RAMA UNIVERSITY

www.ramauniversity.ac.in

FACULTY OF ENGINEERING AND TECHNOLOGY

Department of Mechanical Engineering

BME504:Heat and Mass Transfer

Lecture 8

Instructor:
Aditya Veer Gautam

THE THERMAL RESISTANCE CONCEPT

- **Convection**

Consider convection heat transfer from a solid surface of area $\boldsymbol{A_s}$ and temperature $\boldsymbol{T_s}$ to a fluid whose temperature sufficiently far from the surface is $\boldsymbol{T_\infty}$ with a convection heat transfer coefficient ***h***. Newton's law of cooling for convection heat transfer rate $\dot{Q}_{conv} = hA_s(T_s - T_\infty)$ can be rearranged as

$$\dot{Q}_{conv} = \frac{T_s - T_\infty}{R_{conv}}$$

$$where\ R_{conv} = \frac{1}{hA}$$

$R_{conv} = \frac{1}{hA}$ ***Thermal resistance of the surface against heat convection***, or simply the ***convection resistance of the surface***

THE THERMAL RESISTANCE CONCEPT

- **Radiation**
- When the wall is surrounded by a gas, the radiation effects, which we have ignored so far, can be significant and may need to be considered. The rate of radiation heat transfer between a surface of emissivity ***ε*** and area ***A***$_s$ at temperature T_s and the surrounding surfaces at some average temperature T_{surr} can be expressed as

$$\dot{Q}_{rad} = \varepsilon\sigma A_s({T_s}^4 - {T_{surr}}^4)$$

$$\dot{Q}_{rad} = \frac{(T_s - T_{surr})}{R_{rad}}$$

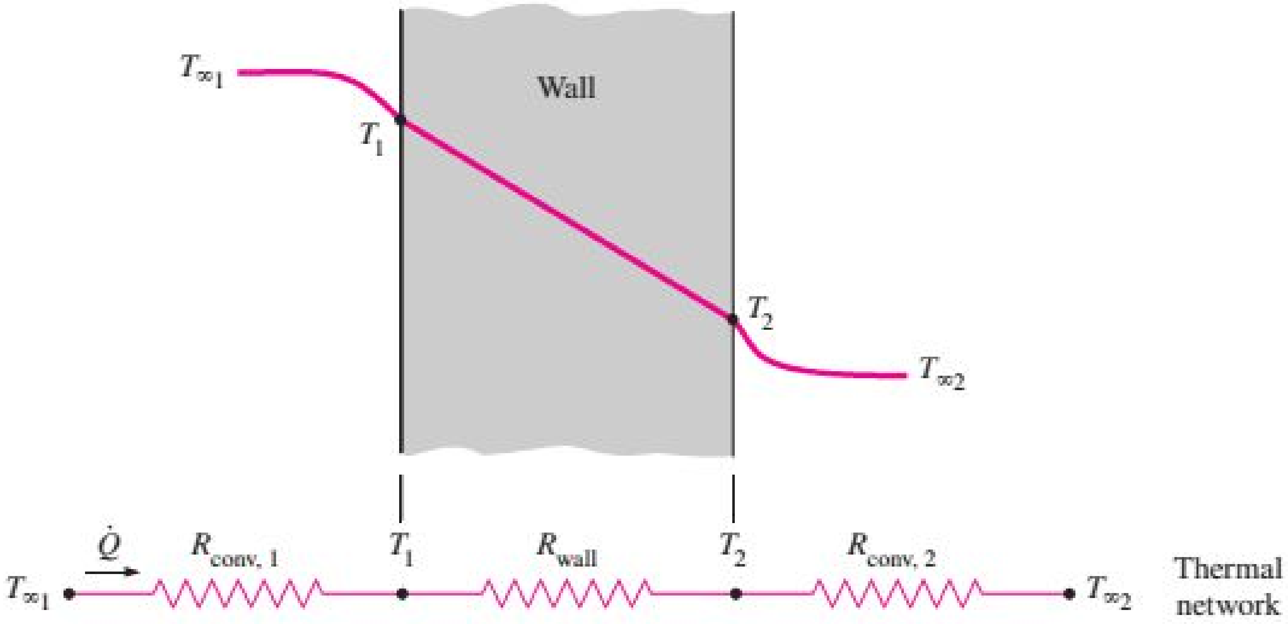
$$where\ R_{rad} = \frac{1}{h_{rad}A_s}$$

$R_{rad} = \frac{1}{h_{rad}A_s}$ thermal resistance of a surface against radiation, or the radiation resistance

$$h_{rad} = \frac{\dot{Q}_{rad}}{A_s(T_s - T_{surr})} = \epsilon\sigma(T_s^2 + T_{surr}^2)(T_s + T_{surr})$$

is the radiation heat transfer coefficient. Note that both T_s& T_{surr} must be in K in the evaluation of

THE THERMAL RESISTANCE CONCEPT



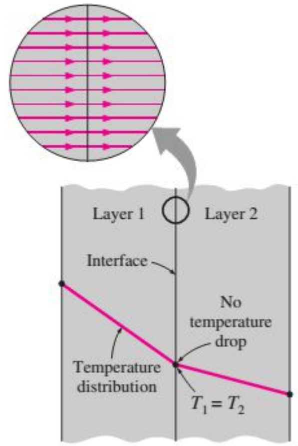
$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{conv,1} + R_{wall} + R_{conv,2}}$$

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

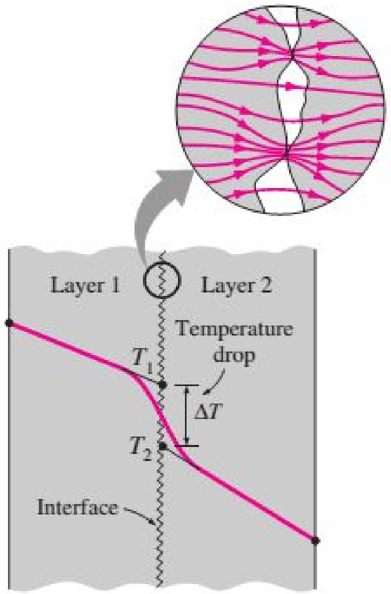
THERMAL CONTACT RESISTANCE

- Reducing Thermal Contact resistance
  - The thermal contact resistance can be minimized by applying thermally conducting liquid called thermal grease such as silicon oil on the surfaces before they are pressed against each other. This is commonly done when attaching electronic components such as power transistors to heat sinks.
  - The thermal contact resistance can also be reduced by replacing the air at the interface by a better conducting gas such as helium or hydrogen
- Another way to minimize the contact resistance is to insert a soft metallic foil such as tin, silver, copper, nickel, or aluminum between the two surfaces

$$R_c = \frac{1}{h_c} = \frac{\Delta T_{\text{interface}}}{\dot{Q}/A}$$



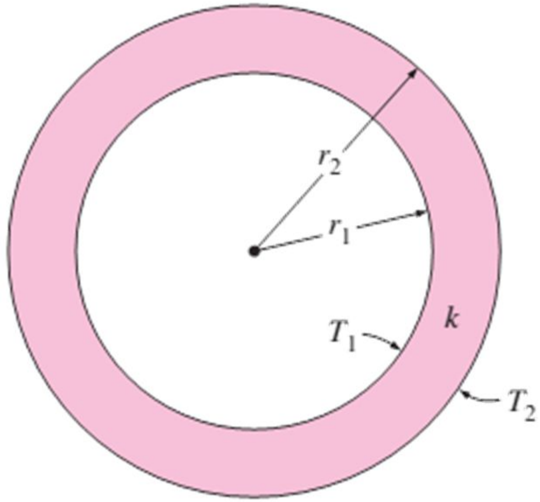
(a) Ideal (perfect) thermal contact



(b) Actual (imperfect) thermal contact

HEAT CONDUCTION IN CYLINDERS AND SPHERES

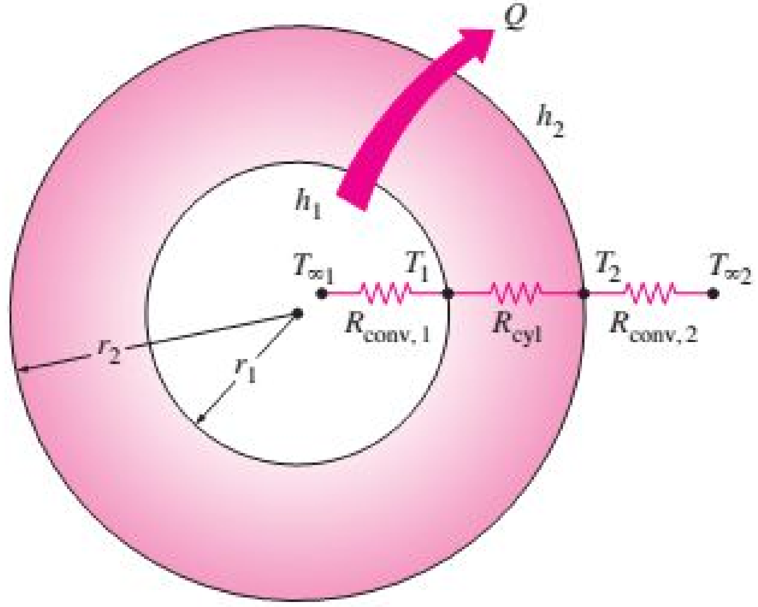
For both cyclinder and sphere $$\dot{Q}_{cond,cyl\ or\ sph} = -kA\frac{dT}{dr}$$	
$$\int_{r=r_1}^{r_2} \frac{\dot{Q}_{cond,cyl\ or\ sph}}{A} = -\int_{T=T_1}^{T_2} kdT$$	
$$\dot{Q}_{cond,cyl} = 2\pi Lk\frac{T_1 - T_2}{In\left(\frac{r_2}{r_1}\right)}$$	$$\dot{Q}_{cond,sph} = 4\pi r_1 r_2 k\frac{T_1 - T_2}{r_2 - r_1}$$
$$\dot{Q}_{cond,cyl} = \frac{T_1 - T_2}{R_{cyl}}$$	$$\dot{Q}_{cond,sph} = \frac{T_1 - T_2}{R_{sph}}$$
$$R_{cyl} = \frac{In\left(\frac{r_2}{r_1}\right)}{2\pi Lk}$$	$$R_{sph} = \frac{r_2 - r_1}{4\pi r_1 r_2 k}$$



HEAT CONDUCTION IN CYLINDERS AND SPHERES

- Cylinder

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

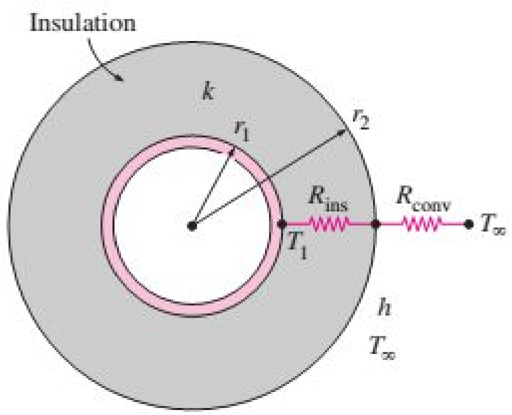


$$R_{total} = R_{conv,1} + R_{cyl} + R_{conv,2}$$

- Sphere

$$R_{total} = R_{conv,1} + R_{sph} + R_{conv,2}$$
$$= \frac{1}{(4\pi r_1^2)h_1} + \frac{r_2 - r_1}{4\pi r_1 r_2 k} + \frac{1}{(4\pi r_2^2)h_2}$$

CRITICAL RADIUS OF INSULATION

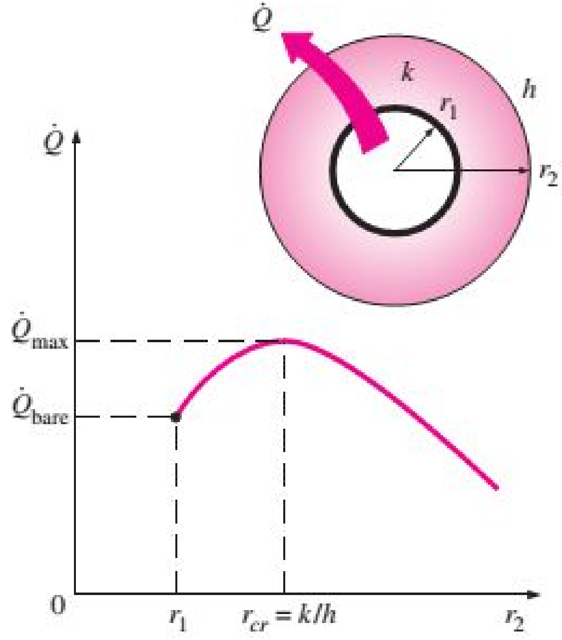


$$\dot{Q} = \frac{T_1 - T_\infty}{R_{ins} + R_{conv}} = \frac{T_1 - T_\infty}{\frac{In\left(\frac{r_2}{r_1}\right)}{2\pi Lk} + \frac{1}{h2\pi r_2 L}}$$

$$\frac{d\dot{Q}}{dr_2} = 0$$

$$r_{cr,cylinder} = \frac{k}{h}$$

$$r_{cr,sphere} = \frac{2k}{h}$$



Questions

Q1 A 3-mm-diameter and 5-m-long electric wire is tightly wrapped with a 2-mm-thick plastic cover whose thermal conductivity is 0.15 W/m · °C. Electrical measurements indicate that a current of 10 A passes through the wire and there is a voltage drop of 8 V along the wire. If the insulated wire is exposed to a medium at 30°C with a heat transfer coefficient of 12 $W/m^2 \cdot °C$, determine the temperature at the interface of the wire and the plastic cover in steady operation. Also determine whether doubling the thickness of the plastic cover will increase or decrease this interface temperature.

Q2 A 2-mm-diameter and 10-m-long electric wire is tightly wrapped with a 1-mm-thick plastic cover whose thermal conductivity is k = 0.15 W/m · °C. Electrical measurements indicate that a current of 10 A passes through the wire and there is a voltage drop of 8 V along the wire. If the insulated wire is ex-posed to a medium at T_∞= 30°C with a heat transfer coefficient of h = 24 W/m2 · °C, determine the temperature at the interface of the wire and the plastic cover in steady operation. Also determine if doubling the thickness of the plastic cover will increase or decrease this interface temperature.

Questions

Q3 A 5-mm-diameter spherical ball at 50°C is covered by a 1-mm-thick plastic insulation (k = 0.13 W/m · °C). The ball is exposed to a medium at 15°C, with a combined convection and radiation heat transfer coefficient of 20 $W/m^2 \cdot °C$. Determine if the plastic insulation on the ball will help or hurt heat transfer from the ball

Q4 The thermal contact conductance at the interface of two 1-cm-thick copper plates is measured to be 18,000 W/m2 · °C. Determine the thickness of the copper plate whose thermal resistance is equal to the thermal resistance of the interface between the plates.

Questions

Q5 A 4-m-high and 6-m-wide wall consists of a long 18-cm 30-cm cross section of horizontal bricks (k = 0.72 W/m ·°C) separated by 3-cm-thick plaster layers (k = 0.22 W/m · °C). There are also 2-cm-thick plaster layers on each side of the wall, and a 2-cm-thick rigid foam (k = 0.026 W/m ·°C) on the inner side of the wall. The indoor and the outdoor temperatures are 22°C and -4°C, and the convection heat transfer coefficients on the inner and the outer sides are h_1 = 10 W/m2 · °C and h_2 = 20 W/m2 · °C, respectively. Assuming one-dimensional heat transfer and disregarding radiation, determine the rate of heat transfer through the wall.