Heat transfer

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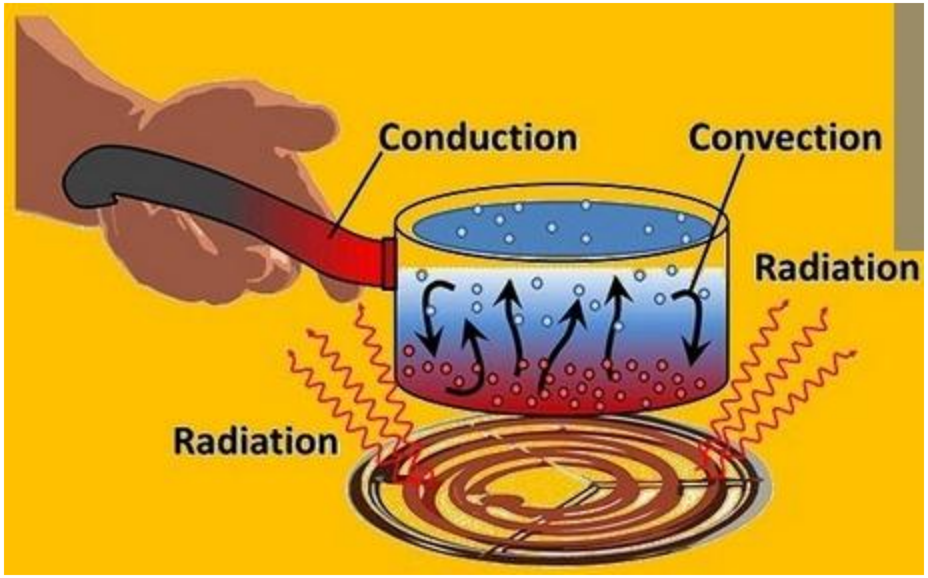
Modes of heat transfer

- When temperature gradient exists in a medium (may be solid, fluid or gas), there is an energy transfer from high temperature region to low temperature region. Doesn't involve any movement of macroscopic portions of matter. This energy transfer is called heat conduction.

- Heat convection refers to heat transfer that will occur between surface and the adjacent moving medium, liquid or gas, when they are at different temperatures. Mixing of fluid medium takes place. It involves the combined effect of conduction and fluid motion.

MODES OF HEAT TRANSFER

- If there is no fluid motion, then the heat is transferred between a solid and its adjacent fluid by pure conduction
- All surfaces at finite temperature emit energy in the form of electromagnetic waves (or photons).This mode of heat transfer is called radiation.
- Radiation does not require the presence of material medium and it is the fastest mode of heat transfer.



Fourier law of heat conduction

- The rate of heat conduction through a medium depends on its geometry, thickness and material of the medium as well as temperature difference.
- The Fourier law states that the time rate of heat transfer through a material
  is proportional to the negative gradient in the temperature and to the area, at right angles to that gradient, through which the heat flows
- The rate of heat conduction per unit area (heat flux) is directly proportional to the negative temperature gradient.

Fourier law of heat conduction

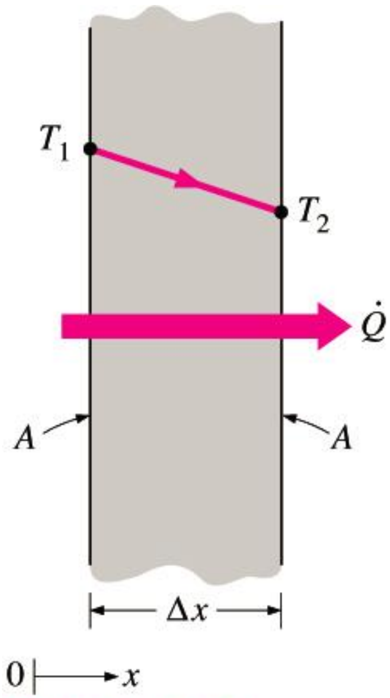


FIGURE 1–22
Heat conduction through a large plane wall of thickness Δx and area A.

$$\frac{Q}{A} \propto \frac{dT}{dx}$$

$$\boxed{q = \frac{Q}{A} = -k\frac{dT}{dx}}$$

$$\boxed{Q = -kA\frac{dT}{dx}}$$

Where q= Heat flux (W/m^2)
Q= Rate of heat transfer W
A= Area normal to direction of heat flow m^2
dT/dx= temperature gradient °C/m
k= Constant of proportionality, called thermal conductivity W/m °C

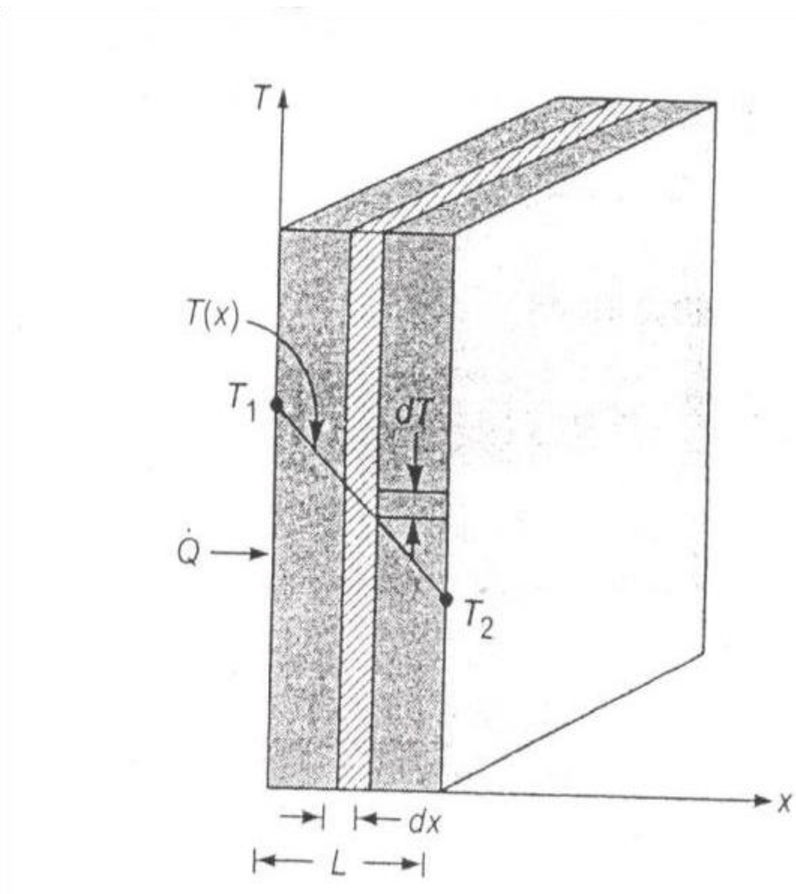
Thermal Conductivity

- a property of the material.
- defined as the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference.
- The unit of thermal conductivity is W/m °C.

Assumptions of Fourier's law

- Heat flow is unidirectional and under steady state.
- Constant temperature gradient
- No internal heat generation
- Homogeneous material

STEADY STATE CONDUCTION IN PLANE WALL



- Consider a plane wall of thickness L as shown in figure. Its left face at x=0 is at temperature is T_1 and at x=L it is T_2.
- The total heat flow rate Q through an area A normal to direction of heat flow.

$$\boxed{Q = kA\left(\frac{T_1 - T_2}{L}\right)}$$

- Temp variation within the slab is linear given by

$$\frac{T_1 - T_x}{T_1 - T_2} = \frac{x}{L}$$

Convection heat transfer-Newton's law of cooling

- **Convection** occurs when a temp diference exists between a surface and its surrounding fluid. It's a combination of conduction, fluid flow and mixing.
- It states that the rate of heat transfer is directly proportional to temperature difference between a surface and fluid .

$$Q \propto A\,(T_s - T_f)$$

$$Q = hA\,(T_s - T_f)$$

Where T_s = Surface temperature °C

T_f = Fluid temperature °C

h= Constant of proportionality called coefficient of convective heat transfer, W/m^2 °C.

$$Q = \frac{T_s - T_f}{\frac{1}{hA}}$$

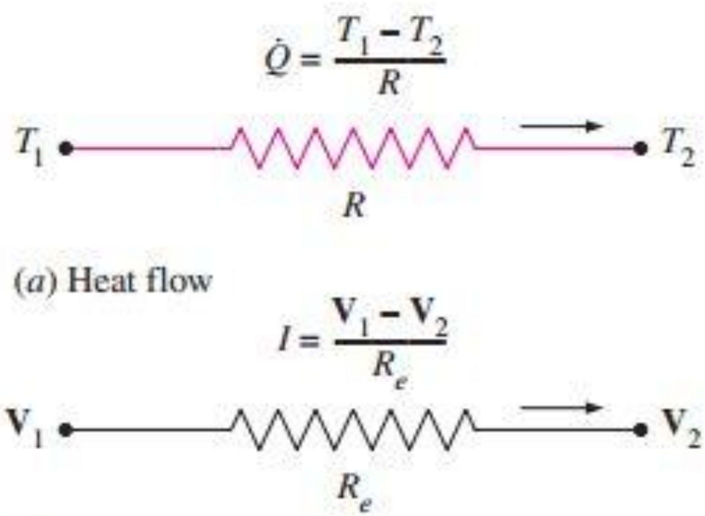
- $\frac{1}{hA}$ is called convective thermal resistance.
- **h** is a function of many variables like shape, dimensions of surface, velocity of flow, density, temperature, viscosity, specific heat, coeff. Of thermal expansion of the fluid and K.

ELECTRICAL AND THERMAL RESISTANCE ANALOGY

Flow of electricity	Heat conduction process
Current (I)	Rate of conduction(q)
Potential difference(ΔE)	Temperature difference(ΔT)
Electrical resitance (R)	Thermal resistance(R_{th})

$$I = \frac{V_1 - V_2}{R_e}$$

$$R_{wall} = \frac{L}{kA}$$



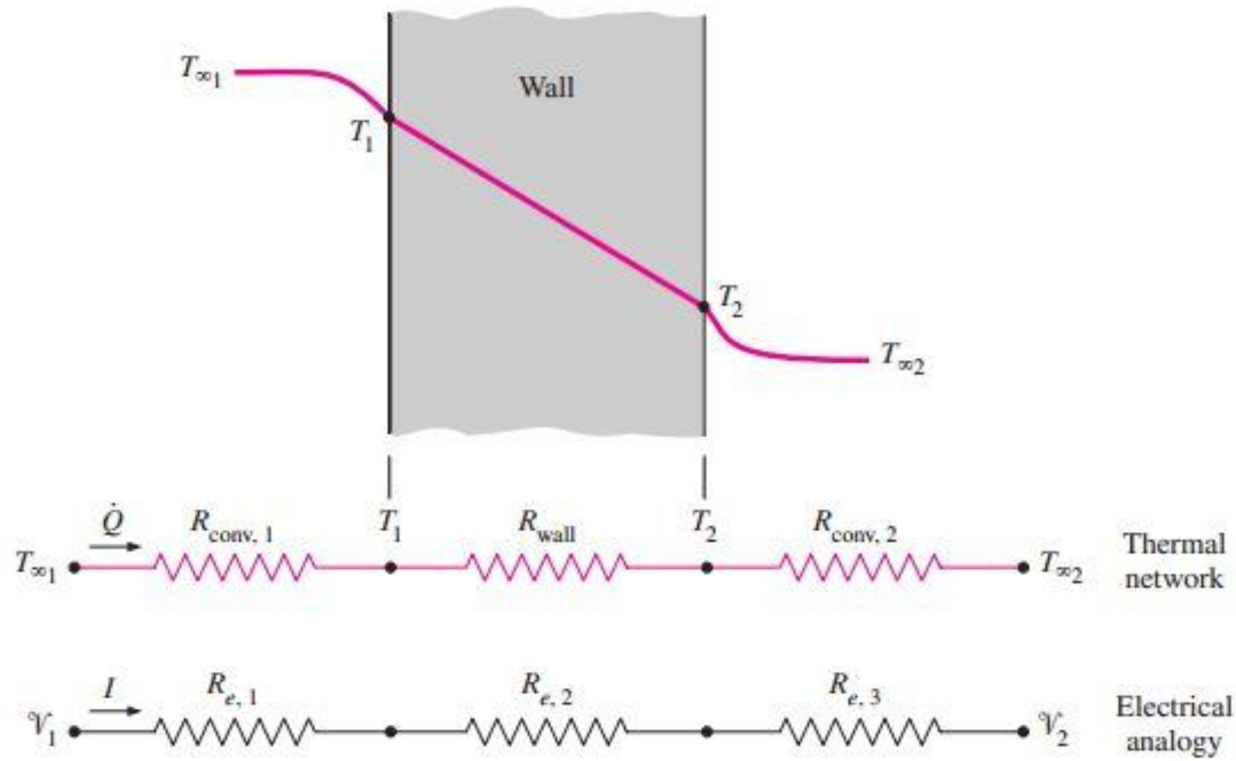
(a) Heat flow

(b) Electric current flow

- Thermal resistance of materials is of great interest to electronic engineers as most electrical components generating heat needed to be cooled.
- Electronic components fail if they overeat.
- Concept of thermal resistance used in composite slab/wall with dissimilar material layers.

Resistance over composite slab

Conductive and convective resistance



$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{conv, 1}} + R_{\text{wall}} + R_{\text{conv, 2}}}$$

$$I = \frac{\mathcal{V}_1 - \mathcal{V}_2}{R_{e,1} + R_{e,2} + R_{e,3}}$$

$$R_{\text{wall}} = \frac{L}{kA}$$

$$R_{\text{conv}} = \frac{1}{hA_s}$$

Overall heat transfer coefficient

- It is sometimes convenient to express heat transfer through a medium in an analogous manner to Newton's law of cooling as

  $$Q = \mathbf{U}A\,\Delta T$$

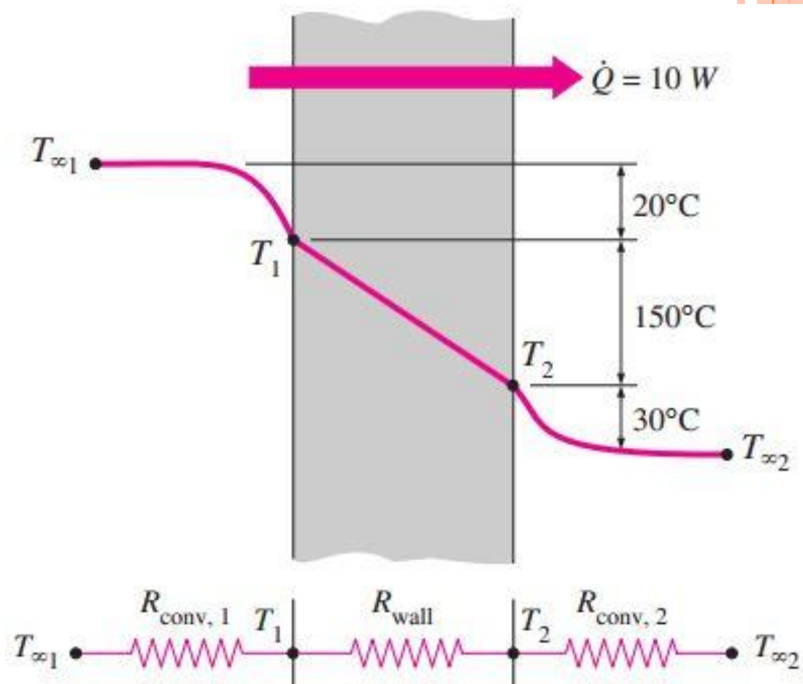
  U is the overall heat transfer coefficient.

- we know, $Q = \Delta T / R_{total}$
  and

$$R_{total} = R_{conv,1} + R_{wall} + R_{conv,2} = \frac{1}{h_1 A} + \frac{L}{kA} + \frac{1}{h_2 A}$$

$$UA = \frac{1}{R_{total}}$$

$$U = \frac{1}{\frac{1}{h1} + \frac{L}{k} + \frac{1}{h2}}$$



U is the ability of composite structure to transfer the heat flux per unit temperature difference through it. Units W/ m^2-deg

U is reciprocal of unit thermal resistance to heat flow.

It represents combined effect of various dimensions, thermal conductivities, heat transfer co efficients, etc. on the heat flow rate.

- The inner surface of a plane brick wall is at 60 deg C and the outer surface is at 35^{0}C. Calculate the rate of heat transfer per m^2 of surface area of the wall, which is 220 mm thick. The thermal conductivity of the brick is 0.51 W/m^{0}C.

Solution. Temperature of the inner surface of the wall $t_1 = 60°C$.

Temperature of the outer surface of the wall,

$$t_2 = 35°C$$

The thickness of the wall, $L = 220$ mm $= 0.22$ m

Thermal conductivity of the brick,

$$k = 0.51 \text{ W/m°C}$$

Rate of heat transfer per m², q :

Rate of heat transfer per unit area,

$$q = \frac{Q}{A} = \frac{k(t_1 - t_2)}{L}$$

or

$$q = \frac{0.51 \times (60 - 35)}{0.22} = \mathbf{57.95\ W/m^2.} \quad \textbf{(Ans.)}$$

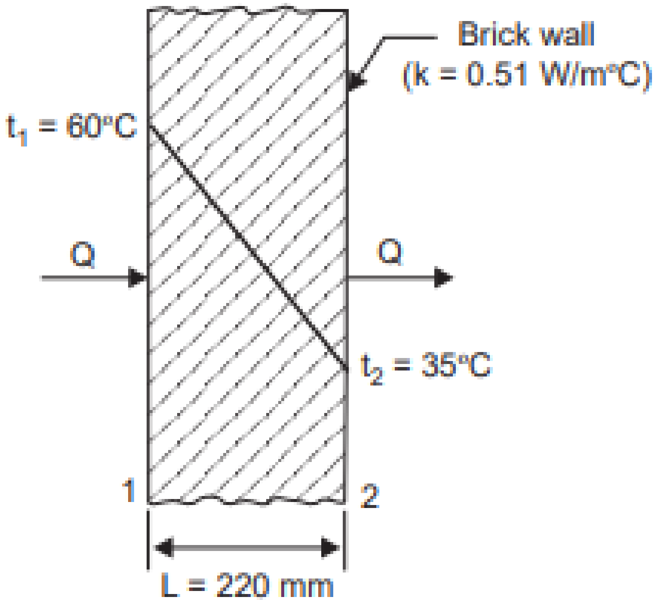


Fig. 15.8

- A mild steel tank of wall thickness 12 mm contains water at 95°C. The thermal conductivity of mild steel is 50 W/m°C, and the heat transfer coefficients for the inside and outside the tank are 2850 and 10 W/m2°C, respectively. If the atmospheric temperature is 15°C, calculate : (i) The rate of heat loss per m2 of the tank surface area ; (ii) The temperature of the outside surface of the tank.

Thickness of mild steel tank wall

$$L = 12 \text{ mm} = 0.012 \text{ m}$$

Temperature of water, $t_{hf} = 95°C$

Temperature of air, $t_{cf} = 15°C$

Thermal conductivity of mild steel,

$$k = 50 \text{ W/m°C}$$

Heat transfer coefficients :

Hot fluid (water), $h_{hf} = 2850 \text{ W/m}^2\text{°C}$

Cold fluid (air), $h_{cf} = 10 \text{ W/m}^2\text{°C}$

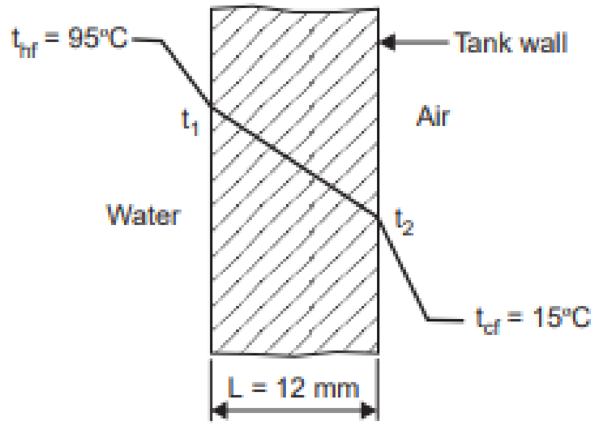


Fig. 15.14

(*i*) **Rate of heat loss per m² of the tank surface area, q :**

Rate of heat loss per m² of tank surface,

$$q = UA(t_{hf} - t_{cf})$$

The overall heat transfer coefficient, U is found from the relation ;

$$\frac{1}{U} = \frac{1}{h_{hf}} + \frac{L}{k} + \frac{1}{h_{cf}} = \frac{1}{2850} + \frac{0.012}{50} + \frac{1}{10}$$

$$= 0.0003508 + 0.00024 + 0.1 = 0.1006$$

$$\therefore \qquad U = \frac{1}{0.1006} = 9.94 \text{ W/m}^2\text{°C}$$

$$\therefore \qquad q = 9.94 \times 1 \times (95 - 15) = \mathbf{795.2 \text{ W/m}^2}. \quad \textbf{(Ans.)}$$

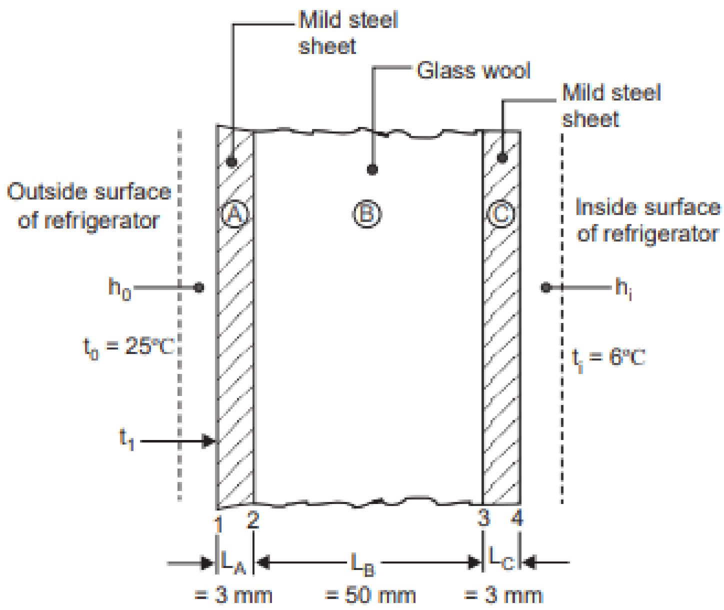
(*ii*) **Temperature of the outside surface of the tank, t_2 :**

We know that, $q = h_{cf} \times 1 \times (t_2 - t_{cf})$

or $$795.2 = 10(t_2 - 15)$$

or $$t_2 = \frac{795.2}{10} + 15 = \mathbf{94.52°C}. \quad \textbf{(Ans.)}$$

- The interior of a refrigerator having wall exposed to heat flow with area 2.5 sq m , is to be maintained at 6°C. The walls of the refrigerator are constructed of two mild steel sheets 3 mm thick (k = 46.5 W/m°C) with 50 mm of glass wool insulation (k = 0.046 W/m°C) between them. If the average heat transfer coefficients at the inner and outer surfaces are 11.6 W/m2°C and 14.5 W/m2°C respectively, calculate : (i) The rate at which heat must be removed from the interior to maintain the specified temperature in the kitchen at 25°C, and (ii) The temperature on the outer surface of the metal sheet.



(*i*) **The rate of removal of heat, Q :**

$$Q = \frac{A(t_0 - t_i)}{\frac{1}{h_o} + \frac{L_A}{k_A} + \frac{L_B}{k_B} + \frac{L_C}{k_C} + \frac{1}{h_i}}$$

$$= \frac{2.5\,(25 - 6)}{\frac{1}{11.6} + \frac{0.003}{46.5} + \frac{0.05}{0.046} + \frac{0.003}{46.5} + \frac{1}{14.5}} = \mathbf{38.2\ W.} \quad \textbf{(Ans.)}$$

(*ii*) **The temperature at the outer surface of the metal sheet, t_1 :**

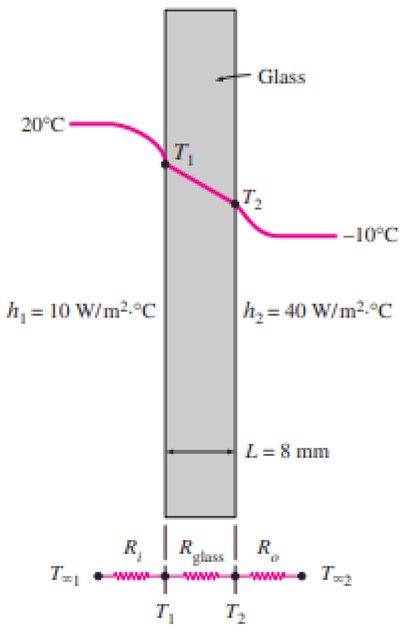
$$Q = h_o\, A(25 - t_1)$$

$$38.2 = 11.6 \times 2.5\,(25 - t_1)$$

$$t_1 = 25 - \frac{38.2}{11.6 \times 2.5} = \mathbf{23.68°C.} \quad \textbf{(Ans.)}$$

Consider a 0.8-m-high and 1.5-m-wide glass window with a thickness of 8 mm and a thermal conductivity of $k = 0.78$ W/m · °C. Determine the steady rate of heat transfer through this glass window and the temperature of its inner surface for a day during which the room is maintained at 20°C while the temperature of the outdoors is -10°C. Take the heat transfer coefficients on the inner and outer surfaces of the window to be $h_1 = 10$ W/m^2 · °C and $h_2 = 40$ W/m^2 · °C, which includes the effects of radiation.

SOLUTION Heat loss through a window glass is considered. The rate of heat transfer through the window and the inner surface temperature are to be determined.



Assumptions 1 Heat transfer through the window is steady since the surface temperatures remain constant at the specified values. **2** Heat transfer through the wall is one-dimensional since any significant temperature gradients will exist in the direction from the indoors to the outdoors. **3** Thermal conductivity is constant.

Properties The thermal conductivity is given to be $k = 0.78$ W/m · °C.

Analysis This problem involves conduction through the glass window and convection at its surfaces, and can best be handled by making use of the thermal resistance concept and drawing the thermal resistance network, as shown in Fig. 3–12. Noting that the area of the window is $A = 0.8 \text{ m} \times 1.5 \text{ m} = 1.2 \text{ m}^2$, the individual resistances are evaluated from their definitions to be

$$R_i = R_{\text{conv, 1}} = \frac{1}{h_1 A} = \frac{1}{(10 \text{ W/m}^2 \cdot {}^\circ\text{C})(1.2 \text{ m}^2)} = 0.08333^\circ\text{C/W}$$

$$R_{\text{glass}} = \frac{L}{kA} = \frac{0.008 \text{ m}}{(0.78 \text{ W/m} \cdot {}^\circ\text{C})(1.2 \text{ m}^2)} = 0.00855^\circ\text{C/W}$$

$$R_o = R_{\text{conv, 2}} = \frac{1}{h_2 A} = \frac{1}{(40 \text{ W/m}^2 \cdot {}^\circ\text{C})(1.2 \text{ m}^2)} = 0.02083^\circ\text{C/W}$$

Noting that all three resistances are in series, the total resistance is

$$\begin{aligned} R_{\text{total}} &= R_{\text{conv, 1}} + R_{\text{glass}} + R_{\text{conv, 2}} = 0.08333 + 0.00855 + 0.02083 \\ &= 0.1127^\circ\text{C/W} \end{aligned}$$

Then the steady rate of heat transfer through the window becomes

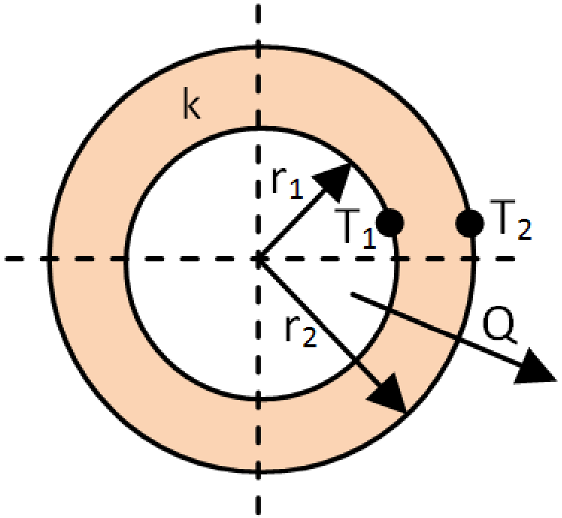
$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}} = \frac{[20 - (-10)]^\circ\text{C}}{0.1127^\circ\text{C/W}} = \mathbf{266\ W}$$

Knowing the rate of heat transfer, the inner surface temperature of the window glass can be determined from

$$\dot{Q} = \frac{T_{\infty 1} - T_1}{R_{\text{conv, 1}}} \longrightarrow \begin{aligned} T_1 &= T_{\infty 1} - \dot{Q} R_{\text{conv, 1}} \\ &= 20^\circ\text{C} - (266 \text{ W})(0.08333^\circ\text{C/W}) \\ &= \mathbf{-2.2^\circ C} \end{aligned}$$

STEADY STATE CONDUCTION IN HOLLOW CYLINDER

- Consider an infinitely long hollow cylinder with inner and outer radii r_1 and r_2 and length L. The temperatures at inner and outer surfaces are T_1 and T_2 respectively.



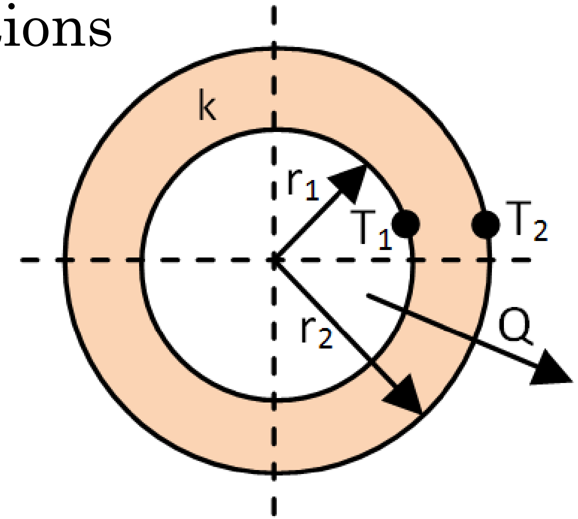
- The Fourier's equation for radial heat flow is:

$$\frac{Q}{A} = -k\frac{dT}{dr}$$

Separating the variables

$$\frac{Q}{A} dr = -k.dT$$

Integrating between the boundary conditions



(i) at $r = r_1$; $T = T_1$

(ii) at $r = r_2$; $T = T_2$

$$\int_{r_1}^{r_2} \frac{Q}{A} \, dr = -\int_{T_1}^{T_2} k \, dT$$

We have,

$Q \neq f(r,t)$ (Steady state and no internal heat generation)

$A \neq f(r)$ (At radius 'r' , $A = 2\pi rL$)

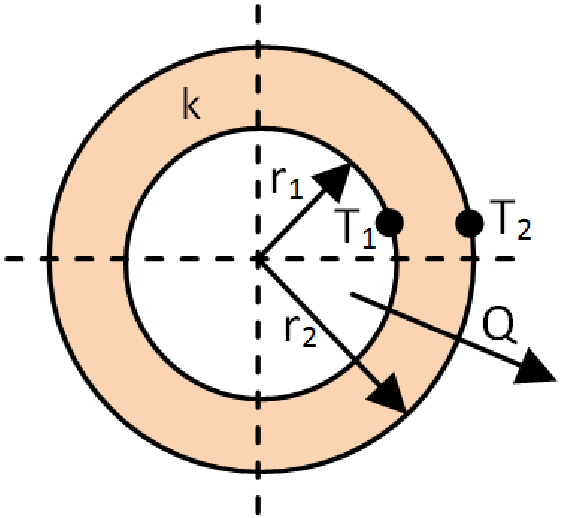
$k \neq f(T)$ (Assumed)

$$\therefore \frac{Q}{2\Pi L} \int_{r_1}^{r_2} \frac{dr}{r} = -k \int_{T_1}^{T_2} dT$$

$$\frac{Q}{2\Pi L}[\ln(r)]_{r_1}^{r_2} = -k[T]_{T_1}^{T_2}$$

$$\frac{Q}{2\Pi L}[\ln(r_2) - \ln(r_1)] = -k[T_2 - T_1]$$

$$\frac{Q}{2\Pi L}[\ln\left(\frac{r_2}{r_1}\right)] = -k[T_2 - T_1]$$



Thus, heat flow rate will be

$$\therefore \quad \boxed{Q = \frac{2\pi Lk(T_1 - T_2)}{\ln\left(\frac{r_2}{r_1}\right)}} \qquad \ldots \text{(iii)}$$

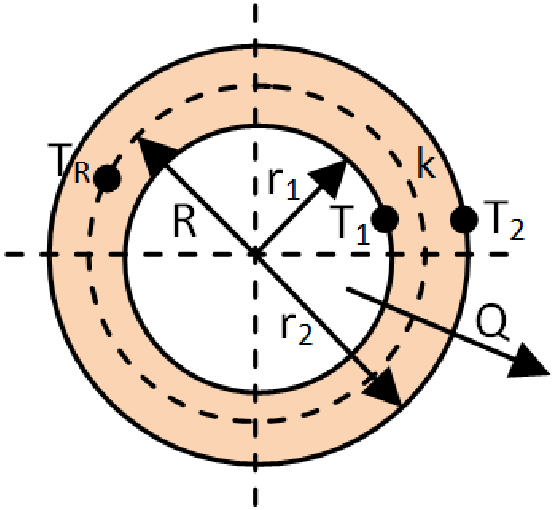
(ii) Temperature Variation inside the cylinder:

If the boundary condition in (ii) is generalized as,

at r = R, T = T_R

Then, the previous equation will result in

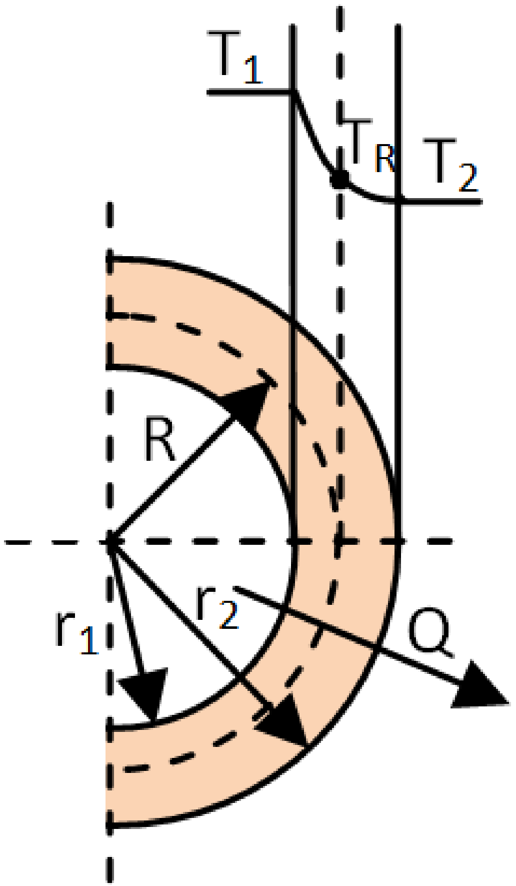
$$\boxed{Q = \frac{2\pi Lk(T_1 - T_R)}{\ln\left(\dfrac{R}{r_1}\right)}} \qquad \text{... (iv)}$$



As Q is the rate of heat transfer through same cylinder, equating equations (iii) and (iv) we get

$$\frac{2\pi Lk(T_1 - T_R)}{\ln\left(\dfrac{R}{r_1}\right)} = \frac{2\pi Lk(T_1 - T_2)}{\ln\left(\dfrac{r_2}{r_1}\right)}$$

$$\frac{(T_1 - T_R)}{(T_1 - T_2)} = \frac{\ln\left(\frac{R}{r_1}\right)}{\ln\left(\frac{r_2}{r_1}\right)}$$

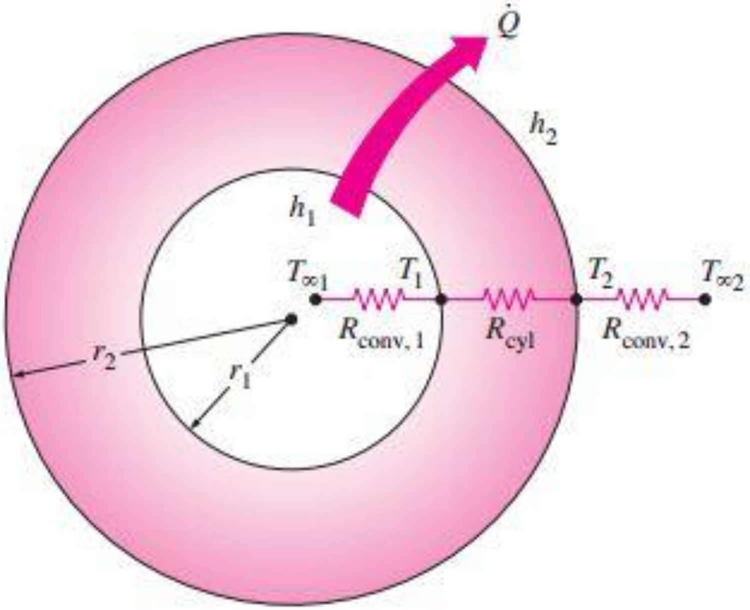


Thus the above equation shows that the temperature variation in cylinder is logarithmic.

Resistance over composite cylinder

- Conductive and convective resistance

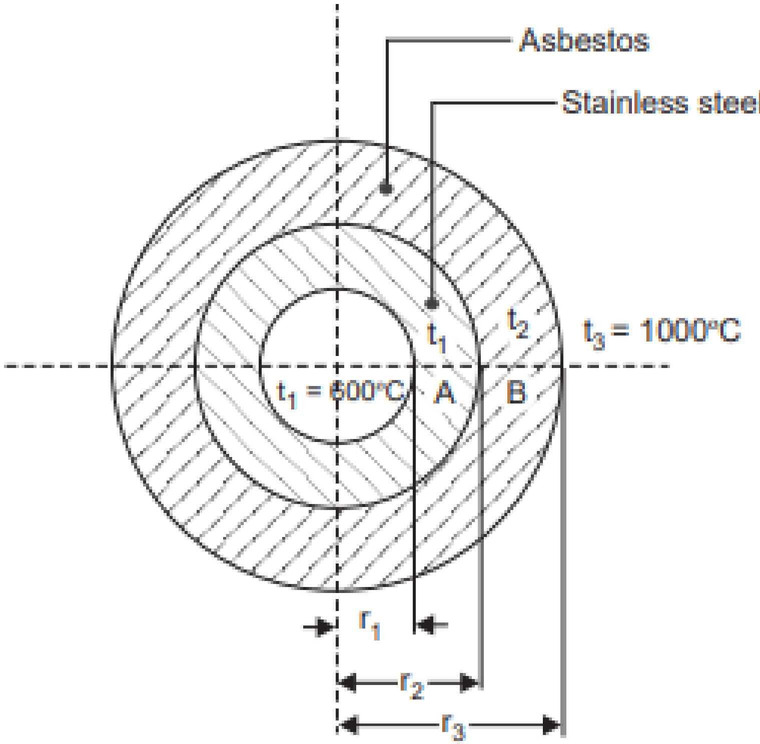
$$R_{cyl} = \frac{\ln(r_2/r_1)}{2\pi Lk} = \frac{\ln(\text{Outer radius/Inner radius})}{2\pi \times (\text{Length}) \times (\text{Thermal conductivity})}$$



$R_{total} = R_{conv,1} + R_{cyl} + R_{conv,2}$

$$R_{total} = R_{conv,1} + R_{cyl} + R_{conv,2}$$
$$= \frac{1}{(2\pi r_1 L)h_1} + \frac{\ln(r_2/r_1)}{2\pi Lk} + \frac{1}{(2\pi r_2 L)h_2}$$

- A thick walled tube of stainless steel with 20 mm inner diameter and 40 mm outer diameter is covered with a 30 mm layer of asbestos insulation (k = 0.2 W/ m°C). If the inside wall temperature of the pipe is maintained at 600°C and the outside insulation at 1000°C, calculate the heat loss per metre of length.



Given, $r_1 = \frac{20}{2} = 10 \text{ mm} = 0.01 \text{ m}$

$r_2 = \frac{40}{2} = 20 \text{ mm} = 0.02 \text{ m}$

$r_3 = 20 + 30 = 50 \text{ mm} = 0.05 \text{ m}$

$t_1 = 600°C,\ t_3 = 1000°C,\ k_B = 0.2 \text{ W/m°C}$

Heat transfer per metre of length, Q/L :

$$Q = \frac{2\pi L\,(t_1 - t_3)}{\dfrac{\ln(r_2/r_1)}{k_A} + \dfrac{\ln(r_3/r_2)}{k_B}}$$

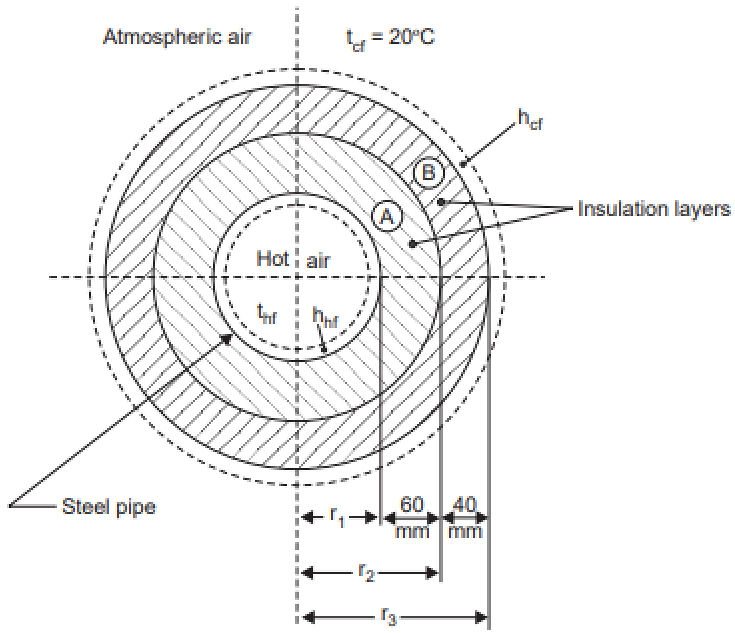
$$Q = \frac{2\pi L\,(t_1 - t_3)}{\dfrac{\ln(r_2/r_1)}{k_A} + \dfrac{\ln(r_3/r_2)}{k_B}}$$

Since the thermal conductivity of satinless steel is not given therefore, neglecting the resistance offered by stainless steel to heat transfer across the tube, we have

$$\frac{Q}{L} = \frac{2\pi(t_1 - t_3)}{\dfrac{\ln(r_3/r_2)}{k_B}} = \frac{2\pi(600 - 1000)}{\dfrac{\ln(0.05/0.02)}{0.2}} = -\ \mathbf{548.57\ W/m.}\quad \textbf{(Ans.)}$$

Negative sign indicates that the heat transfer takes place *radially inward.*

- Hot air at a temperature of 65°C is flowing through a steel pipe of 120 mm diameter. The pipe is covered with two layers of different insulating materials of thickness 60 mm and 40 mm, and their corresponding thermal conductivities are 0.24 and 0.4 W/m°C. The inside and outside heat transfer coefficients are 60 and 12 W/m°C. The atmosphere is at 20°C. Find the rate of heat loss from 60 m length of pipe.



Given : $r_1 = \frac{120}{2} = 60 \text{ mm} = 0.06 \text{ m}$

$r_2 = 60 + 60 = 120 \text{ mm} = 0.12 \text{ m}$

$r_3 = 60 + 60 + 40 = 160 \text{ mm} = 0.16 \text{ m}$

$k_A = 0.24 \text{ W/m°C}$; $k_B = 0.4 \text{ W/m°C}$

$h_{hf} = 60 \text{ W/m}^2\text{°C}$; $h_{cf} = 12 \text{ W/m}^2\text{°C}$

$t_{hf} = 65\text{°C}$; $t_{cf} = 20\text{°C}$

Length of pipe, $L = 60$ m

Rate of heat loss, Q :

Rate of heat loss is given by

$$Q = \frac{2\pi L(t_{hf} - t_{cf})}{\left[\frac{1}{h_{hf} \cdot r_1} + \frac{\ln(r_2/r_1)}{k_A} + \frac{\ln(r_3/r_2)}{k_B} + \frac{1}{h_{cf} \cdot r_3}\right]}$$

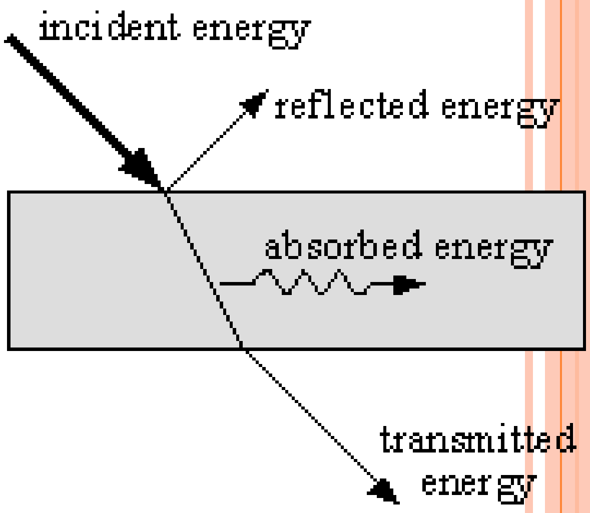
$$= \frac{2\pi \times 60(65 - 20)}{\left[\frac{1}{60 \times 0.06} + \frac{\ln(0.12/0.06)}{0.24} + \frac{\ln(0.16/0.12)}{0.4} + \frac{1}{12 \times 0.16}\right]}$$

$$= \frac{16964.6}{0.2777 + 2.8881 + 0.7192 + 0.5208} = 3850.5 \text{ W}$$

i.e., Rate of heat loss = **3850.5 W (Ans.)**

RADIATIVE PROPERTIES

- When radiation strikes a surface, a portion of it is reflected, and the rest enters the surface.
- Of the portion that enters the surface, some are absorbed by the material, and the remaining radiation is transmitted through.
- The ratio of reflected energy to the incident energy is called *reflectivity*, ρ.
- *Transmissivity* (τ) is defined as the fraction of the incident energy that is transmitted through the object.
- *Absorptivity* (α) is defined as the fraction of the incident energy that is absorbed by the object.



- The three radiative properties all have values between zero and 1.
- Furthermore, since the reflected, transmitted, and absorbed radiation must add up to equal the incident energy, the following can be said about the three properties:

$$\alpha + \tau + \rho = 1$$

Radiation heat transfer- Stefan Boltzmann law

- It states that the rate of radiation heat transfer per unit area from a black surface is directly proportional to fourth power of the absolute temperature of the surface.

$$\frac{Q}{A} \propto \left(T^4\right)$$

$$\frac{Q}{A} = \sigma T_s^4$$

Where

T_s = Absolute temperature of surface K

σ = Constant of proportionality called Stefan Boltzmann constant and has value of 5.67×10^{-8} $W/m^2 K^4$

Radiation heat transfer- Stefan Boltzmann law

- The heat flux emitted by a real surface is less than that of black surface and is given by

$$\frac{Q}{A} = \sigma\, \varepsilon T_s^4$$

Where

ε = a radiative property of the surface is called the emissivity

- The net rate of radiation heat exchange between a real surface and its surroundings is

$$\boxed{\frac{Q}{A} = \sigma\varepsilon\left(T_s^4 - T_\infty^4\right)}$$

Where T∞ = Surrounding temperature K

Ts = Surface temperature K

HEAT EXCHANGER

It is the device used for the heat exchange between the two fluids that are at different temperatures is called heat exchanger,

Notable examples are:

a)Boilers, super heater and reheaters,

b)Radiators of automobiles,

c)Oil coolers of heat engine,

d)Evaporator and condensor of refrigeration system ,

e)Regenerator of gas turbine power plants,

f)Water and air coolers or heaters.

CLASSIFICATION OF HEAT EXCHANGERS

Heat exchangers can be classified

- According to heat transfer process
- According to the constructional features and
- According to flow arrangement

According to heat transfer process

- According to heat transfer process heat exchangers are classified as

1. Direct-contact type heat exchanger

2. Direct transfer-type heat exchanger

I. Recuperators

II. Regenerators

Direct –contact type heat exchanger

In this type of heat exchanger the two immiscible fluids at different temperatures come in direct contact.

For the heat exchange between the two fluids , one fluid is sprayed through the other

Ex. – cooling towers, jet condensers

Direct transfer-type heat exchanger

- In this type of heat exchanger, the cold and hot fluids flow simultaneously through the device and the heat is transferred through the wall separating them.

- These types of heat exchangers are further classified as

  I. Regenerators

  II. Recuperator

RECUPERATORS

- These are also called as transfer type heat exchangers.

- In this heat exchangers, the hot and cold fluids are separated by a plane wall or tube surface, hence heat is indirectly transferred from hot fluid to cold fluid by convection and conduction.

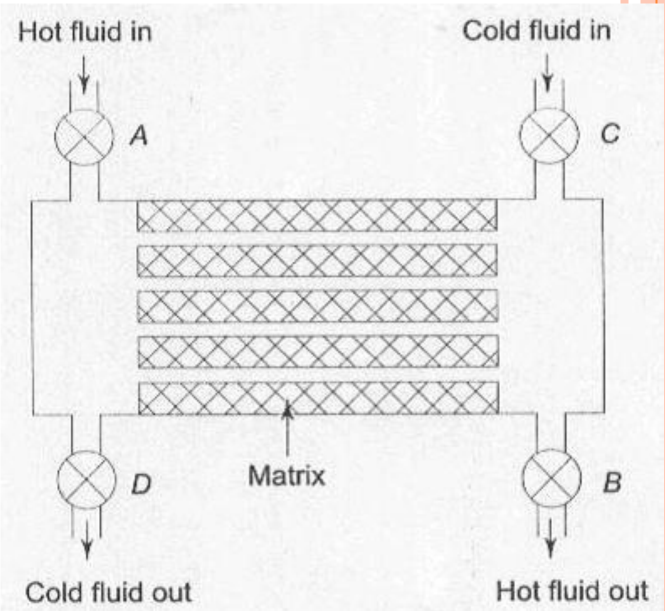
Regenerators

- These are also called as storage type heat exchangers.

- In this type of heat exchanger, hot and cold fluid flow alternatively on the same surface. The hot surface gives heat to the surface and cold fluid extracts heat from it.

- These are preheaters for steam power plant, blast furnaces, oxygen producers

- **Stationery matrix type:**
- Heat storing matrix is stationery
- Two fluids flow over the matrix intermittently, no mixing of fluid.
- **Rotating matrix type:**
- Heat storing matrix continuously rotates about its axis, while its portion passes from hot fluid zone to cold fluid zone alternatively.
- Some fluid mixing may take place.



ACCORDING TO THE CONSTRUCTIONAL FEATURES

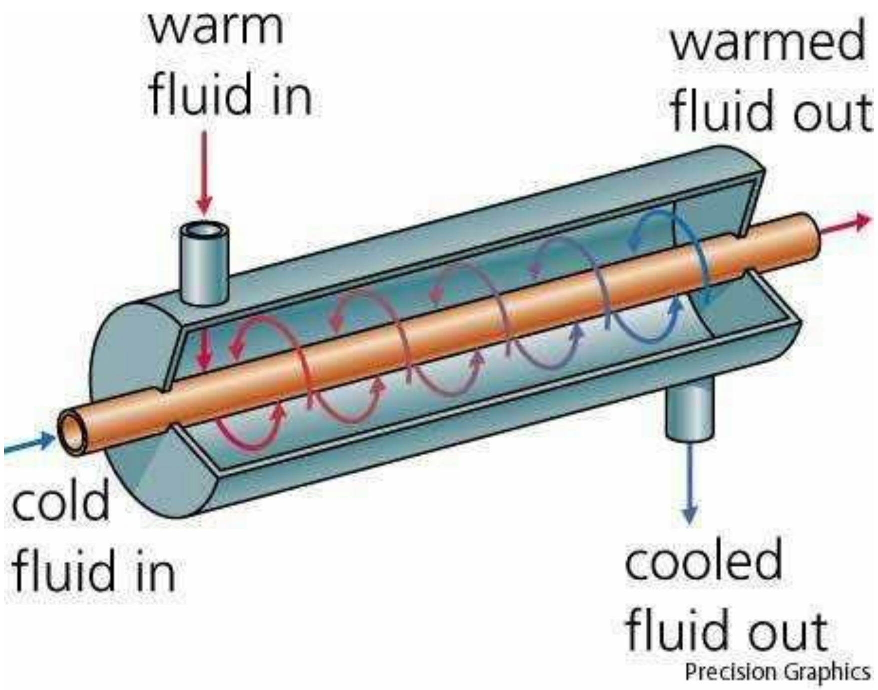
- According to constructional features heat exchangers are classified as

1. Tubular heat exchanger
2. Shell and tube-type heat exchanger
3. Finned tube type heat exchanger
4. Compact heat exchanger

Tubular heat exchanger

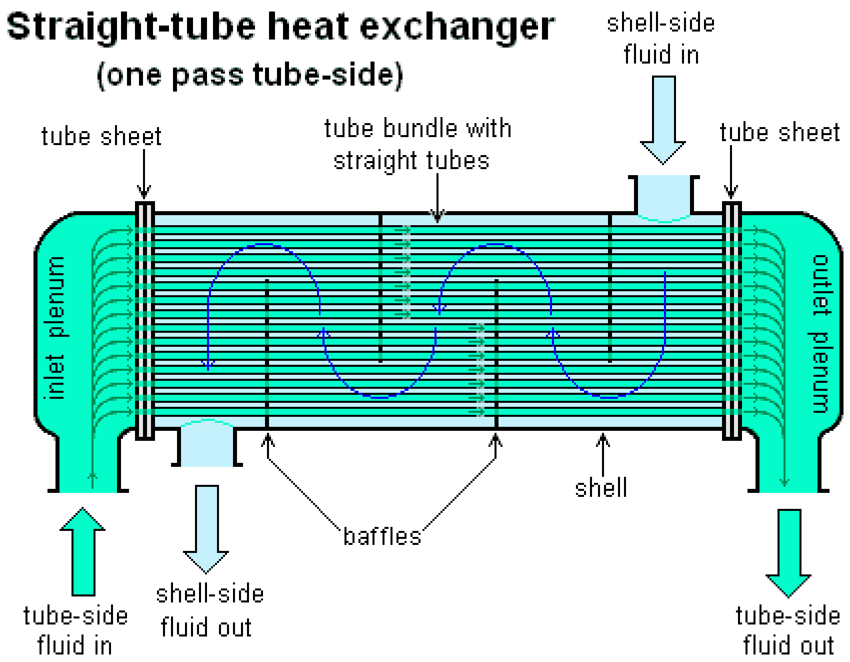
- Also called as
  tube-in-tube or concentric tube or double-pipe heat exchanger.

- These are widely used in many sizes and different flow arrangements.



SHELL AND TUBE-TYPE HEAT EXCHANGER

- Also called as surface condensers and are most commonly used for heating, cooling, condensation or evaporation applications.
- It consists of a shell and number of tubes housed in it.
- These have large surface area in small volume.



Finned tube type heat exchanger

- When a high-operating pressure or an enhanced heat transfer rate is required, the extended surfaces are used on one side of heat exchanger.
- These heat exchangers are used for liquid-to-gas heat exchange.
- Fins are always used on gas side.
- The tube fins are used in gas turbines, automobiles aero planes, cryogenics etc.

Compact heat exchanger

- These are a special class of heat exchanger in which the transfer area per unit volume is greater than 700 m^2/m^3.

- These heat exchangers have dense arrays of finned tubes or plates, when at least one of the fluid used is gas.

- Example- automobile radiators.

According to flow arrangement

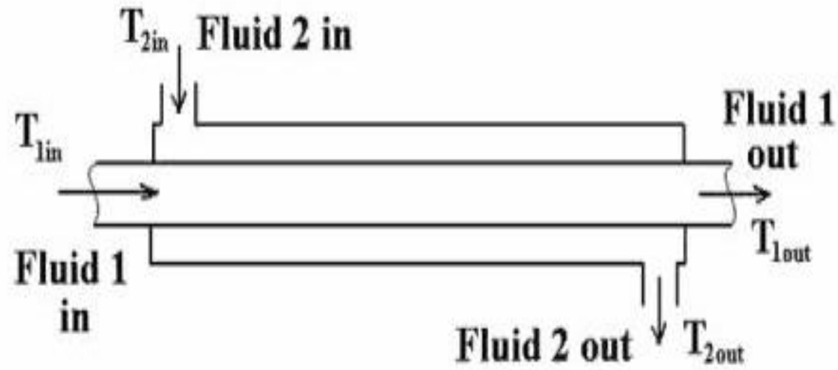
- According to flow arrangement heat exchangers are classified as

1. Parallel flow heat exchanger
2. Counter flow heat exchanger
3. Cross flow heat exchanger

Parallel flow heat exchanger

- Also called as unidirectional flow or concurrent flow
- The hot and cold fluids enter at same end of the heat exchanger.
- <u>Examples:</u>

1. Oil coolers
2. Oil heaters
3. Water heaters

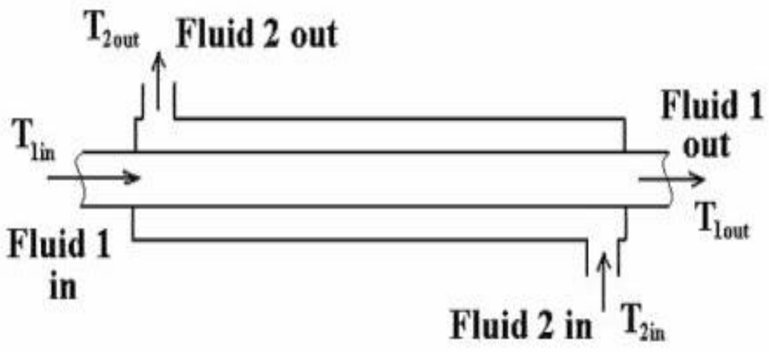


Double Pipe Heat Exchanger
Parallel Flow

Counter flow heat exchanger

- The hot and cold fluids enter at the opposite ends of heat exchanger.

- Flow through in opposite direction and leave at opposite end

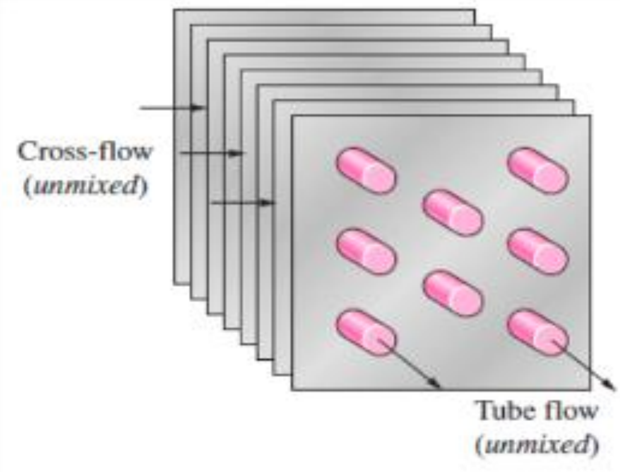


Double Pipe Heat Exchanger

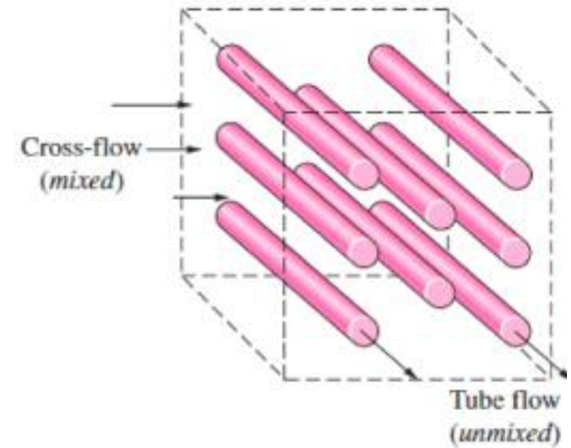
Counterflow

CROSS FLOW HEAT EXCHANGER

- The two fluids flow at right angles to each other.
- In the cross flow heat exchanger, the fluid flow may be mixed or unmixed.
- If both the fluids flow through individual channels and are not free to move in transverse direction, the arrangement is called unmixed, fig. (a)



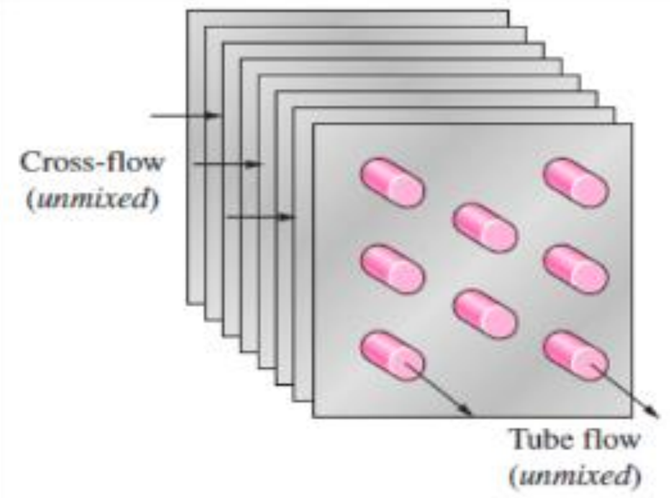
(a) Both fluids unmixed



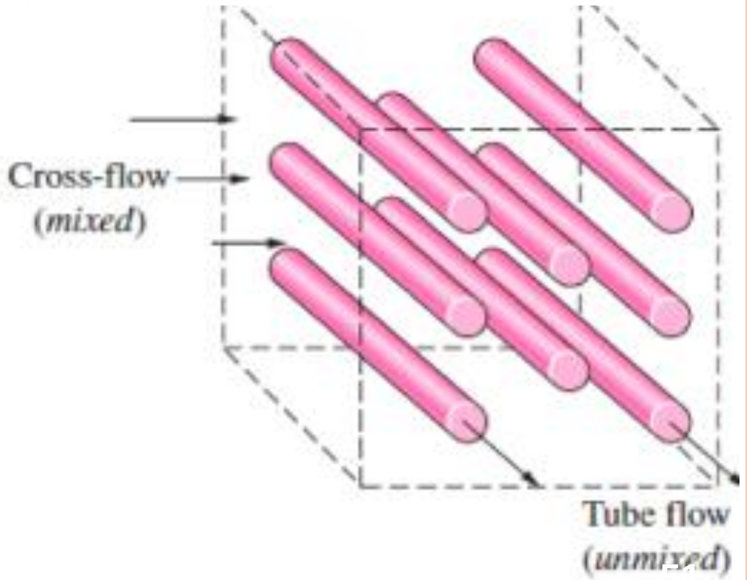
(b) One fluid mixed, one fluid unmixed

Cross flow heat exchange

- If any fluid flows on the surface and is free to move in the transverse direction, then fluid stream is said to be mixed, fig (b).



(*a*) Both fluids unmixed



(*b*) One fluid mixed, one fluid unmixed