Lecture no.19

Radiation Heat Transfer and Heat exchanger types

Example Air at 20 °C blows over a hot plate 50 by 75 cm maintained at 250 °C. The convection heat transfer coefficient is 25 W/m².°C. Calculate the heat transfer?

Solution:

From Newton's Law of cooling;

$$q = hA(T_w - T_\infty)$$
$$q = (25) W/m^2.K\ (0.5x0.75)\ m^2 (250\text{-}20) K$$
$$q = 2.156\ kW$$

Example An electric current is passed through a wire 1 mm in diameter and 10 cm long. The wire is submerged in liquid water at atmospheric pressure, and the current is increased until the water boils. For this situation $h = 5000\ W/m^2.°C$, and the water temperature will be 100 °C. How much electric power must be supplied to the wire to maintain the wire surface at 114 °C.

Solution:

Total convection loss is

$$q = hA(T_w - T_\infty)$$

The surface area of the wire

$$A = \pi dL = \pi\ (1x10^{-3})(10x10^{-2})$$
$$= 3.142\ x\ 10^{-4}\ m^2$$

Therefore, the heat transfer is

$$q = (5000 w/m^2.°C)(3.142\ x\ 10^{-4}\ m^2)(114\text{-}100)$$

= 21.99 W and this is equal to the electric power which must be applied.

1. **Radiation Heat Transfer**

- Heat may also transfer through regions where perfect vacuum exist. The mechanism in this case is electromagnetic radiation which is propagated as a result of a temperature difference. This is called *thermal radiation.*
- This is confirmed by our experienced everyday experience of being warmed by the sun, which separated from the earth by approximately 1.5 x 10^{11} m of empty space.
- Thermal radiation can of course transport through any 'transparent' medium such as air. Ideal *thermal radiator, or black body,* will emit energy at a rate

$$q_{emitted} = \sigma A T^4 \qquad [6.3]$$

where;
σ is the proportionality constant and is called the Stefan-Boltzmann constant with value of 5.669 x 10^{-8} W/m^2.K^4.

- This equation is called Stefan-Boltzmann law of thermal radiation and it apply to only blackbodies. This equation is valid only for thermal radiation; other type of electromagnetic radiation may not be treated so simply.

$q_{emitted} = \sigma A T^4$ govern only radiation emitted by a blackbody.

The net radian exchange between two surface will be proportional to the difference in absolute temperature to the fourth power. i.e: q net exchange/ A α ($T_1^4 - T_2^4$)

$$q \text{ net exchange}/ A = \sigma (T_1^4 - T_2^4)$$

2. ***Blackbody***

- It is a perfect emitter of radiation. At a particular temperature the blackbody would emit the maximum amount of energy possible for that temperature. \
- his value is known as the blackbody radiation. It would emit at every wavelength of light as it must be able to absorb every wavelength to be sure of absorbing all incoming radiation.
- The maximum wavelength emitted by a blackbody radiator is infinite. It also emits a definite amount of energy at each wavelength for a particular temperature, so standard black body radiation curves can be drawn for each temperature, showing the energy radiated at each wavelength (Fig. 1).

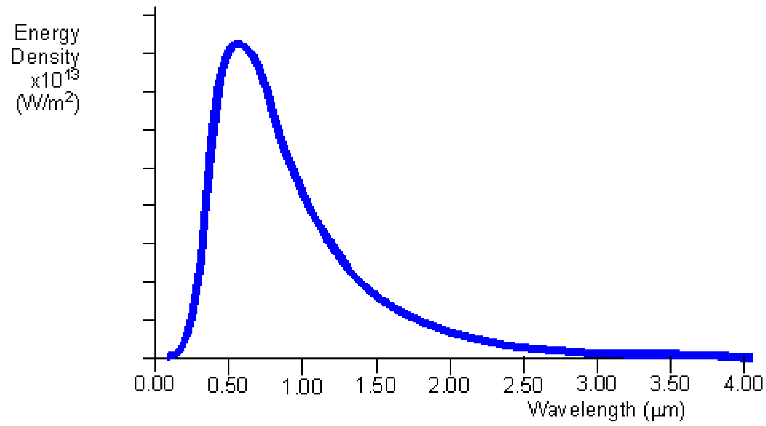


Figure 1: Theoretical black body curve for 5000K

- Again, blackbody is a body which radiates energy according to the T^4 law. Other type of surface, such as glossy painted surface or a polished metal plate, do not radiate as much energy as the blackbody.
- However, the total radiation emitted by this body still generally follows the T_1^4 proportionality. To take account of the "gray" nature of such surfaces we introduce another factor, called the emissivity, ϵ which relates the radiation of the "gray" surface to that of an ideal black surface. In addition, we must take into account the fact that not all the radiation leaving one surface will reach the other surface since electromagnetic radiation travels in straight line and some will lost to the surrounding.
- Therefore two new factors in (Eq 8.2)take into account both situation, so that

$$q = F_\epsilon F_G \sigma A (T_1^4 - T_2^4) \qquad [6.4]$$

F_ϵ = emissivity function

F_G = geometric "view factor" function

A simple radiation problem is encounter when we have a heat-transfer surface at temperature T_1 completely enclosed by much larger surface maintained at T_2. The net radiant exchange in this case can be calculated with,

$$q = \epsilon_1 A \sigma_1 (T_1^4 - T_2^4)$$

where,

ϵ_1 = emissivity of material

Example

Two infinite black plates at 800 ^{0}C and 300 ^{0}C exchange heat by radiation. Calculate the heat transfer per unit area. Given: $\sigma = 5.669 \times 10^{-8}$ $W/m^2.K^4$

Solution:

$$q/A = \sigma (T_1^4 - T_2^4)$$

$$= 5.669 X 10^{-8})W/m^2.K^4 (10734 - 5734)K^4$$

$$= \underline{69.03\ kW/m^2}$$

3. Heat exchanger types

Heat exchangers are classified according to *flow arrangement* and *type of construction*.

Six (6) types of heat exchanger are:

(a) Concentric Tube Heat Exchangers

(b) Cross-Flow Heat Exchangers

(c) Cross-counter Flow (Coil) Heat Exchangers

(d) Shell-and-Tube Heat Exchangers

(e) Compact Heat Exchangers

(f) Plate-Type Heat Exchangers

(a) Concentric Tube Heat Exchanger

It also called double-pipe heat exchangers or co-axial flow heat exchangers [Figure1].

One fluid flows inside the tube and the other fluid flows inside the annulus.

In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to exit at the other side. [Figure 2. a]

In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. Counter current design is more efficient, in that it can transfer more heat [Figure 2. b].

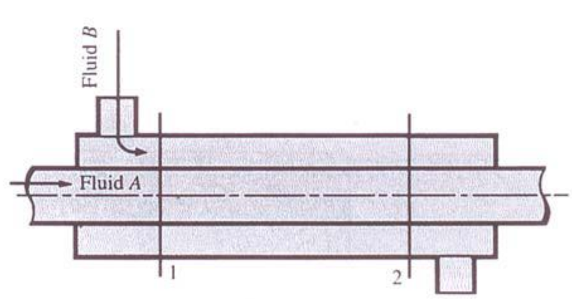
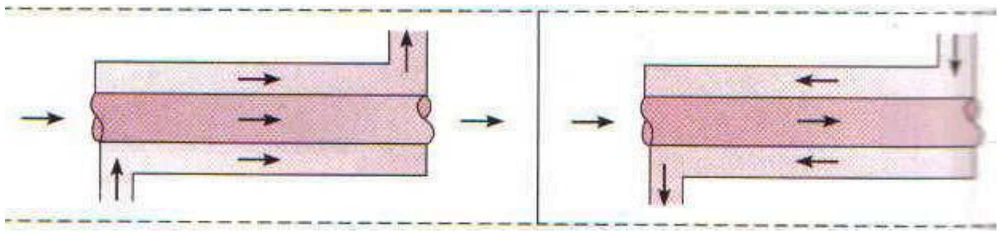


Figure 1: Concentric tube heat exchangers

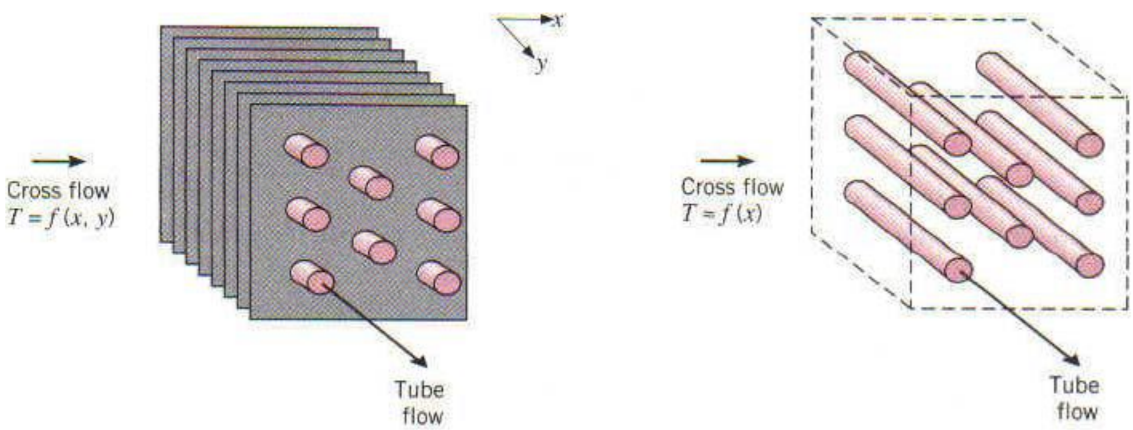


(a) Parallel flow (b) Counterflow

Figure 2: Concentric tube heat exchangers

(b) Cross Flow Heat Exchanger

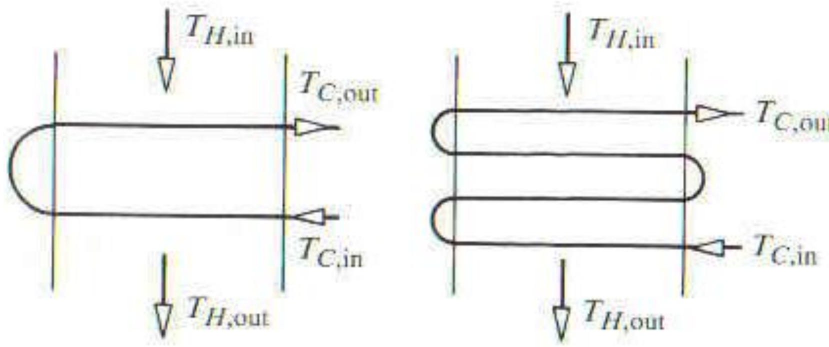
In a cross-flow heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger. In finned tubular heat exchangers, the fin-side fluid is unmixed because the fins confine the flow to one direction. Example: automobile radiator. In unfinned tubular heat exchangers, the fin-side fluid is mixed because the flow in transverse direction is possible. [*Figure 3*]. The use of fins to improve the convection coefficient of fin-side fluid by increasing the outside surface area.



(a) Finned with both fluids unmixed (b) Unfinned with one fluid mixed and the other unmixed

Figure 3: Cross-flow heat exchangers

(c) Cross-counter Flow (Coil) Heat Exchangers



(a) Two-pass **(b) Four-pass**

Figure 4: Cross-counter Flow (Coil) Heat Exchangers

(d) Shell-and-Tube Heat Exchangers

Tubular heat exchangers consist of a tube bank enclosed by a shell. One fluid flows inside the tubes and the other flows inside the shell.

Figure 5, show the simplest form of shell and tube heat exchanger which involves single tube and shell passes.

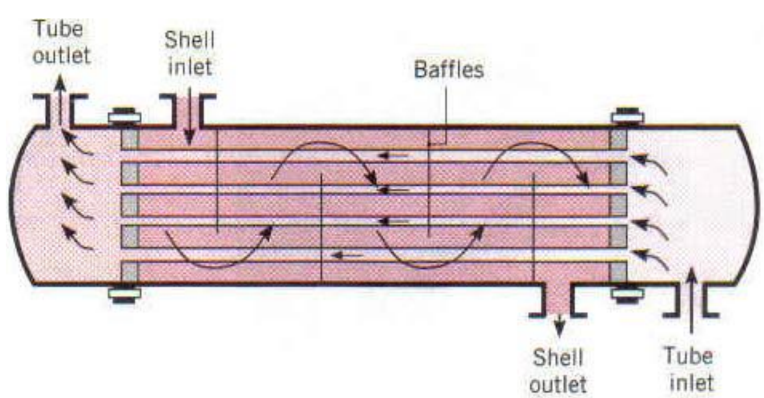


Figure 5: Shell and tube heat exchanger with one-shell pass one-tube pass (1-1) (cross-counterflow mode of operation)

- Baffles are usually installed to increase the convection coefficient of the shell-side fluid by inducing turbulence and a cross-flow velocity component.
- Baffled heat exchanger with one shell pass and two tube passes and with two shell passes and four tube passes are shown in Figures 6a and 6b, respectively.

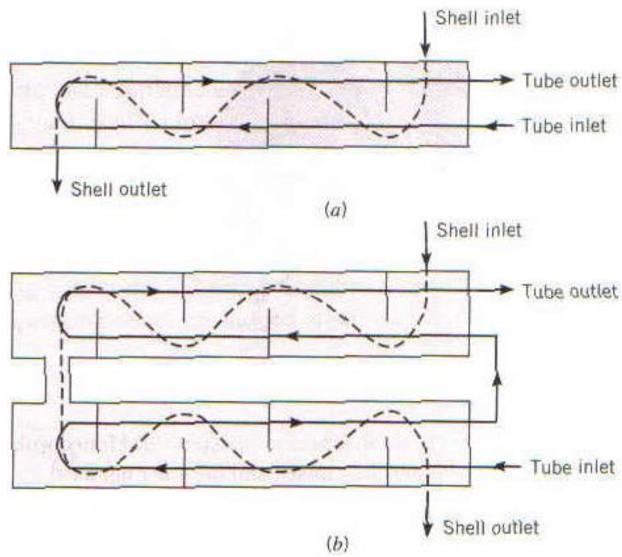
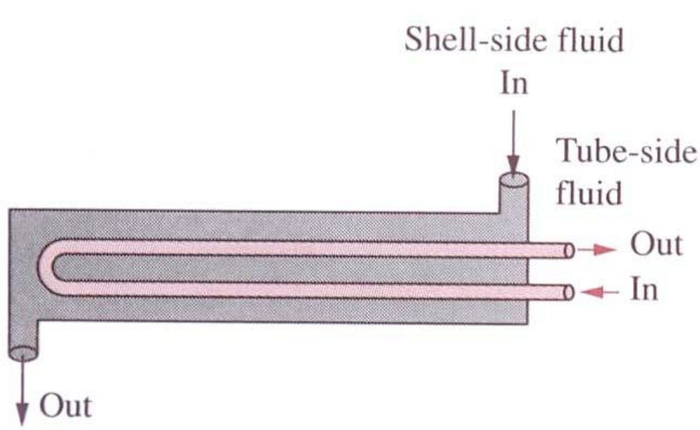


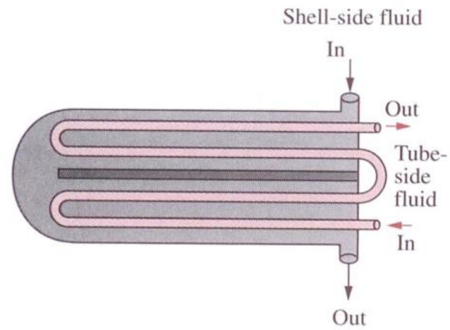
Figure 6: Shell-and-tube heat exchanger. (a) One shell pass and two tube passes. (b) Two shell passes and four tube passes

Shell-and-tube heat exchangers are classified according to the number of shell and tube passes involved.

- Heat exchangers in which all the tubes make one U-turn in the shell, for example, are *called one-shell-pass and two-tube-passes* heat exchangers.
- Heat exchanger that involves two passes in the shell and four passes in the tubes is called a *two-shell-passes and four-tube-passes* heat exchanger [*Figure 7*]



(a) One-shell pass and two-tube passes



(b) Two-shell passes and four-tube passes
Figure 7: Multipass flow arrangement in shell-and-tube heat exchangers

(e) Compact Heat Exchanger

Used to achieve very large heat transfer area per unit volume.

Have dense arrays of finned tubes or plates.

Typically used when at least one of the fluids is a gas, characterized by small convection coefficient.

The tubes may be flat or circular, and the fins may be plate or circular (Figure 8a, 8b and 8c).

Parallel plates may be finned or corrugated and may be used in single-pass or multi-pass mode (Figure 8d and 8e).

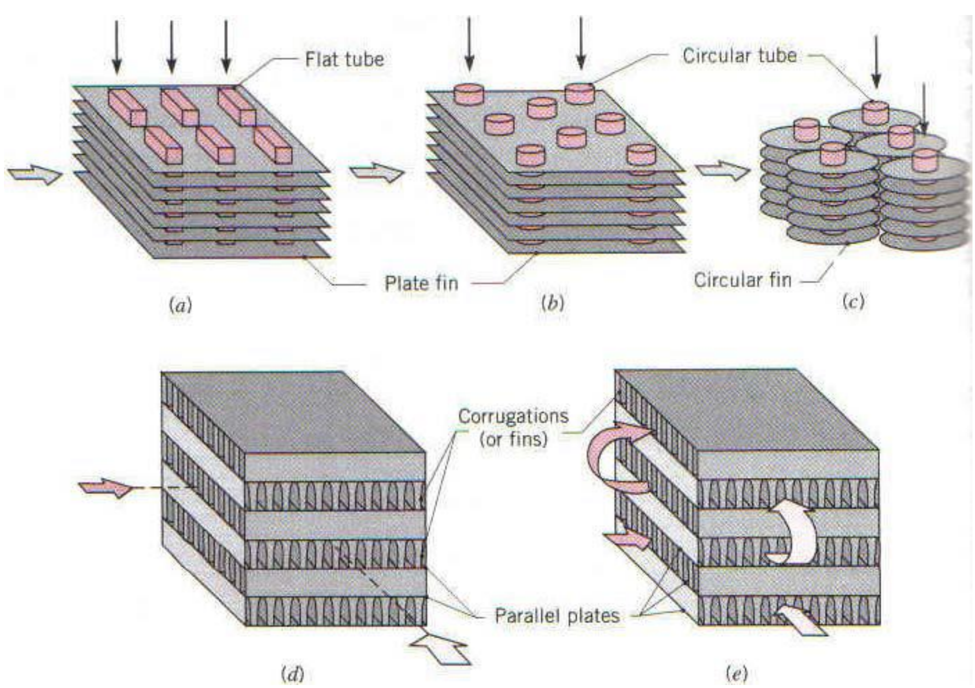
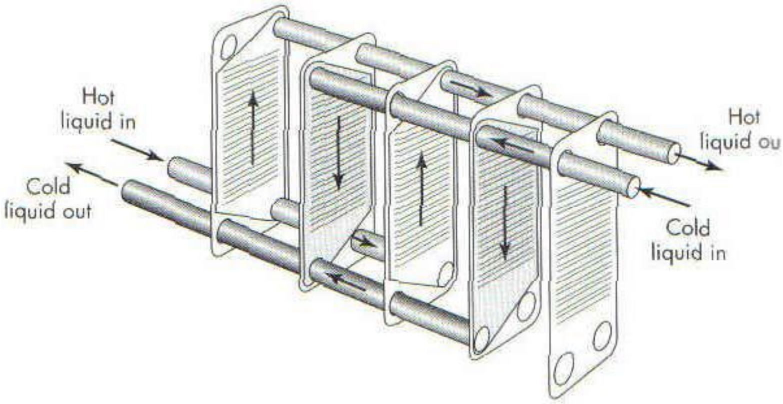


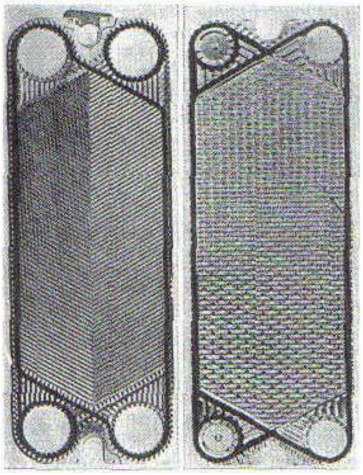
Figure 8: Compact heat exchanger cores. (a) Fin-tube (flat tubes, plate fins; (b) Fin-tube (circular tubes, plate fins); (c) Fin-tube (circular tubes, circular fins); (d) Plate-fin (single pass); (e) Plate-fin (multi-pass)

(f) Plate-Type Heat Exchangers

Gasketed plate exchanger, alternative to shell-and-tube exchangers for applications at moderate temperature and pressure. Consists of many corrugated stainless-steel sheets separated by polymer gaskets and clamped in a steel frame. Inlet portals in the gaskets direct the hot and cold fluid to alternate spaces between plates. Adjoining plates have different pattern or angle of corrugation. Corrugations induce turbulence for improved heat transfer. Widely used in dairy and food processing



(a) General layout



(b) Detail of plate design

Figure 9: Plate-Type Heat Exchangers