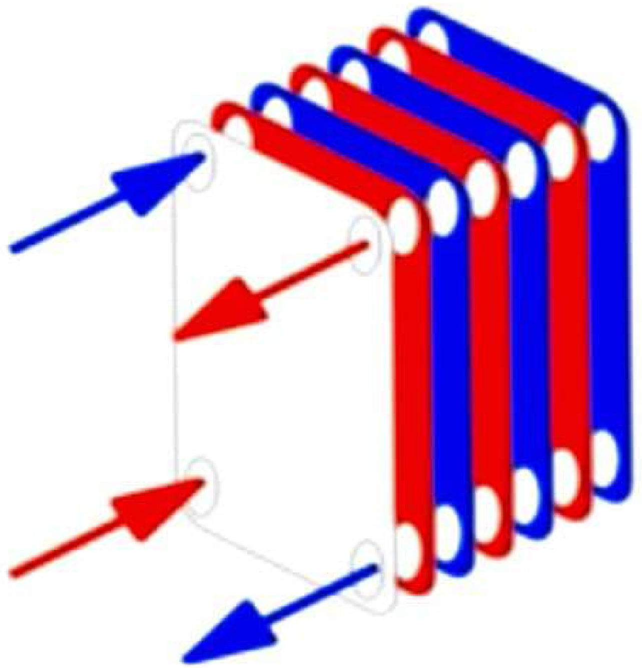
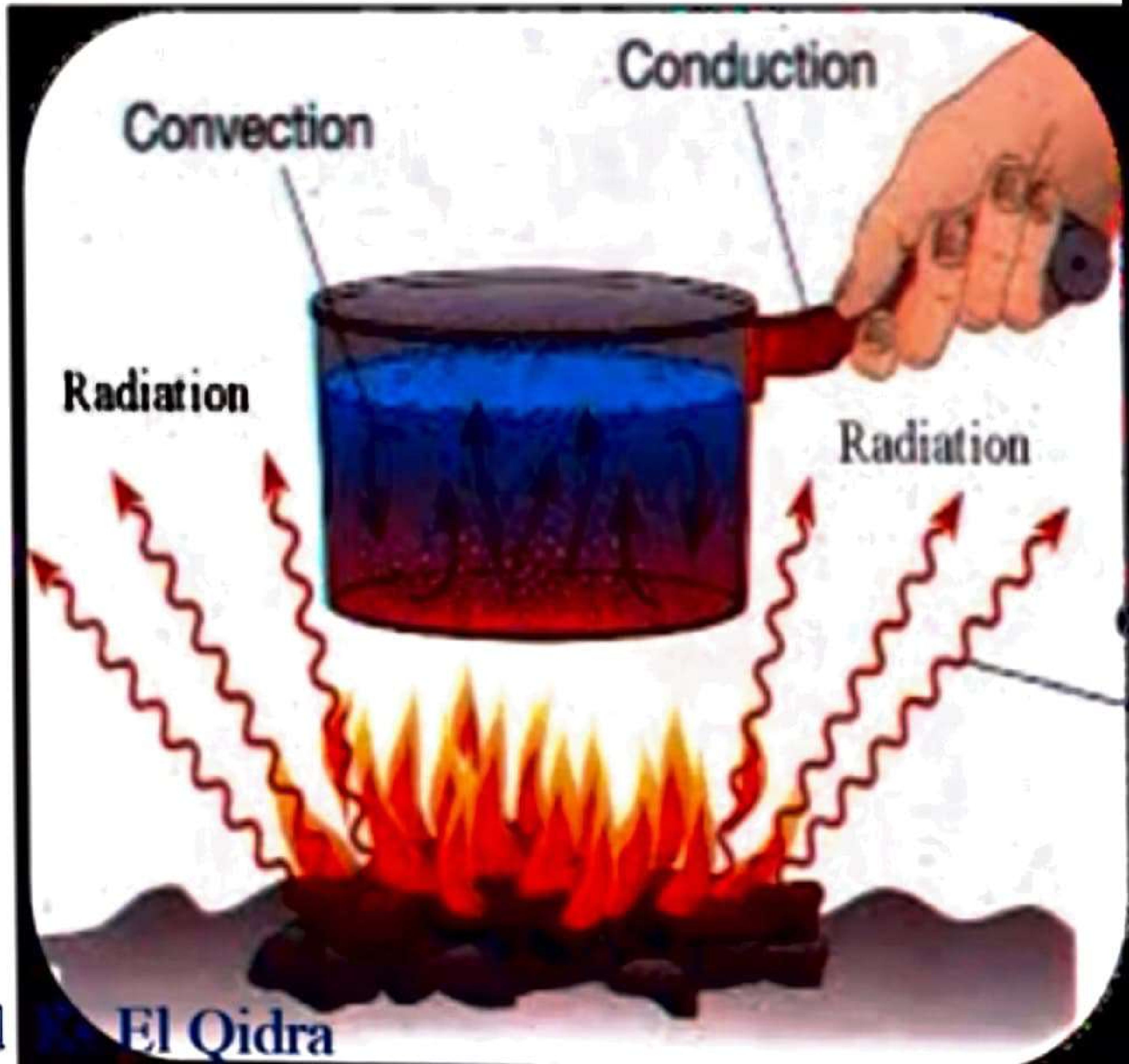
Heat Transfer and Heating Process





Prepared by Dr. Riad E. El Qidra

Definitions

- **Heat :**

The form of energy that can be transferred from one system to another as a result of temperature difference.

- **Temperture :**

Is the degree hotness or coldness of an object.

- **Heat Transfer :**

It is the transfer of heat from region of high temperature to a region of low temperature (driving force is the temperature difference).

Heat transfer applications

1. **Evaporation:** heat is supplied in order to convert a liquid into a vapor.
2. **Distillation:** heat is supplied to the liquid mixture for separation of individual vapor component.
3. **Drying:** for drying the wet granules.
4. **Crystallization:** saturated solution is heated to bring out super saturation, which promotes crystallization of drugs.
5. **Sterilization:** Autoclaves are used with stream as a heating medium.

Mechanisms of heat transfer

❖ Heat transfer from one place to another takes place by three different mechanisms and all three may occur simultaneously.

1. **Convection**

2. **Conduction**

3. **Radiation**

1- Conduction

- Is the transfer of thermal energy by molecular action, without any motion of the medium.

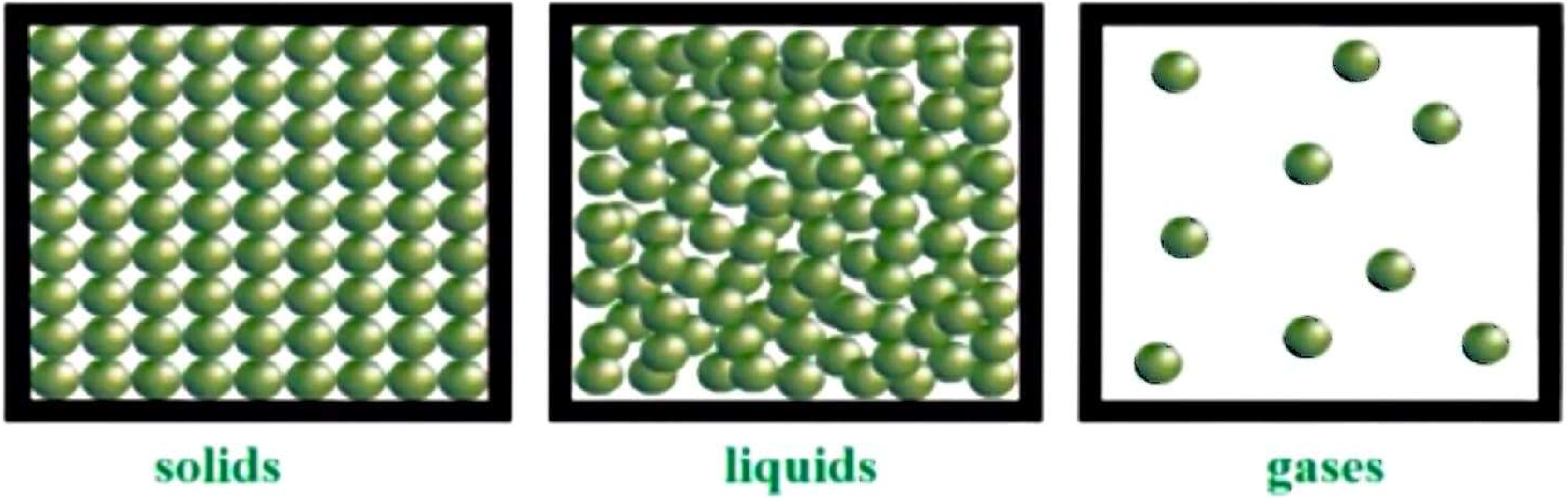
- It is the transfer of energy from one molecule to the other adjacent to it without displacement of particles.

- Conduction can occur in solids, liquids, and gases,

- But it is usually most important in solids.

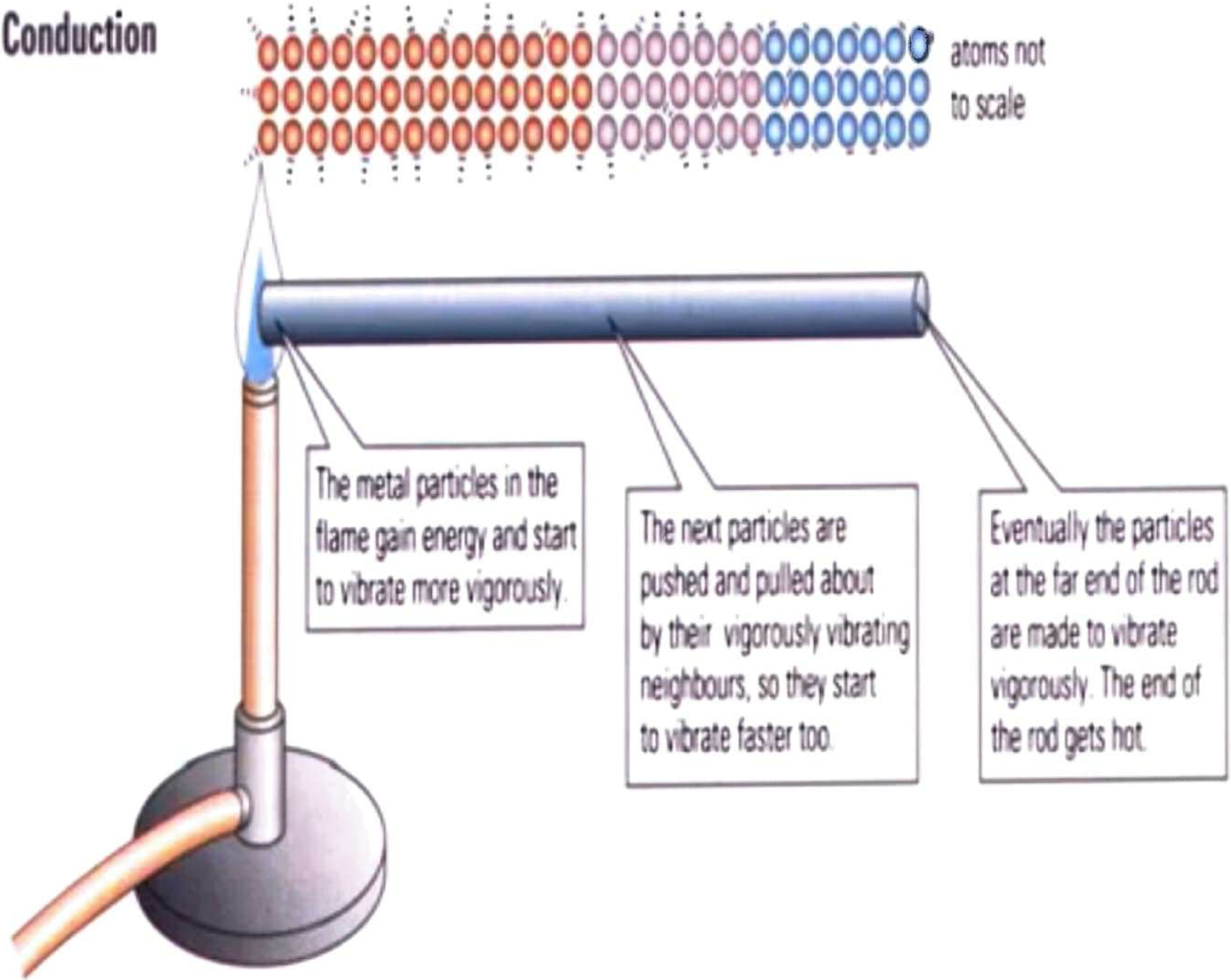
What is Conduction?

How are the particles arranged in a solid, a liquid and a gas?



Conduction is the transfer of energy from more energetic particles of a substance to adjacent less energetic ones result of interaction between particles.

Conduction



atoms not to scale
The metal particles in the flame gain energy and start to vibrate more vigorously.
The next particles are pushed and pulled about by their vigorously vibrating neighbours, so they start to vibrate faster too.
Eventually the particles at the far end of the rod are made to vibrate vigorously. The end of the rod gets hot.

2- Convection

- ❖Is the transfer of thermal energy by the actual motion of the medium itself.

- ❖The medium in motion is usually a gas or a liquid.
- ❖Heat is transferred from lower layer to middle to upper.

- ❖Convection is the most important heat transfer process for liquids and gases. It may me:

A. **Natural :** Caused by difference is density arising from temperature gradient.

B. **Forced** : By mixing like a fan or pump.

3- Radiation

- The energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.
- All bodies with temperature above absolute zero radiate heat in the form of electromagnetic waves which travel in straight line at the speed of light.
- Radiation may be transmitted, reflected or absorbed.
- The absorbed fraction is transformed into heat

  Example : Sun

Radiation

- Radiative heat transfer can be mathematically expressed with Stefan-Boltzsman law;

$$Q = \sigma AT4$$

Where,

- Q = heat transfer per unit time
- σ = stefan Boltzmann constant
- A = Area of the emitting body
- T = absolute temperature

$$\frac{P}{A} = \sigma T^4 \; J/m^2 s \quad \text{Stefan-Boltzmann Law}$$

$$\sigma = 5.6703x10^{-8} \; watt/m^2 K^4$$

Sources of heat energy:

1- Direct:

e.g. flame and electrical heater.

2- Indirect:

It involves 2 steps:

a-Transfer of heat from one system to HTA **heat transfer agent** (Brine steam, water, oil and air).

b-Transfer of heat from heat transfer agent to second system.

F° = C° X 1.8 + 32　　　　**ft = 12 inch**

Steam

Properties:

- It is usually under pressure.
- It has very high heat content.
- It's raw material (water) is cheap, clean, odorless and tasteless, so accidental contamination is not serious (as oil)
- It is used to give both sensible heat and latent heat.

Classification:

1-Saturated Steam (wet):

- Arises directly from boiling water.
- Easily condensed on any cooler surface due to presence of suspended water droplet.

2-Unsaturated Steam (dry):

- Its pressure less than that of wet steam at the same temperature.
- Not condense on a slightly cooler surface.

3-Superheated steam:

- Obtained by heating a saturated steam.

Devices involved in the designing of heating equipment's (Heaters &Heat exchangers).

1- Steam Dryers (Water Separator)

- They are used to separate water from steam.

- Steam dryers act by causing a quick change of direction of wet steam so that the water is left behind and

- the dry steam goes forward.

<table>
<tr><th>Simple type</th><th>Screw type</th></tr>
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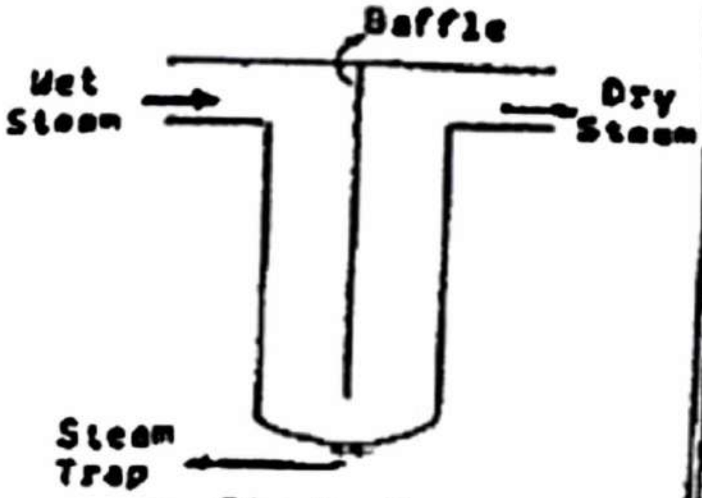
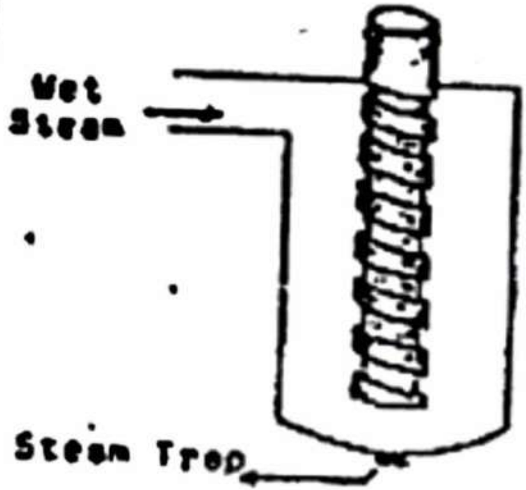


a. Simple Type.

</td><td>



b. Screw-Type.

</td></tr>
<tr><td>The wet steam enters the vessel at the top and passes down one side and up on the other side leaving the water in the bottom of the vessel.</td><td>The wet steam passes into the upper part of a cylindrical vessel containing a central pipe its outside wall is screw so that wet steam take spiral movement round the pipe and centrifugal force generated throw water on the inner wall of the outer vessel and water drips down into the bottom, while dry steam which changes its direction rapidly passes up and out by the pipe.</td></tr>
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2- Steam Traps

Device that used to prevent outlet of live steam

Types:

A- Mechanical

Depend on the physical difference between vapor and liquid.

B- Thermostatic

Depend on that condensate can loose its sensible heat and have lower temperature than steam (i.e. depend on the temperature difference between condensate and steam)

A- Mechanical steam traps:

1- Float type steam trap:-

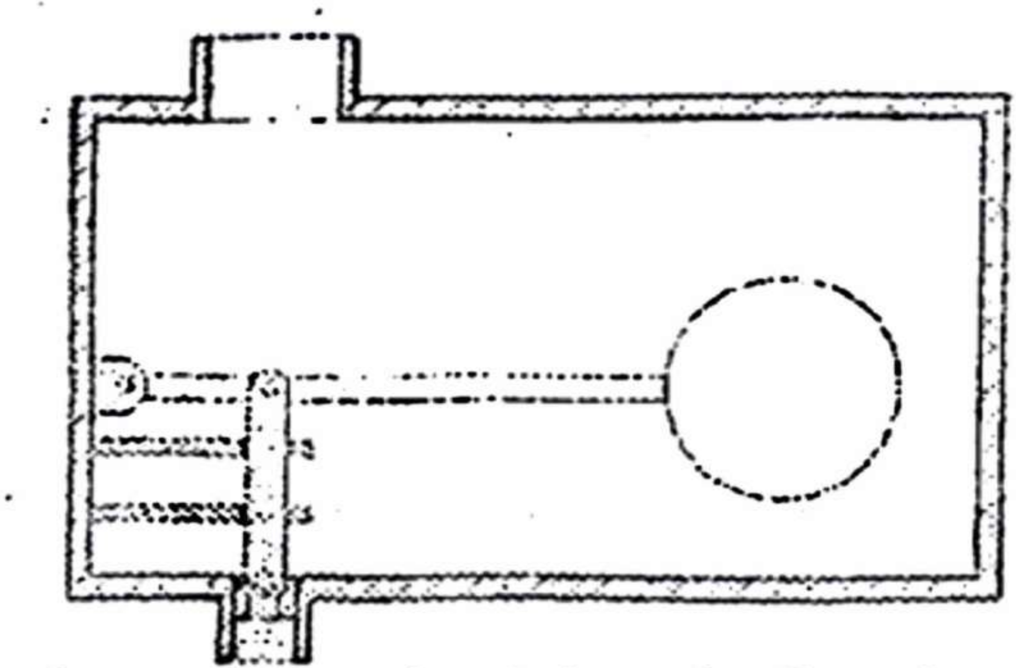
- When the condensate level rises, the float rises and
- the outlet is opened till the condensate is discharged, then
- the float falls and the outlet is closed and so on.

2- Bucket steam trap:

- The outlet is closed when the bucket floats on the condensate.
- When the condensate overflows into the bucket , it sinks and
- the outlet is opened-and the condensate is pushed out by the pressure of steam till the bucket floats up to close the outlet and so on.

A- Mechanical steam traps:

1- Float steam trap



When the condensate level rises, the float rises and the outlet is opened till the condensate is discharged, then the float falls and the outlet is closed and so on.

B-Thermostatic steam traps:

1- Simple thermostatic trap:

Disadvantage:

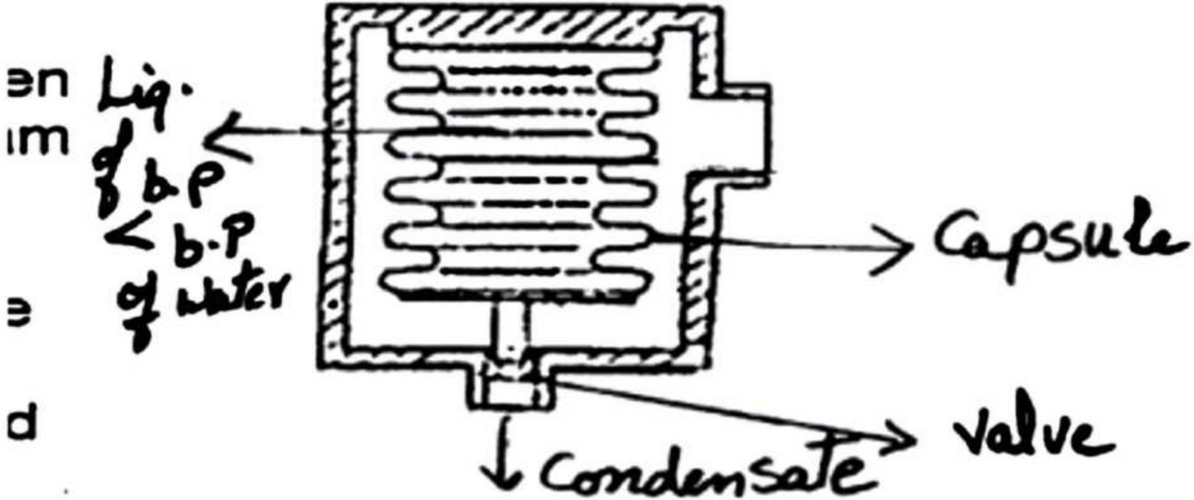
- Slight variation in the steam pressure, and temperature may cause the trap to stay either open or closed.

2- Balanced pressure expansion steam trap :

- It consists of a closed capsule made of cu alloy and fixed at the top.
- It has corrugated surface.
- It contains a liquid having a boiling point lower than that of water.
- when the capsule is surrounded by steam the liquid inside it will boil and the capsule expand and the outlet is closed.
- In presence of condensate the capsule become cold and contracts and opens the outlet and discharges the condensate.
- It is used for steam pans and steam heated stills.

B-Thermostatic steam traps:

1- Balanced pressure expansion steam trap



It consists of a closed capsule made of **cu alloy** and fixed at the top. It has corrugated surface. It contains a liquid having a boiling point lower than that of water. when the capsule is surrounded by steam the liquid inside it will boil and the capsule expand and the outlet is closed. In presence of condensate the capsule become cold and contracts and opens the outlet and discharges the condensate.

3- Thermal Insulation (lagging material)

Substance that used to prevent heat loss.

A good lagging material should:

- Have low thermal conductivity.
- Suppress convection currents.

Examples of lagging materials:

1. Cork:

- charring occur at moderate temperature, used in refrigeration

2. Asbestos:

- used for steam pipes and hot plastic material

3. 85% magnesia with asbestos:

- used for steam pipe and hot plastic material.

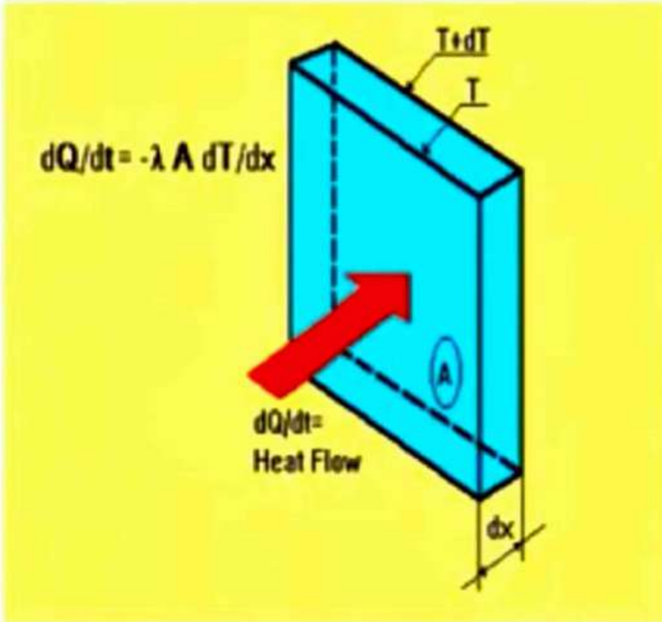
Economic thickness of lagging:

As thickness increase ⟹ heat loss decrease ⟹ but cost increase. There is an optimum thickness.

Fourier law Of Conduction

In 1822 Fourier postulated that the rate of heat transfer is proportional to the temperature gradient present in a solid.

$$\dot{Q}_{cond} = -kA\frac{dT}{dx} \qquad (W)$$



$$\text{Rate of heat flow} = \frac{\text{thermal conductivity (k)} \times \text{cross-section area (A)} \times \text{temperature difference } (\Delta\theta)}{\text{length } (l)}$$

Single and compound(composite)wall resistance in series

- Up to now a wall has been treated as if it consisted of only one material.
- Walls are made up of many different materials of different thicknesses.
- We solve this more general problem by considering the compound wall.

$$q = \frac{(T_1 - T_5)}{\frac{X_1}{K_1 A} + \frac{X_2}{K_2 A} + \frac{X_3}{K_3 A} + \frac{X_4}{K_4 A}}$$

Thermal conductivity:

- The rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.

- The thermal conductivity of a material is a measure of the ability of the material to conduct heat.

- A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or

Material	Thermal conductivity (W/m K)
Copper (pure)	399
Gold (pure)	317
Aluminum (pure)	237
Iron (pure)	80.2
Carbon steel (1 %)	43
Stainless Steel (18/8)	15.1
Glass	0.81
Plastics	0.2 – 0.3
Wood (shredded/cemented)	0.087
Cork	0.039
Water (liquid)	0.6
Ethylene glycol (liquid)	0.26
Hydrogen (gas)	0.18
Benzene (liquid)	0.159
Air	0.026

Unit of Heat Transfer

Symbol	Metric System	English System
Q	Joules (J)	British Thermal Units
q	Watts (W) = Joule/sec	Btu/hour
A	Meter^2 (m^2) or (cm^2)	Foot square(ft^2)
X	Meter (m) or (cm)	Foot
θ	Hours or seconds	Hours or seconds
T	Degree Kelvin(°K)	Degree Fahrenheit (°F)
K	W/m °K W/cm °K × 100 ↑	Btu/hr.ft. °F Btu/sec.ft.°F × 3600 ↑

Conversion Factors Between the Two Systems for (**K**):

1- W/m °K X 0.578176 → Btu/hr.ft.°F

← X 1.729580

2- W/cm °K X 57.8176 → Btu/sec.ft.°F

← X 0.01729580

Problems

Calculate the quantity of heat transfer (Q) through a certain heat transfer medium, employing the encircled data in the following table.

No.	θ (Hours)	K	X (inch)	A (ft^2)	T_1 (°F)	T_2 (°F)
1	0.2	10	0.1	2	170	70
2	0.4	20	0.2	4	180	75
3	0.6	30	0.3	6	190	80
4	0.8	40	0.4	8	200	85
5	1	50	0.5	10	210	90

$q = Q / \theta = KA (T_1 - T_2) / X$

q = rate of heat transfer (Btu / hr) Q = quantity of heat transfer (Btu)

θ = time (hour)k = thermal conductivity coefficient (Btu / hr. ft °F)

A = surface area (ft^2) T = temperature (°F) X = wall thickness (ft)

N.B 1ft = 12 inch (so any inch in the data must be converted to foot by dividing it with 12)

Problem 1 :

$Q / \theta = KA (T_1 - T_2) / X =$

$$Q / 0.2 = \frac{10 \times 2 (170 - 70)}{0.1 / 12} = 48000 \text{ Btu}$$

Heating Equipment's:

1- Heaters

2- Heat Exchangers

3- special Forms

1- Heaters or (Tubular heat exchangers)

It is the simplest form of heater. It is single pass tubular heater.

Construction:

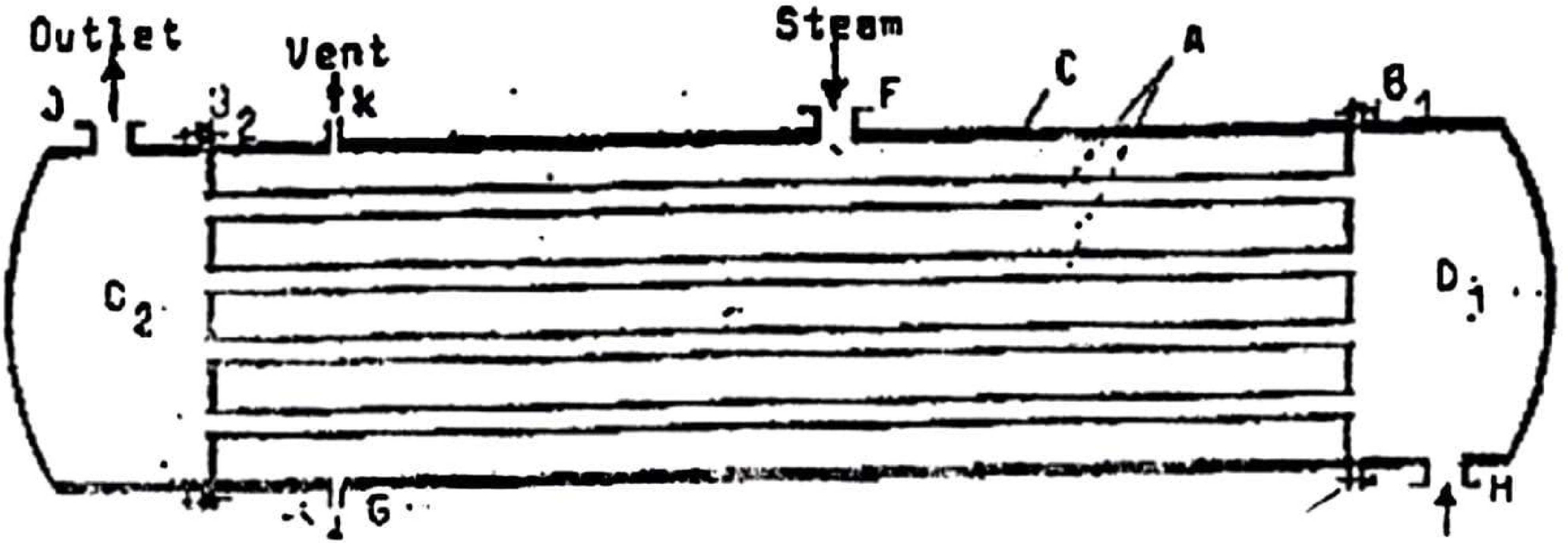
- It consists of bundle of parallel tubes relatively thin walled.
- Ends of tubes are expanded into two sheets.
- Bundles of tubes are enclosed in a cylindrical shell.
- Two distribution chambers are provided at each end.
- Fluid inlet is provided to left distribution chamber.
- Heated fluid outlet is provided to right distribution chamber.
- Steam is provided by connections, non condensate vapor escape through vent.
- Condensate vapor drains at the bottom.

Advantages:

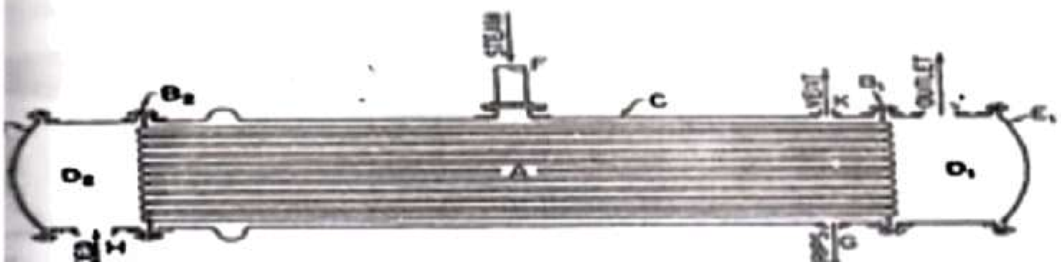
- Large heating surface can be packed into small volume.

Disadvantages:

1. Velocity of fluid is low because of large cross section area.
2. Due to high temperature loosening and leakage take place.



Single pass tubular heater

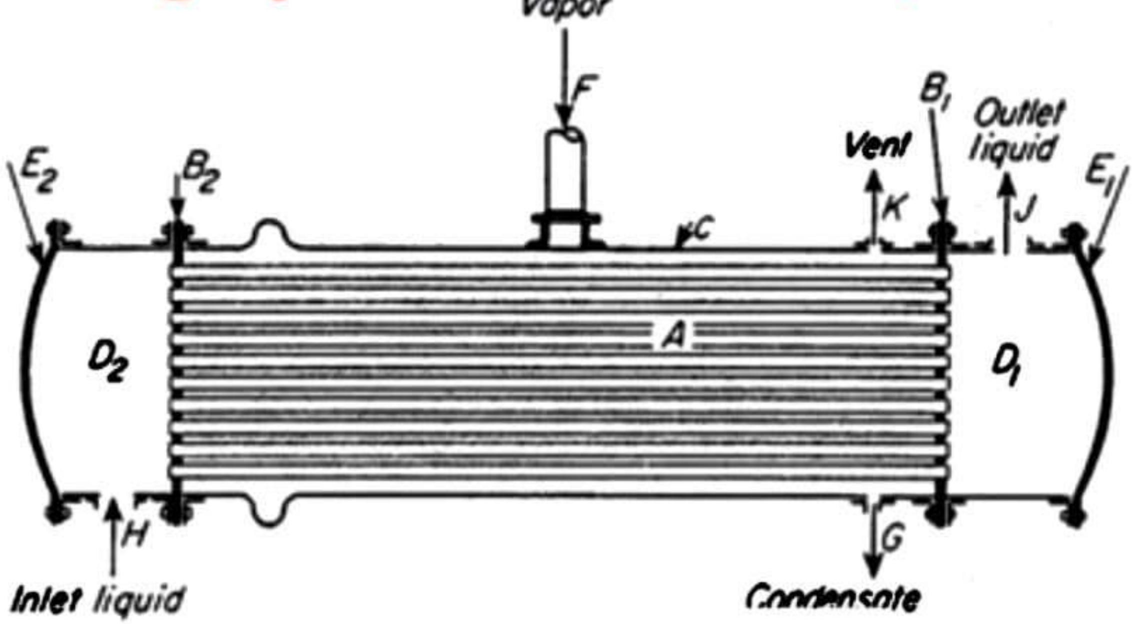


Single-pass tubular heater: *A*, tubes; *B_1*, *B_2*, tube sheets; *C*, shell; *D_1*, *D_2*, distribution chambers; *E_1*, *E_2*, covers; *F*, steam inlet; *G*, condensate outlet; *H*, ... *J*, liquor outlet; *K*, noncondensed-gas vent.

Single-pass Tubular Heater (1-1 exchanger)

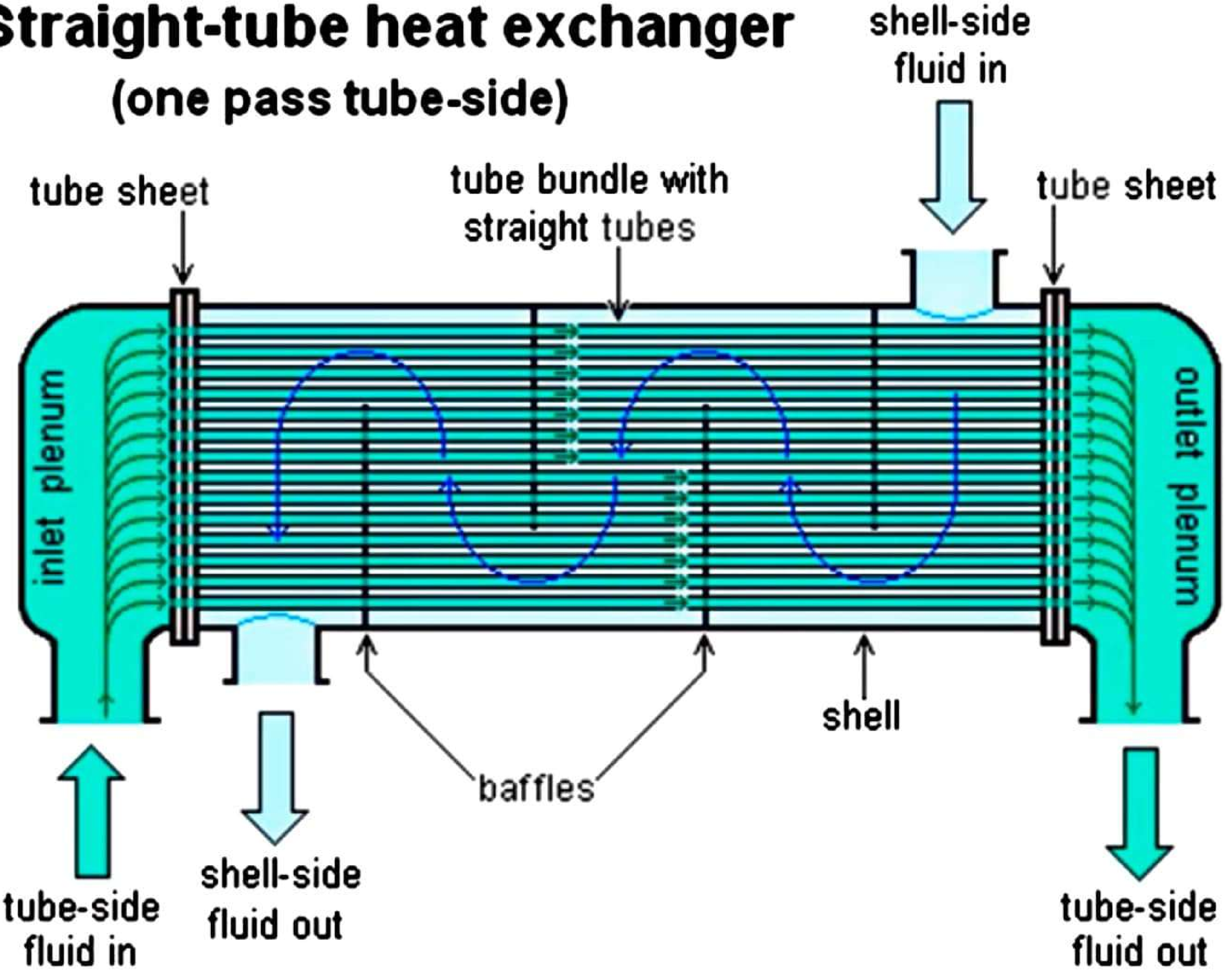
Single Pass Shell/Tube Condenser

Single-pass Tubular Heater (1-1 exchanger)



Single-pass tubular condenser: *A*, tubes; B_1, B_2, tube sheets; *C*, shell; D_1, D_2, channels; E_1, E_2, channel covers; *F*, vapor inlet; *G*, condensate outlet; *H*, cold-liquid inlet; *J*, warm-liquid outlet; *K*, non-condensed-gas vent.

Straight-tube heat exchanger
(one pass tube-side)



2- Heat exchanger

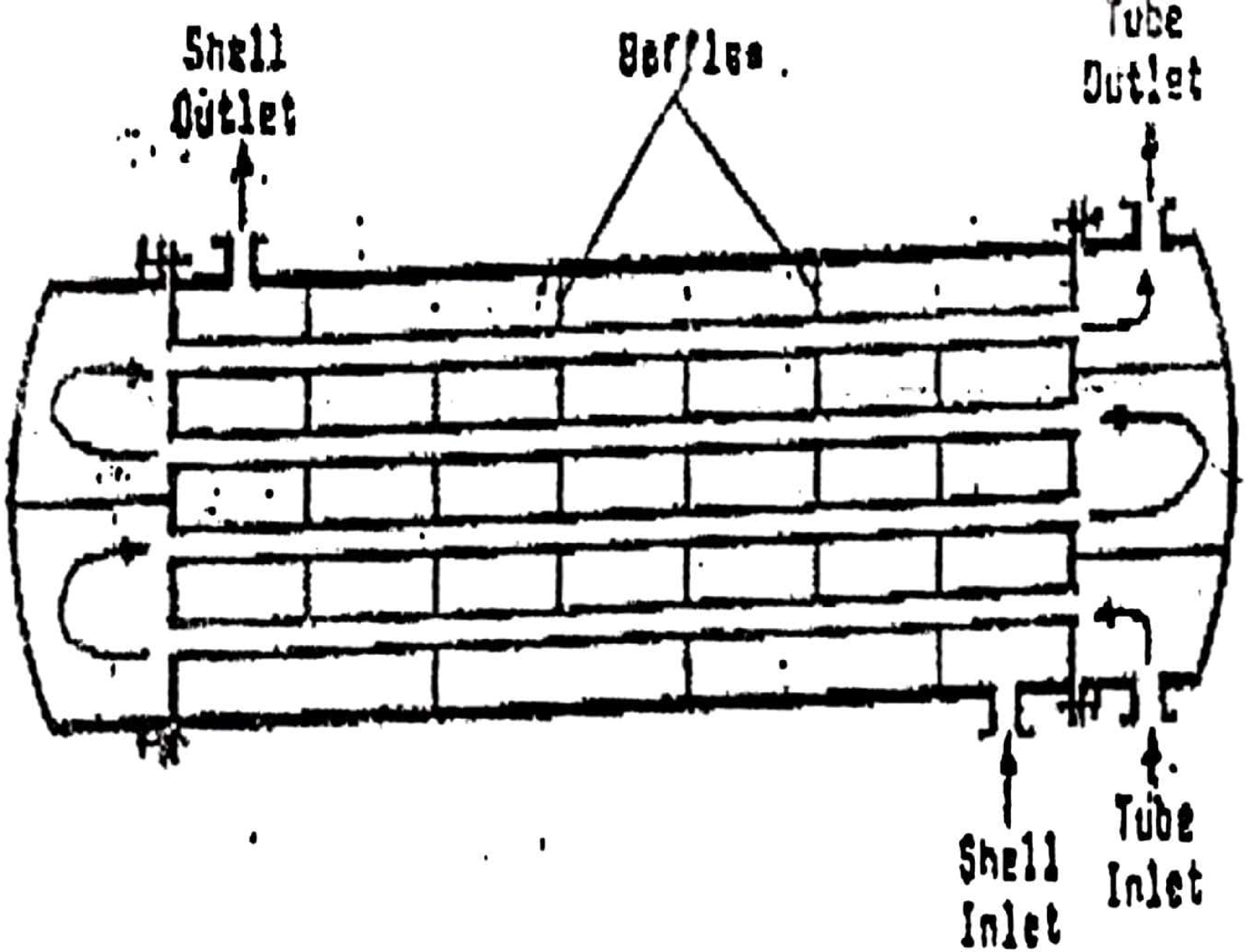
1- Fixed–head heat exchanger (1–4) exchanger

- ❖The tubes have at each end plate or sheets fixed to shell.
- ❖Internal fluid to be heated makes several passes in the exchange: (4 passes).
- ❖Baffles increase the velocity of flow outside the tube hence giving better heat transfer,

Disadvantages:

1-Tube bundle cannot be removed for cleaning.

2-Tubes has no chance for expansion due to baffles



Fixed–head heat exchanger (1–4) exchanger

Fixed head heat exchanger

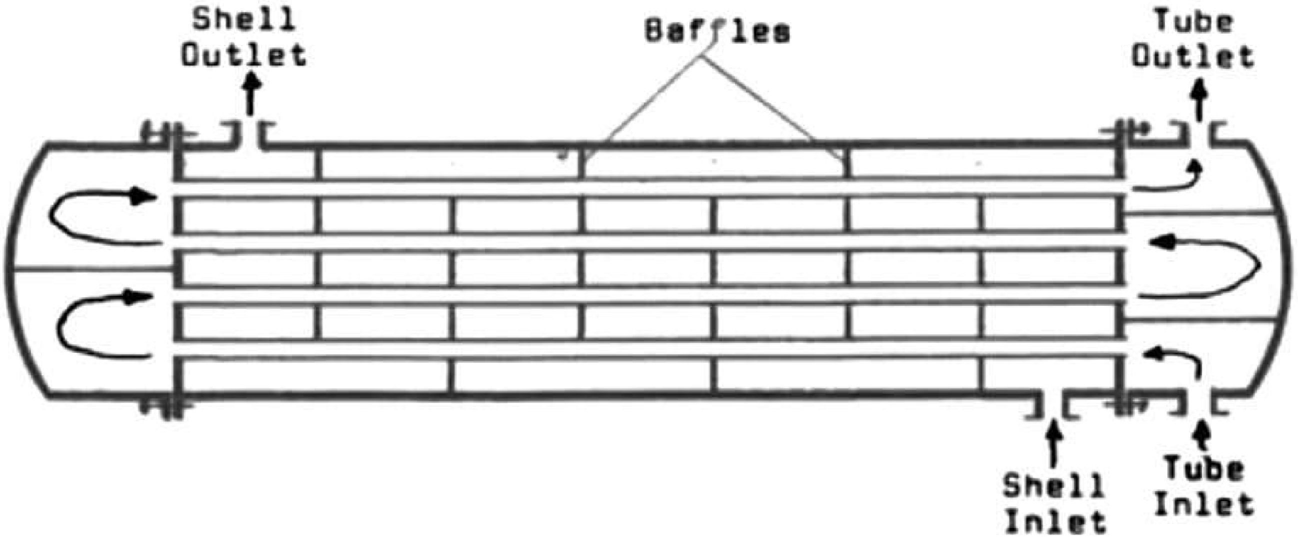
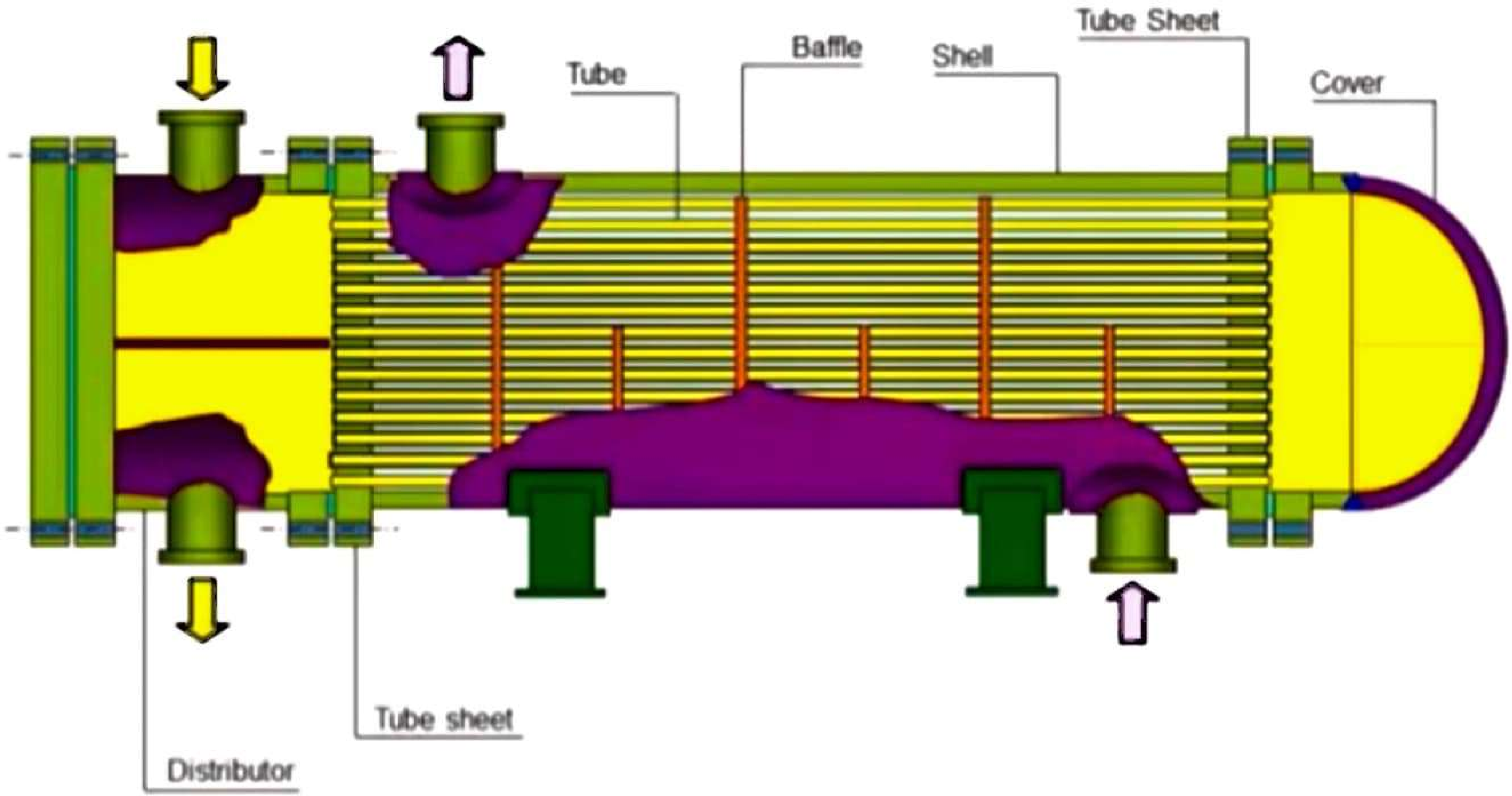


Fig. 6: Fixed-Head Heat Exchanger (1-4 Exchanger).

FIXED TUBESHEET HEAT EXCHANGER

CROSS SECTION VIEW ASSEMBLY



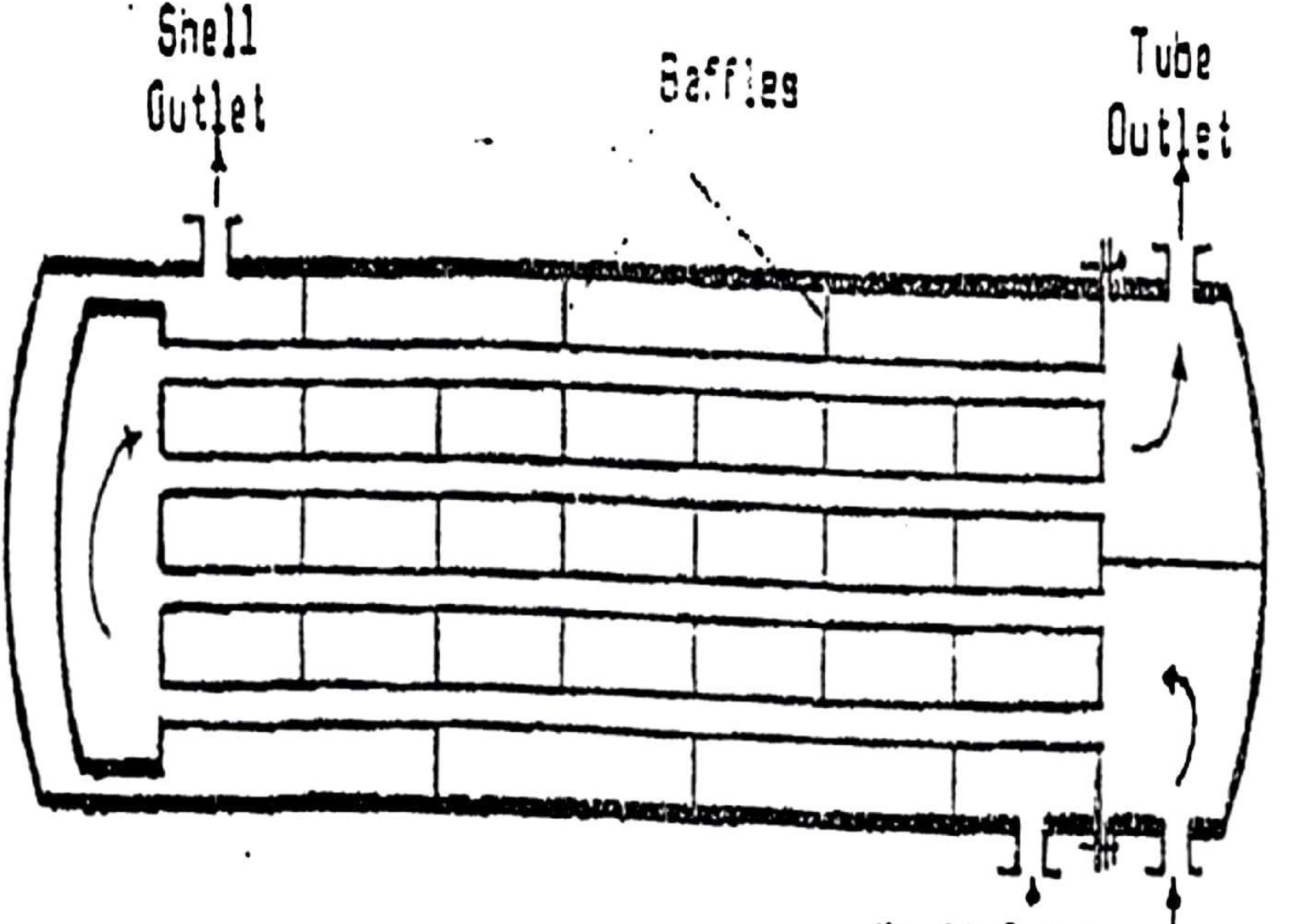
2- heat exchanger

2- Floating-head heat exchanger (1-2) and (2-4) exchanger:

- One tube plate is fixed from one end and
- The second end is bolted to a floating head cover
- So that the tube bundle can move relative to the shell.

Advantages:

1. Tube bundle can be removed for cleaning and
2. Can be expanded

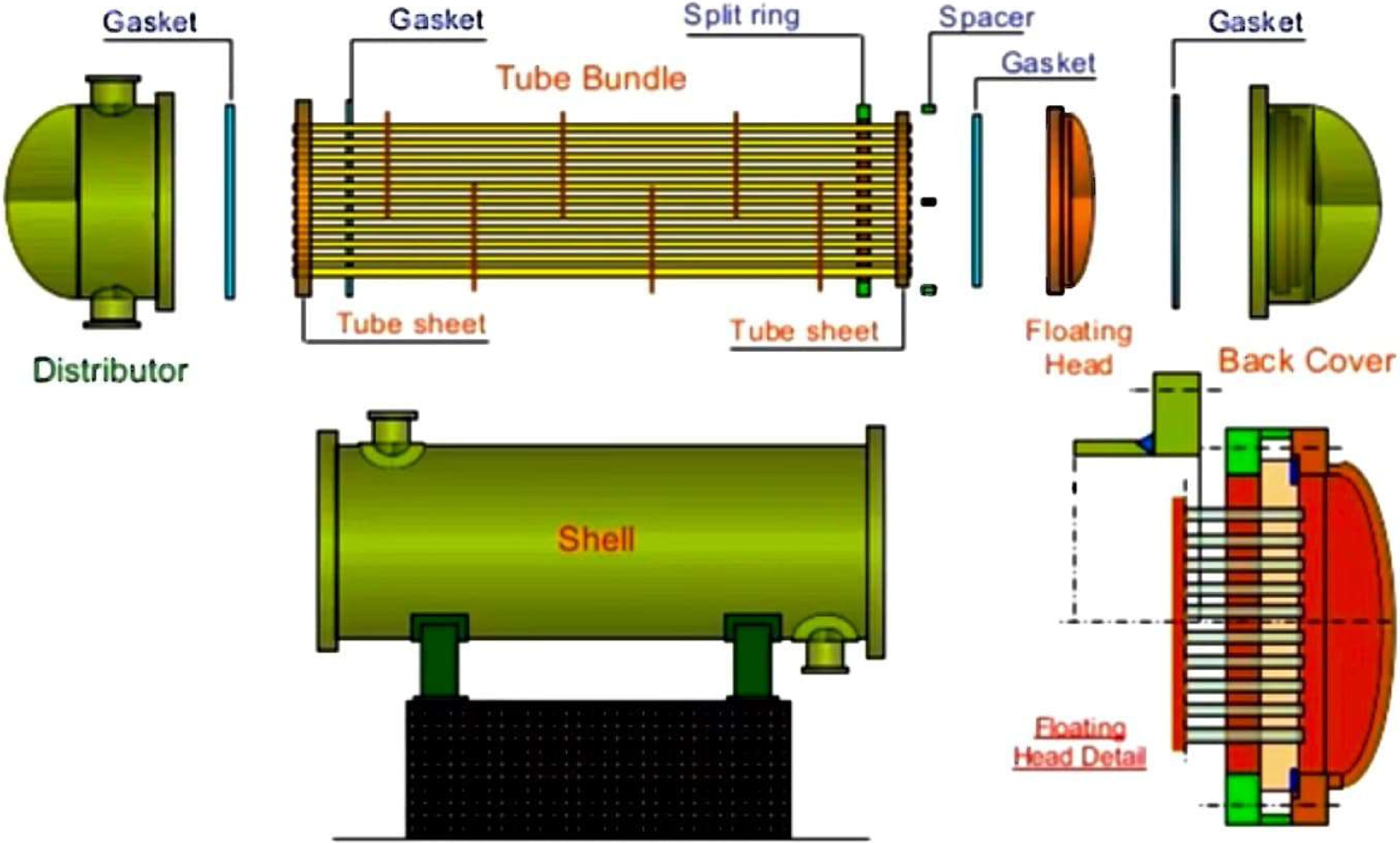


Floating-head heat exchanger (1-2) exchanger

Floating-Head Heat

FLOATING HEAD Heat Exchanger

Split View of Parts



Factors to be considered in the design of heat exchangers:

Any heat exchanger consists of a shell side and tube side.

1-Factors affecting shell side	2-Factors affecting tube side
Heat transfer can be increased fitting alternating baffles: - To multiply the path of heating liquid so it flow first in one direction and then opposite direction. - To increase the velocity of flow of steam so increase heat transfer. - To support the tubes.	When heat flows under steady state condition the amount of heat transfer q is given by Fourier's equation $q = \frac{K A \Delta T}{X}$ Q = rate of heat transfer B.T.U/hr. K = Thermal conductivity coefficient of material. A = area Ft^2 T = Temperature difference ^{o}F X = Thickness Ft - Tubes must be of high thermal conductivity (K) to absorb more heat e.g. copper -Tubes should be long (A) -Tubes should be thin (X) - Tubes should be high in number. - Internal tube composed from cupper and external tube composed from cast iron.

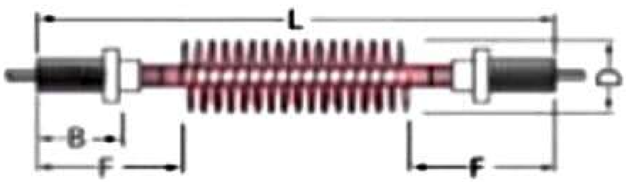
3- Special forms of heat exchangers:
1-Finned Tube Exchangers:

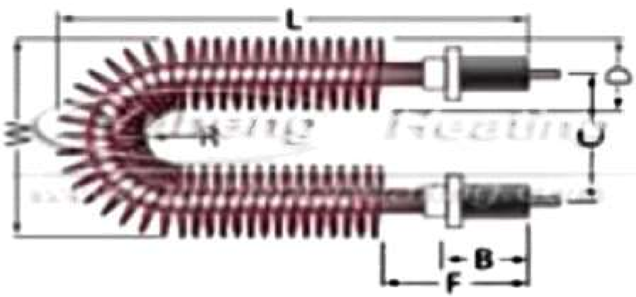
for viscous liquids (large surface area).

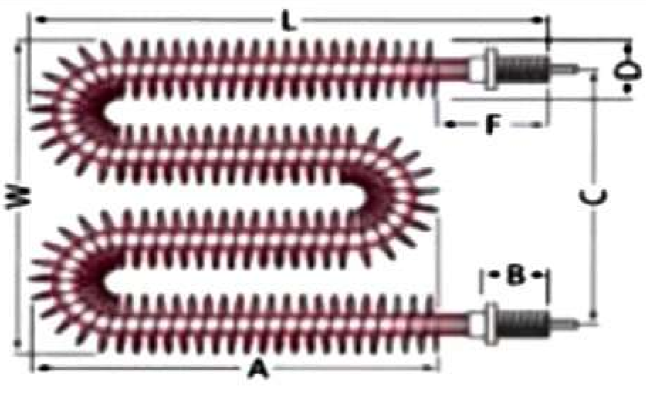
- ❖ Radial fins
- ❖ Longitudinal fins
- ❖ For air/gas heaters where film heat transfer coefficients on gas side will be very low compared with condensing steam on the other side of tube. Rate of heat transfer is increased by increasing surface area on side of tube with the limiting (low) heat transfer coefficient (gas side).

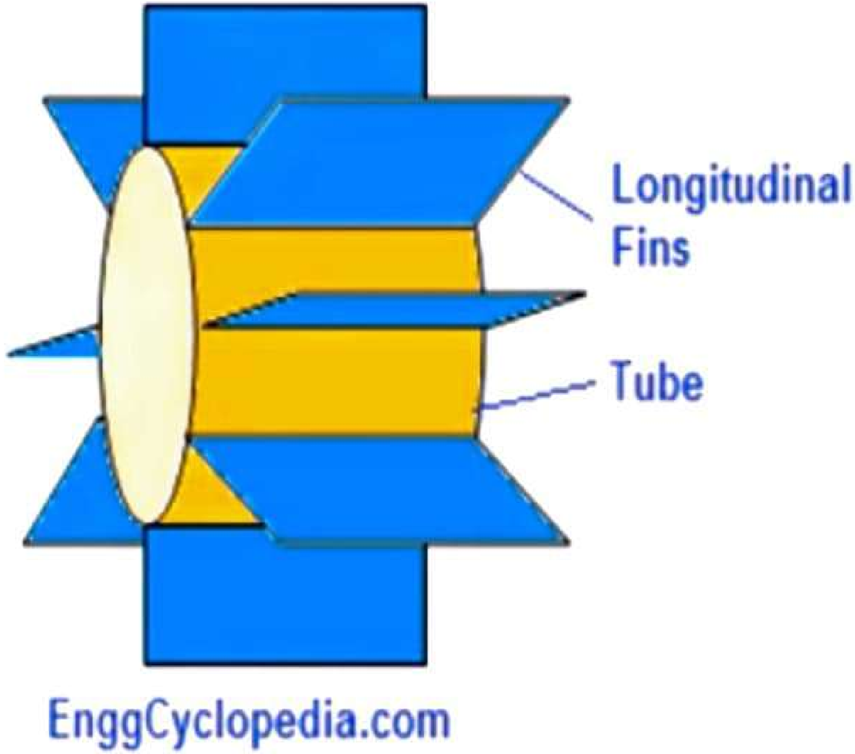
1-Finned Tube Exchangers:

Radial fins









1-Finned Tube Exchangers:

Longitudinal fins

2-Plate Heat exchanger

- ❖ It consists of a series of parallel plates supported on a frame.
- ❖ The plates are spaced about 5 mm apart by rubber gasket cemented into a channel around the edge of each plate.
- ❖ The hot fluid passes between alternating pairs of plates exchanging heat with cold fluid in the adjacent spaces.

Advantages:

- ➢ produces large surface area for viscous liquids easy to clean.

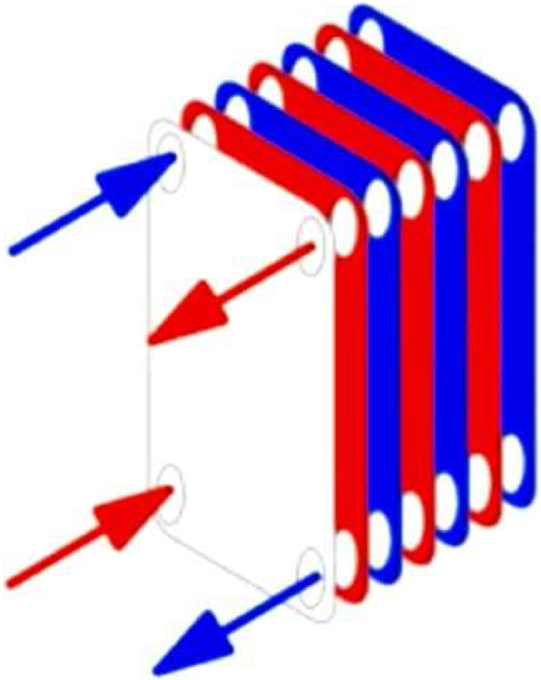
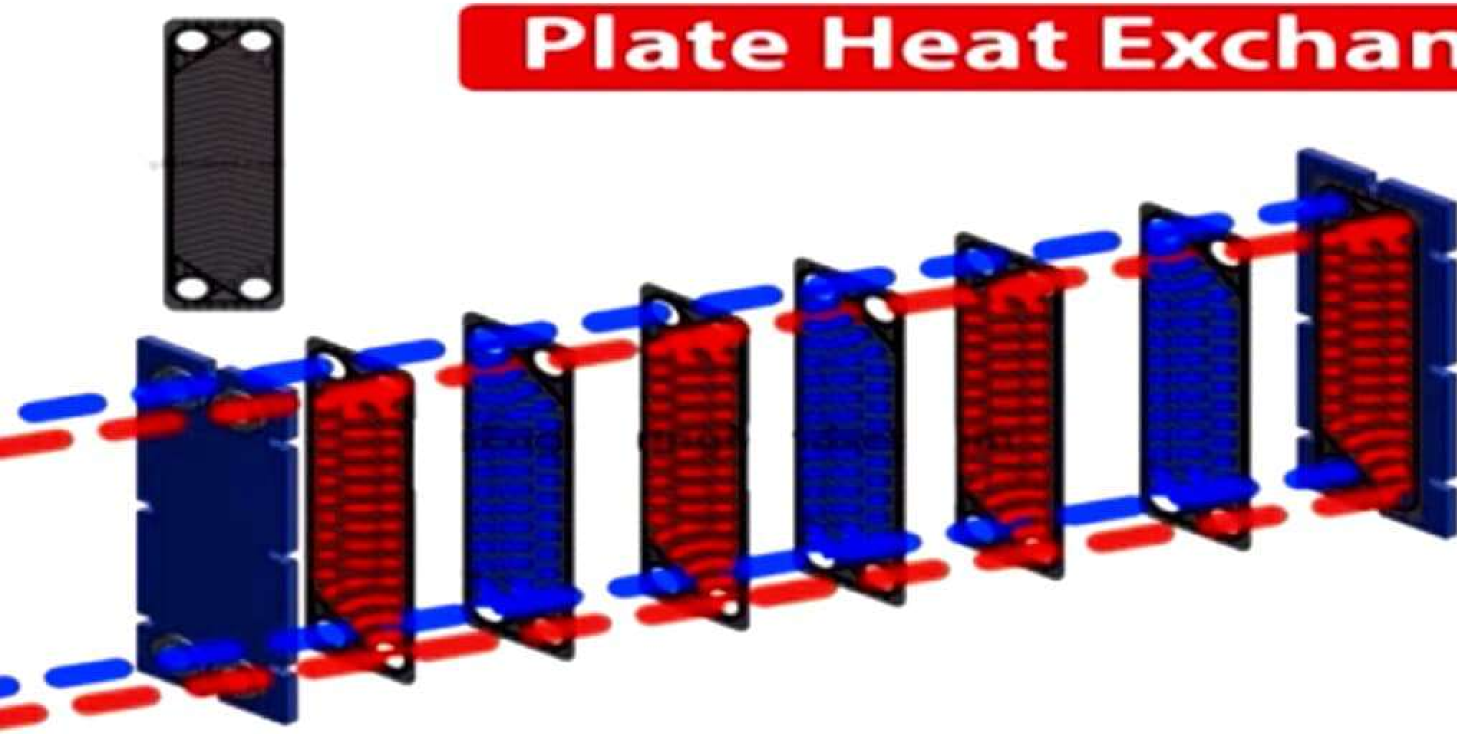
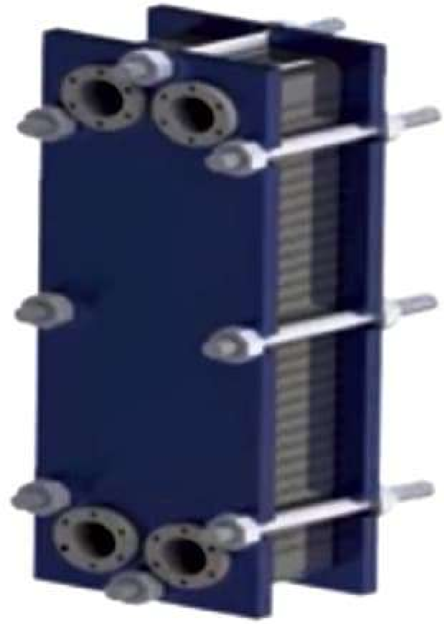


Plate Heat Exchanger



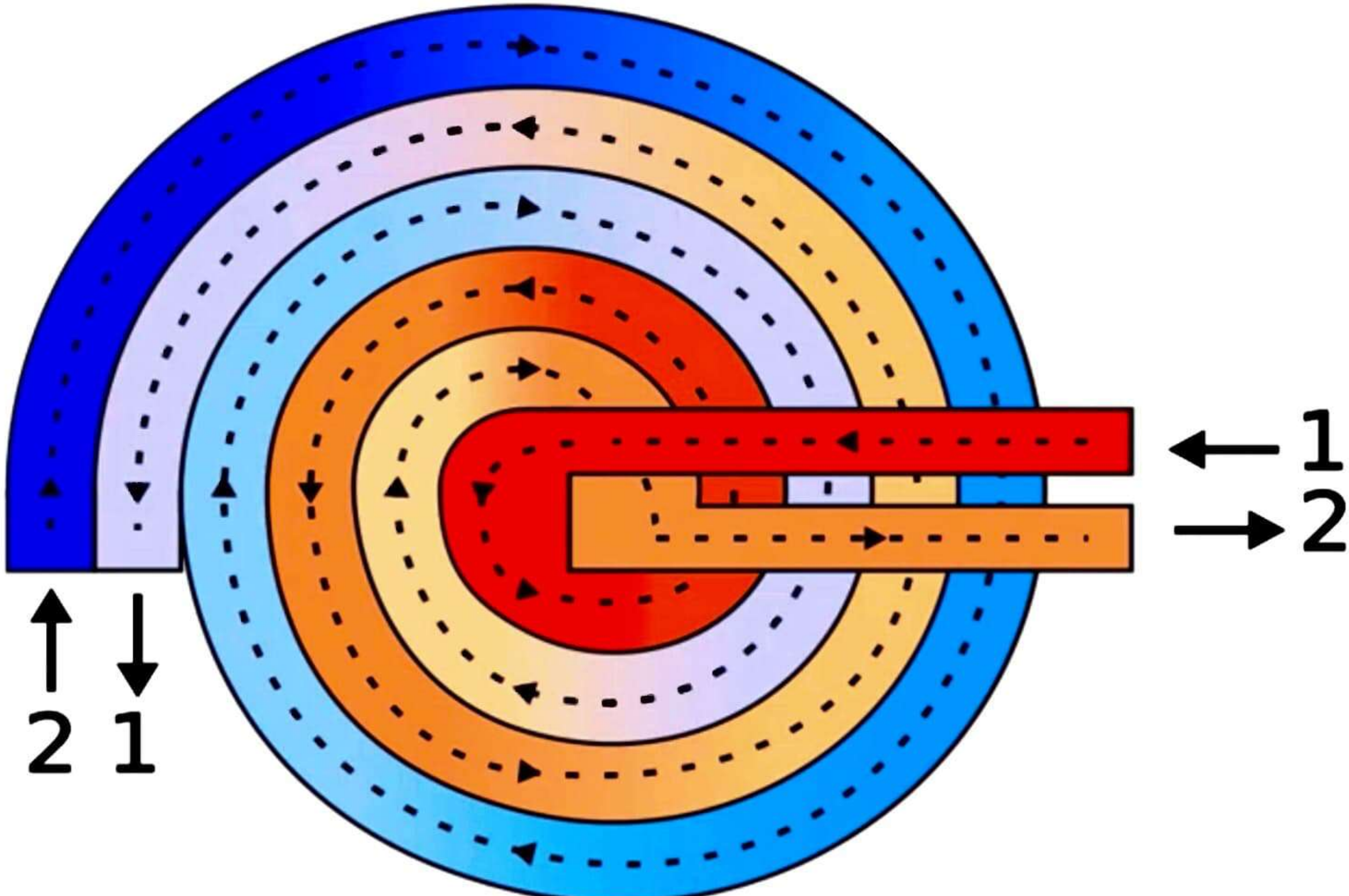


3-spiral heat exchanger (frytherm):

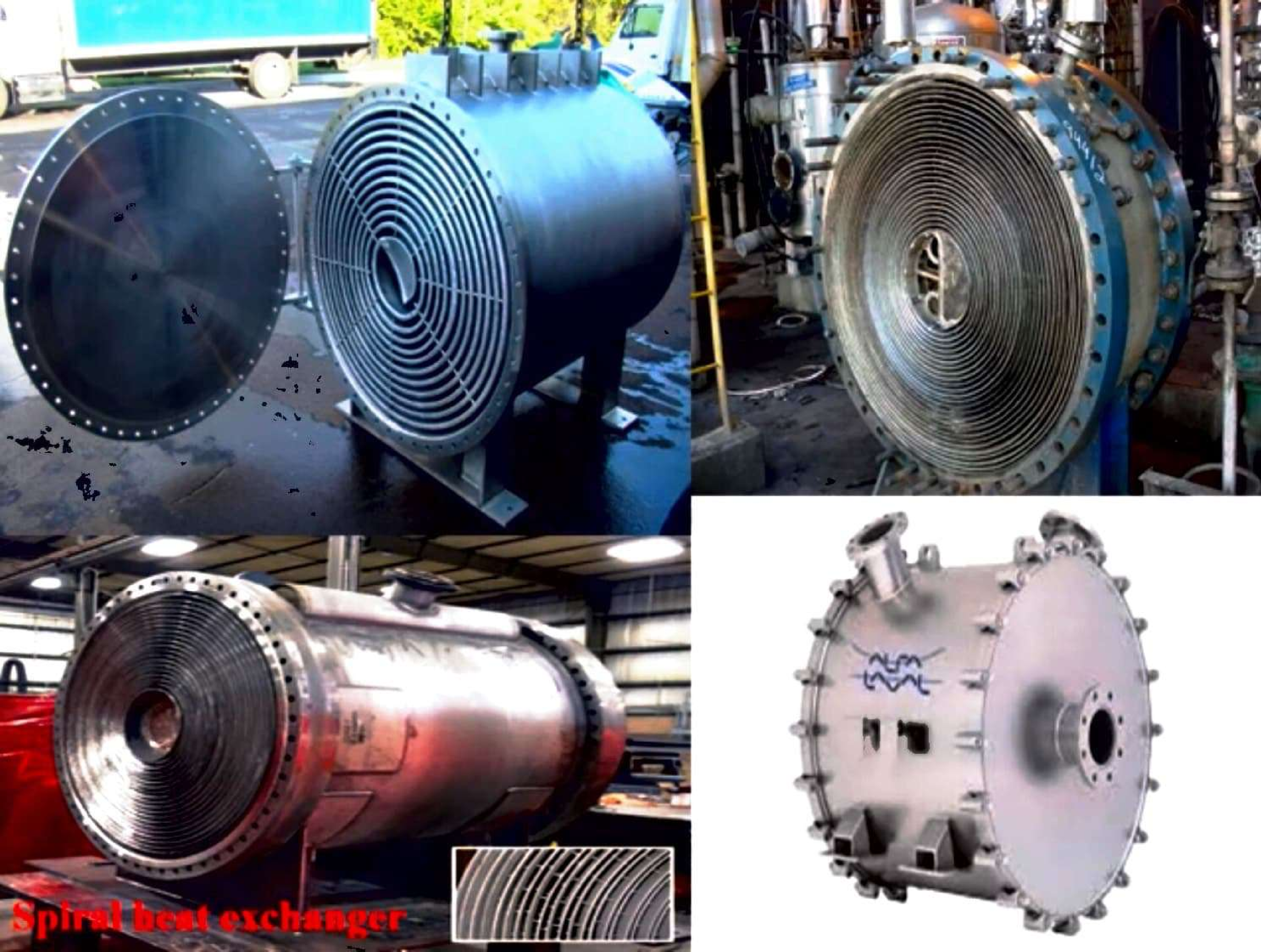
- ❖ Two liquids flow counter currently through the channel formed between the spiral plates.
- ❖ Suitable for heating and cooling products which are:
- ❖ Highly viscous
- ❖ Products containing solid matter.
- ❖ Products whose viscosity changes during heat exchange.
- ❖ Products which have tendency to crystallize (scrapers).

Advantages:

- Large surface area in small place.
- Low cost.
- Reduction in energy consumption.
- Velocity very high, heat transfer coefficient high.



Spiral heat exchanger


Spiral heat exchanger