\text{Rate} = \frac{\text{Driving force}}{\text{Resistance}}$$

The driving force is the temperature gradient.

Fourier's law

Fourier's law states that the rate of heat flow through a uniform material is proportional to the area perpendicular to the heat flow (A), the temperature drop (dt) and inversely proportional to the length of the path of flow.

Consider an area A of a wall of thickness L. Let the temperature be uniform over the area A on one face of the wall. Both sides of the wall has a temperature gradient. If a thin thickness dL, parallel to the area A, be taken at some intermediate point in the wall, with a temperature difference of dt across such a layer, then Fourier's law may be represented by he equation:



$$\frac{dQ}{d\theta} = -\frac{kAdt}{dL} \qquad \text{eqn 1}$$

Where k = proportionality constant

If the temperature gradient dt/dL does not vary with time (this case is observed at steady state of heat flow) then the rate of heat flow is constant with time and

$$\frac{dQ}{dt} = \text{constant} = q = -\frac{KAdt}{dL} \qquad \text{eqn. 2}$$

Since normally we know only the temperature at the two faces of the wall hence integrating the Fourier's equation:

$$\frac{q\,dL}{A} = -k\,dt \qquad \text{eqn. 3}$$

On integration, if t_1 is the higher temperature than t_2.

$$q\int_0^L \frac{dL}{A} = -\int_{t_1}^{t_2} k\,dt = \int_{t_2}^{t_1} k\,dt \qquad \text{eqn. 4}$$

If A does not vary with L (i.e. the case of a flat wall) then equation 4 integrates to

$$\frac{qL}{A} = k(t_1 - t_2) = k\Delta t$$

or, by rearranging we get $q = \frac{k\ A\,\Delta t}{L}$ or, $q = \frac{\Delta t}{L/kA}$ eqn. 5

In equation 5 **Δt** is the driving force and the resistance is **L / k A**..

Thermal conductivity

The proportionality in constant **k** in equation $q = \frac{k\,A\,\Delta t}{L}$ is called the *thermal conductivity* (also called the coefficient of thermal conductivity) of the material of which the wall is made.

If	q	is expressed in Btu / hr
	A	in ft^2
	t	in ^0F and
	L	in ft

the unit of **k** will be : $\frac{(Btu)(ft)}{(hr)(ft^2)(^0F)}$

The numerical value of the thermal conductivity depends upon

(i) The material of which the body is made of

The thermal conductivities of liquids and gases are smaller compared to solids. For example at 212^0F the thermal conductivity of

silver is 240 (Btu)(ft) / (hr)(ft^2)(^{0}F)

water is 0.35 (Btu)(ft) / (hr)(ft^2)(^{0}F) and

air is 0.017 (Btu)(ft) / (hr)(ft^2)(^{0}F)

(ii) and upon its temperature.

The variation of thermal conductivity with temperature is meager (very small) but it is assumed that the variation is linear; that is:

$$k = a + b\,t$$

where a and b are constants and t is the temperature.

Compound resistances in series

Consider a flat wall constructed of a series of layers.

- L_1, L_2, L_3 are the thickness of the layers.
- K_1, K_2, K_3 are the thermal conductivities of the layers
- Let the area of the compound wall, at right angles to the heat flow be A.

Let t_0, t_1, t_2 and t_3 be the temperatures at the surfaces of the wall and at each junction according to the figure where $t_0 > t_1 > t_2 > t_3$.

Therefore, $\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3$

where, $\Delta t_1 = t_3 - t_0$.

$\Delta t_1 = t_1 - t_0$.

$\Delta t_1 = t_2 - t_1$.

$\Delta t_1 = t_3 - t_2$.

Again from Fourier's law

$$q_1 + \frac{k_1 A \Delta t_1}{L_1} \quad \text{or,} \quad \Delta t_1 = q_1 \frac{L_1}{k_1 A} = q_1 R_1$$

$$q_2 + \frac{k_2 A \Delta t_2}{L_2} \quad \text{or,} \quad \Delta t_2 = q_2 \frac{L_2}{k_2 A} = q_2 R_2$$

$$q_3 + \frac{k_3 A \Delta t_3}{L_3} \quad \text{or,} \quad \Delta t_3 = q_3 \frac{L_3}{k_3 A} = q_3 R_3$$

Since all the heat passing through the first resistance must pass through the second and in turn, pass through the third, so q_1, q_2 and q_3 must be equal and all of them can be represented by q.

$$\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3$$

$$= q R_1 + qR_2 + qR_3.$$

$$= q (R_1 + R_2 + R_3)$$

$$\therefore \quad q = \frac{\Delta t}{R_1 + R_2 + R_3}$$

If the equivalent resistance of the compound wall is R then $q = \frac{\Delta t}{R} = \frac{t_3 - t_0}{R_1 + R_2 + R_3}$

$$\therefore \quad R = R_1 + R_2 + R_3.$$

OVERALL HEAT TRANSFER COEFICIENT

Heat transfer from a warmer fluid to a cooler fluid, usually through a solid wall separating the two fluids, is found in different heat transfer equipment like heat exchangers, evaporators etc.

For example a liquid is flowing through a pipe and that liquid is heated by a steam from outside the pipe. In this case heat will be transferred from steam to the liquid. Both steam and the liquid are having Reynolds number above 4000 i.e. they are flowing in turbulent motion. In this case steam will produce a thin film on the outside surface of the pipe and the liquid will form another film at the inside surface of the pipe wall [*because the flow is very slow near the solid wall hence in the film viscous flow will prevail*]. Beyond these films the steam and the liquid are remaining in turbulent motion i.e. complete mixing is going on.

Heat is transferred through these stagnant films by *conduction* and when it reaches the bulk of the fluid, heat is mixed by *forced convection*. Since the bulk of the fluids are in great motion hence the heat transfer within the bulk is very rapid. Since the *thermal conductivities* of the fluids are low hence (although the films are very thin) the *resistance* offered by it to the flow of heat is very large.

Temperature gradients in forced convection

Let us consider that heat is flowing from a hot fluid through a metal wall to a cold fluid.

- The dotted lines F_1F_1 and F_2F_2 on each side of the solid wall is representing the *boundaries of the films in viscous flow*; all parts of the fluids to the right of F_1F_1 and to the left of F_2F_2 are in turbulent flow.
- The temperature gradient from the bulk of the hot fluid to the metal wall is represented by the curved line $t_at_bt_c$.

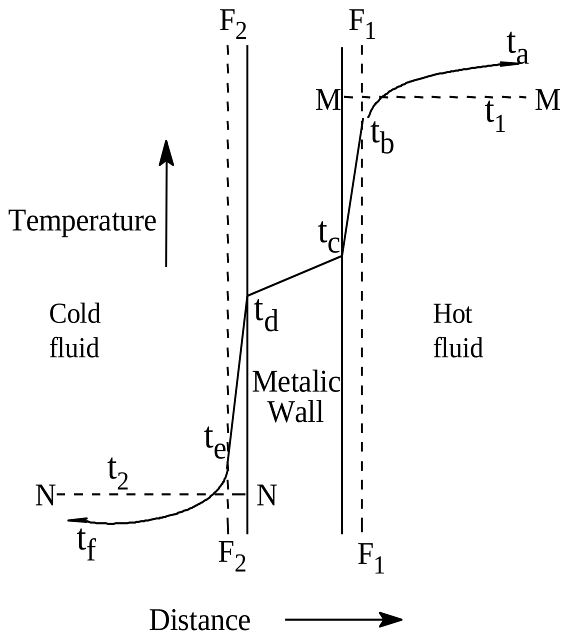


Fig. Temperature gradients in forced convection

The temperature t_a is the maximum temperature in the hot fluid (i.e. in the bulk of the fluid).

The temperature t_b is the temperature at the boundary between the viscous and turbulent flow.

The temperature t_c is the temperature at the actual interface between the fluid and the solid wall.

Similarly for fluid 2 the curved line is $t_dt_et_f$.

- When a thermometer (or any heat-sensing instrument) is inserted into the bulk of the fluid it will show a temperature t_1 and t_2 respectively for the two fluids. This t_1 is neither t_a nor t_b but this will be an average temperature and $t_a < t_1 < t_b$. t_1 is shown as a straight line MM.

The same remarks will apply for cold fluid also whose average temperature t_2 is represented by the line NN.

The temperature gradient t_dt_c is caused by the flow of heat in pure conduction through the solid wall and this $(t_c - t_d)$ smaller than $(t_1 - t_2)$.

Surface coefficients

Since the thickness of the film is not known, the simple equation of conduction cannot be applied in this case. The difficulty is circumvented by the use of *surface coefficient*.

The *surface coefficient* on the hot side is defined by the relation

$$h_1 = \frac{q}{A_1 (t_1 - t_C)}$$

where, h_1 = surface coefficient of the fluid on the hot side [Btu/(ft^2 ^{0}F s)]

q = amount of heat flowing from hot to cold fluid. [Btu / s]

A_1 = area of the metal wall on the hot side in a plane at right angle to the heat flow.[ft^2]

$(t_1 - t_C)$ = temperature gradient. [^{0}F]

If we compare $q = h_1 A_1 (t_1 - t_C)$ equation with $q = \frac{k\,A\,\Delta t}{L}$ then it is evident that

h_1 is analogous to (k / L) and $(1/h_1A_1)$ is the resistance term same as that of (L / kA) and h_1 contains the effect of both the viscous film and of the thermal resistance of the turbulent core that causes the temperature difference $(t_1 - t_C)$.

In the same way h_2 may be defined as $h_2 = \frac{q}{A_2 (t_d - t_2)}$

So the resistance imparted by the hot side = $\frac{1}{h_1 A_1}$

Resistance imparted by the metallic wall = $\frac{L}{k\,A_m}$

Resistance imparted by the cold side = $\frac{1}{h_2\,A_2}$

Overall heat transfer coefficient

If this resistances are substituted in the equation for compound resistance in series $q = \frac{t_1 - t_2}{R_1 + R_2 + R_3}$

then $q = \frac{t_1 - t_2}{\frac{1}{h_1 A_1} + \frac{L}{k A_m} + \frac{1}{h_2 A_2}}$

If the numerator and denominator are multiplied with A_1 then

$$q = \frac{A_1 \Delta t}{1/h_1 + A_1 L / kA_m + A_1 / h_2 A_2}$$

So the *overall heat transfer coefficient* U_1 is defined by the equation

$$U_1 = \frac{1}{1/h_1 + A_1 L / kA_m + A_1 / h_2 A_2}$$

Therefore $q = U_1 A_1 \Delta t$ states that the *rate of heat transfer is the product of three factors: overall heat transfer coefficient (U_1), temperature drop (Δt), and area of heating surface(A_1).*

For a tubular pipe $A_1 = \pi D_1 L$where D_1 and L are the inner diameter and length of the pipe respectively. Similarly $A_2 = \pi D_2 L$ and $A_m = \pi D_m L$.

So another form of overall heat transfer coefficient:

$$U_1 = \frac{1}{1/h_1 + D_1 L / kD_m + D_1 / h_2 D_2}$$

Analogous equation can be written for U_m and U_2.

HEAT EXCHANGERS

Some of the processes that involves heat transfer in pharmaceutical industries are:

- Preparation of starch paste (in steam jacketed kettle)
- Crystallization
- Evaporation
- Distillation

The equipment's used for heat transferring are known as heat exchangers.

Classification of heat exchangers

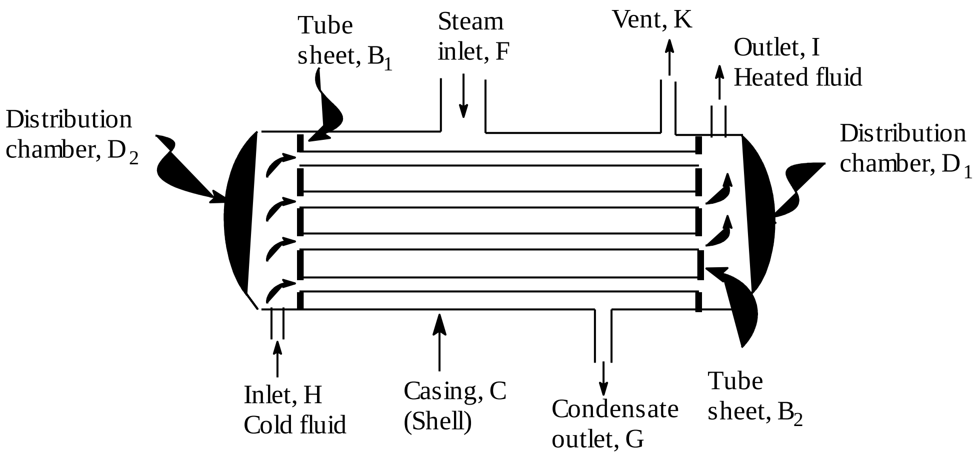
On the basis of transfer of heat, heat exchangers are classified as:

1. *Direct transfer type*: The hot and cold fluids are separated by a metal wall through which the heat is transferred from hot fluid to cold fluid. E.g. shell and tube heater,
2. *Storage type*: First a hot fluid is flown through a porous solid medium to heat the medium, then the cold fluid is flown through the hot solid porous medium to extract the heat from it. This type of heat exchangers is not used in pharmaceutical industries.
3. *Direct contact type*: Hot fluid is passed through the cold fluid and in this case the hot and cold fluids are not separated physically. For example steam is bubbled through a cold liquid.

Tubular heater

Tubular heaters consists of circular tubes, one fluid flows through the inner tube, while the other flows through the outside space. The heat transfer takes place across the wall of the tube.

1. Single Pass Tubular heater:



Construction: It consists of a bundle of *parallel tubes*, which are relatively thin-walled. The ends of these tubes are fitted to two *tube-sheets* B1 and B2. The bundles of parallel tubes are enclosed in a cylindrical shell or *casing* (C, made of cast iron) to which the tube-sheets (B1 and B2) are fitted. Two *distribution chambers* D1 and D2 are provided at each end of the casing (C). *Cold fluid inlet* (H) is fitted with distribution chamber D2 and *hot fluid outlet* (I) is fitted with the distribution chamber D1. *Steam inlet* F, *steam outlet* K(called *vent*) and *condensate outlet* G are fitted to the shell.

Working: Steam is introduced through the steam inlet F into the space surrounding the parallel tubes. Heat is transferred to the cold liquid inside the tubes and steam is condensed. The condensate is removed through condensate outlet G placed at the bottom of the casing. Non-condensable gases, if any, escapes through the vent K provided at the top of the shell.

The fluid to be heated is pumped through the cold fluid inlet (H) in to distribution chamber D1, flows through the tubes and collects in the distribution chamber D2. Heat is transferred from the steam to the cold fluid through the metal wall. The hot fluid leaves the heater through outlet (I).

Advantages: Large heating surface is packed into a small volume.

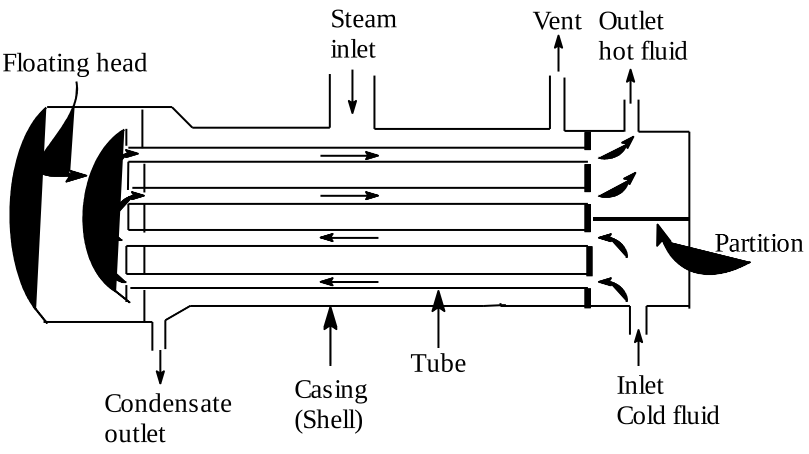
Disadvantages:

(a) The velocities of the fluid flowing through these tubes are low because of large cross-sectional area or surface area.

(b) The expansion of the tubes and shell takes place due to difference in temperatures. This may lead to loosening of the tube sheets form the casing.

(c) Initial cost and maintenance costs are very high.

2. Floating-head two-pass heater



Construction:

It consists of a bundle of parallel tubes. They are enclosed in a shell (casing). The right side of the distribution chamber is partitioned and fluid inlet and outlet are connected to the same chamber. The partition is such that both have equal number o ftubes. On left side the distribution chamber is not connected to the casing. It is structurally independent, hence known as *floating head*. The ends of the tubes are fitted with the floating head. Casing is provided with steam inlet, vent, and condensate outlet.

Working:

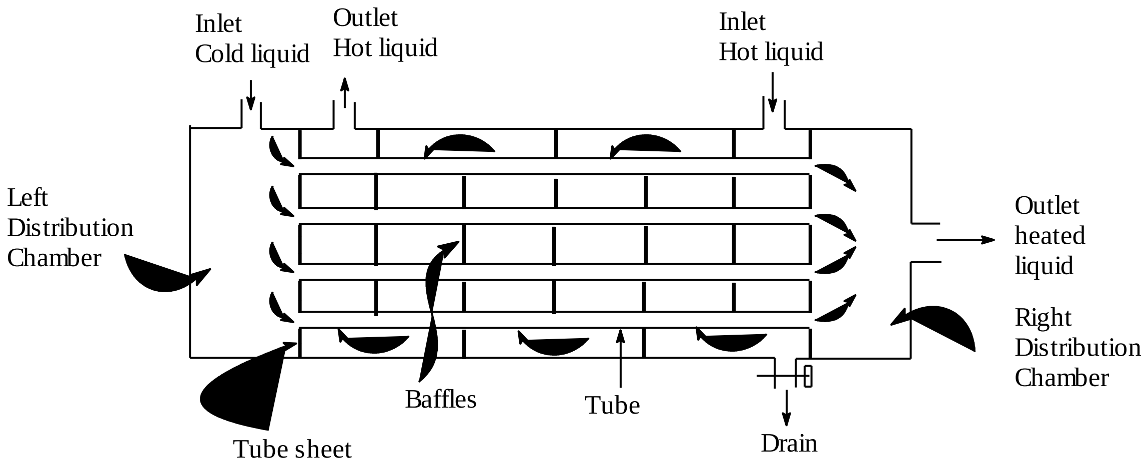
Steam is introduced through the steam inlet of the casing (shell). Steam heats the tubes. The condensate escapes through the condensate outlet fitted at the bottom of the casing. Non-condensable gas, if any, escapes through the vent of the casing provided at the top.

The cold fluid is introduced through the cold fluid inlet into the right-hand distribution chamber. The fluid flows through few tubes present in the lower part of the distribution chamber. The fluid reaches the *floating head* and changes direction and flows through the upper tubes again to the right-hand distribution chamber. The hot fluid is taken out through the outlet.

During this process the fluid in the tubes get heated due to heat transfer through the metallic wall.

Advantages: Due to differences in temperature the tubes and shells may expand and the joints may get loose. Since, the floating head part is independent of shell (or casing) hence the problem of loosening is prevented in this type of heater.

3. Liquid-to-liquid heat interchanger



Construction:

Construction is same as that of single-pass tubular heater, only difference is that it contains *baffles* to lengthen the path of flow of outer liquid. A set of parallel tubes are fitted to two *tube-sheets* at two ends. The tubes and the tube-sheets are placed inside the shell. Cold liquid inlet is fitted to the left-hand side distribution chamber and outlet is fitted with the right-hand side of the distribution chamber. Hot liquid is entering through the right-hand top side of the shell and leaving the shell through the outlet placed on the top, left-hand side of the shell.

Baffles consists of circular metal sheet, with one side cut away. Baffles are placed inside the shell at appropriate places. Baffles have perforation on it through which the tubes pass.

Working:

The hot liquid is pumped from the left-top of the shell. The fluid flows through the shell (i.e. outside of the tubes) and moves down directly to the bottom (due to baffle), again moves up – like this it flows from the left to right-hand side of the shell.

Baffles increases the velocity of the hot fluid outside the tubes, which creates more turbulence. This reduces the film thickness at the outside of the tube and thus increases the film coefficient and thus heat transfer increases.

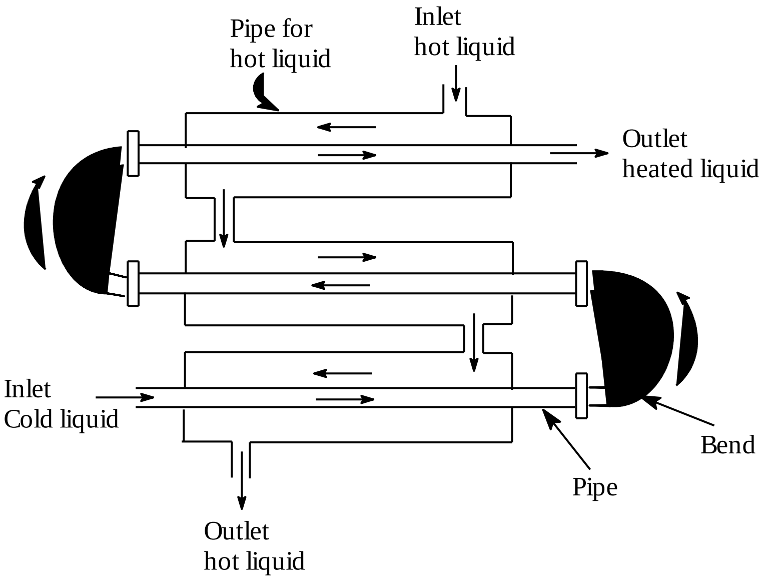
The baffles also get heated and add to the heat transfer to cold liquid.

The cold liquid is pumped through the inlet at the left-hand side distribution chamber. The liquid passes through the tubes and gets heated. The heated liquid is collected from the right-hand side distribution chamber.

Advantages: Heat transfer is rapid.

4. Double-pipe heat interchanger

N.B. In a liquid-to-liquid heat interchanger, the fluid to be heated is passed only once through the



tubes before it is discharged, i.e. single pass. The heat transfer in this case is not efficient. In double-pipe heat interchanger number of pass can be increased as desired.

Construction:

In this case two pipes are used – one is inserted into the other. Cold fluid is passed though inner tube. The outer pipe acts as a jacket for the circulation of hot fluid. All jacketed sections are interconnected.

Normally the number of pipe-sections are few. The length of the pipe is also less. The inner tubes may be made of glass and standard iron. The pipes are connected with standard return bends and the pipes are stacked vertically. The pipes may have longitudinal fins on its outer surface for better heat transfer.

Working: The hot liquid is pumped into the jacketed section. It is circulated through the annular spaces between them and carried from one section to the next section. Finally it leaves the jacket. In this process the pipes get heated.

The liquid to be heated is pumped through the inlet of the inner tube. The liquid gets heat up and flows through the bend tube into the next tube-section and finally leaves the exchanger.

Limitation: Double-pipe heat interchanger is economical when the heating surface area is less than 9 m^2.

Sources of heat

1. Steam
2. Electricity: Heating coil made with nichrome wire. Used in heating oven, tray dryer. Air can be heated by passing through heating coil. Water can be heated by using heating element. Heating element is a coil of nichrome wire covered with a nonconductor and enclosed within a steel pipe.
3. Infra red source: Infra Red heating source with carbon filament. Used for drying films, coatings etc. as the materials are conveyed under the IR heat source.

Steam as heating media

Steam has wide-spread application in pharmaceutical industries. The applications are as follows:

1. Steam has very high heat content. – Under 1 atm pressure saturated steam has 540cal/gm of latent heat.
2. The heat of steam is given up at constant temperature. – When steam condenses no temperature change takes place only the latent heat is given up.
3. The raw material of steam is water. It is cheap and easily available.
4. Steam is clean, odourless and tasteless, so that any accidental contamination of a product are not likely to be serious.
5. Steam is easy to generate, distribute and control.

Properties of steam

One kg of water is taken in a closed vessel one side of which is closed by a moving frictionless piston. By changing the weight of the piston the pressure inside the vessel can be changed. Let us imagine that the piston is giving a **constant pressure, P** and the temperature inside is **0^0C**.

1. <u>State-1</u>: Heat (h) is added until water starts to boil. This h amount of heat is required to raise the temperature of water from 0^0C to t_s. So

   $$h = ms\Delta t \quad \text{where } m = 1 \text{ kg, } s = \text{specific heat of water} = 1000 \text{ J/kg/}^0\text{C}$$
   $$= 1 \times 1000 \times (t_s - 0)$$
   $$= t_s \text{ kJ}$$

2. <u>State-2</u>: If more heat is added, q fraction of water will be vaporized. If the latent heat of vaporization of water is L kJ/kg then the steam contains qL kJ amount of heat and the total heat of water and steam = (h + qL) kJ.

When steam remains in contact with water that steam is called *wet steam* and q is known as *dryness fraction*.

3. State-3: If further heat is added, a point will be reached when all the water will be converted to steam i.e. q = 1. The total heat of the steam is now Hs = (h + L) kJ. The temperature is still t_s. Since no water is there in contact with steam hence this type of steam is called *dry saturated steam*.
4. Staet-4: If more heat is provided to dry saturated steam then the temperature of the steam will be increase above t_s (say t_{sup}). This type of steam is called *super-heated steam*.

   The total heat content = $H_s + H_{sup} = h + L + H_{sup}$.

Generation of steam

The steam is generated in central boiler house at high pressure. High-pressure steam may be used to generate electricity by driving a turbine and the low-pressure steam that is exhausted can be used to heat various processes. Under high pressure steam can carried through pipes to different equipments.

Distribution of steam

From the boiler the steam is distributed through piping of adequate size and minimum length to minimize heat loss. To reduce heat loss the pipes should be *lagged*, i.e. the pipes are covered with a porous, poor conducting material such as asbestos, kieselguhr or glass wool. The porous medium entraps a stagnant layer of air around the pipe.

An alternative method of reducing heat loss is by covering the pipes with several layers of aluminium sheets. The surface of the aluminium reduces radiation heat loss and the air entrapped within the layer of aluminium sheets reduces heat loss due to convection and conduction.

Boiler capacity

The output of a boiler is often expressed in pounds of steam delivered per hour. Since this value may vary in temperature and pressure over time, a more accurate and complete expression is that of heat transferred over time, expressed as British thermal units per hour. Boiler capacity is usually expressed as kBtu/hour (1000 Btu/hour).

Steam Pressure

If pressure increases the temperature of the steam will increase, thus making it super-heated steam. Super-heated steam contains less amount of latent heat compared to dry saturated-steam. Since the latent heat is the useful heat, steam should be used at the lowest pressure that will give a suitable temperature gradient.