Radiation Heat Transfer

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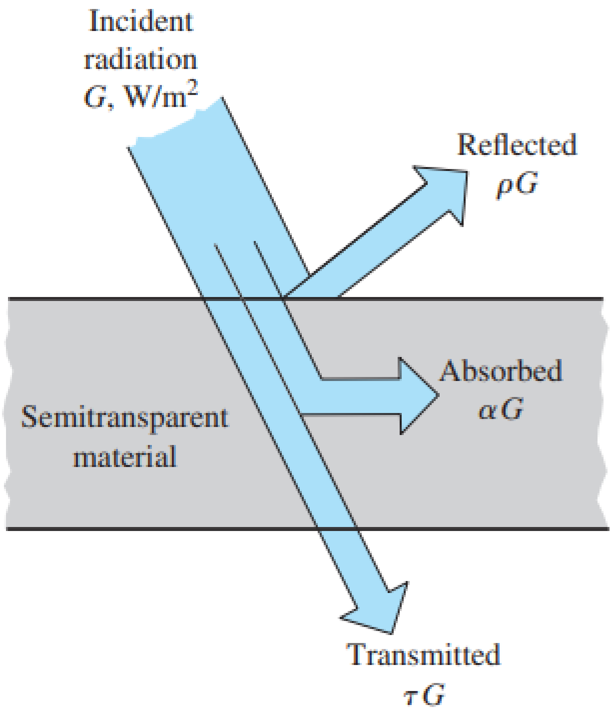
- Thermal radiation is that electromagnetic radiation emitted by a body as a result of its temperature.
- Radiation heat transfer is a process where heat waves are emitted that may be absorbed, reflected, or transmitted through a colder body. Sun heats the earth by electromagnetic waves.
- the transfer of radiation through space will be considered
- The Heat Transfer by radiation is between two bodies is
- $Q = A\varepsilon\sigma(T_1^4 - T_2^4)$
- Where σ=Stefan-Boltzmann constant =5.67x$10^{-8} W/m^2k^4$ $\varepsilon = emmisisvity$
- $\varepsilon = 1.0$ for black body and $\varepsilon < 1.0$ for non black body

• RADIATION PROPERTIES

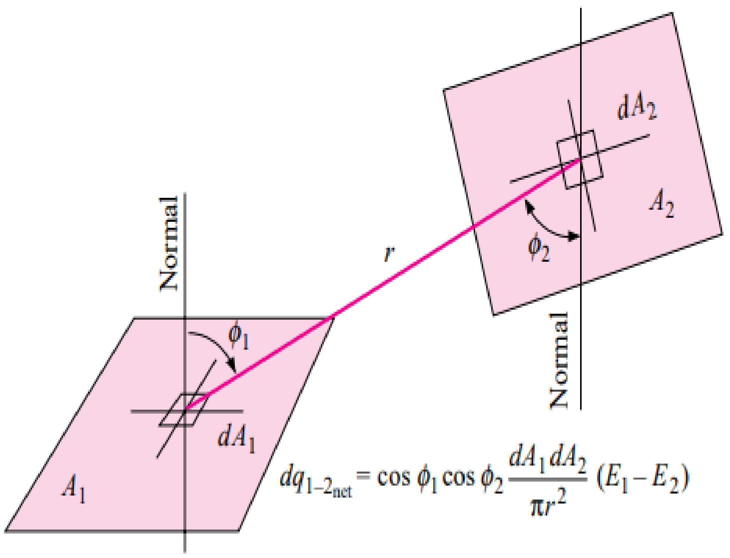
- When radiant energy strikes a material surface, part of the radiation is reflected, part is absorbed, and part is transmitted, as shown in Figure. We define the reflectivity ρ as the fraction reflected, the absorptivity α as the fraction absorbed, and the transmissivity τ as the fraction transmitted. Thus:
- $\tau + \alpha + \rho = 1$
- For oblique body $\tau = 0$
- The $\alpha + \rho = 1$

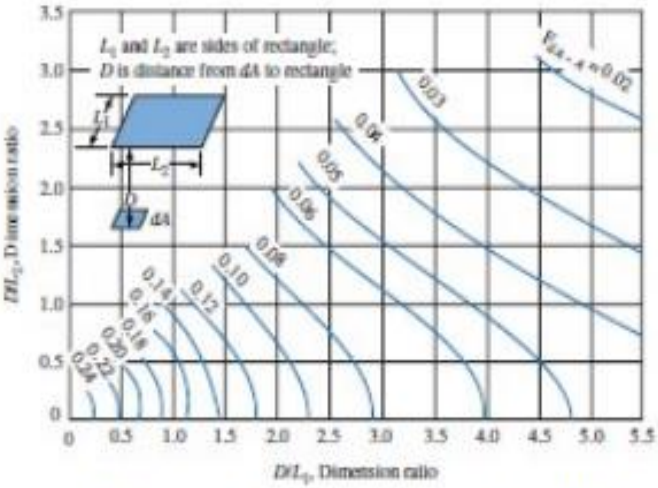


• RADIATION SHAPE FACTOR

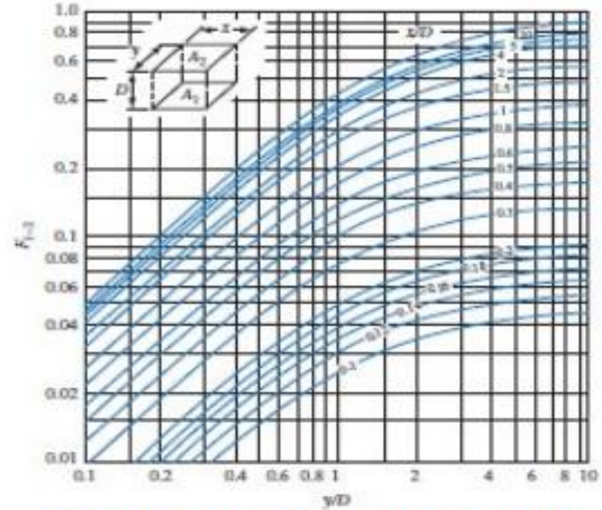
- The fraction of radiation energy that leaves one surface and reach the other surface is defined as Shape Factor, view factor, angle factor, and configuration factor
- For a black body
- $\dot{Q}_{12} = A_{12}F_{12}\sigma(T_1^4 - T_2^4) = A_2F_{21}\sigma(T_1^4 - T_2^4)$
- It means that $A_1F_{12} = A_2F_{21}$
- And $F_{i1} + F_{i2} + F_{i3} + \cdots = 1$
- Or $\sum_{i=1}^{n} F_{ij} = 1$
- $F_{ii} = 0$ for plane and convex
- $F_{ii} \neq 0$ for concave
- $F_{ij} = F_{ji}$ for parallel large

surfaces that $A_i = A_j$

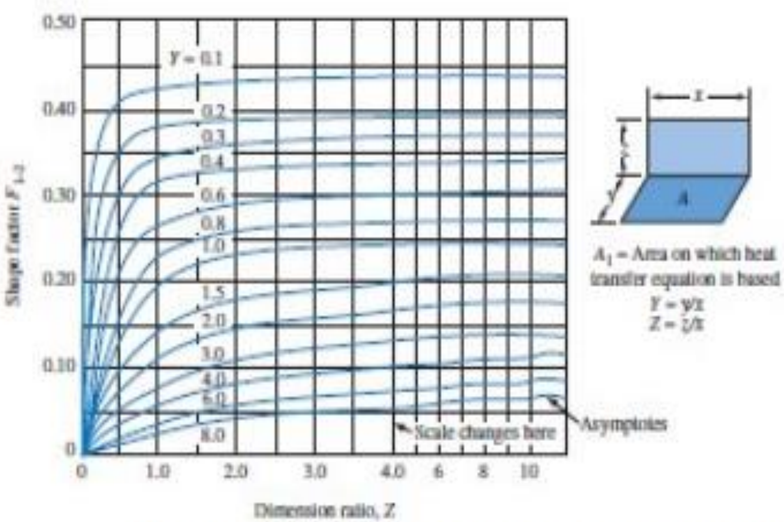




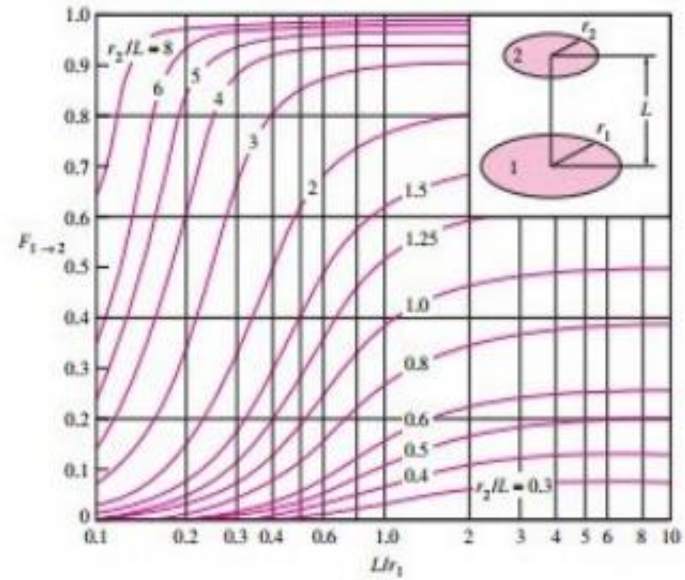
Shape Factor Between a Surface Element dA And A Rectangular Surface A Parallel To It



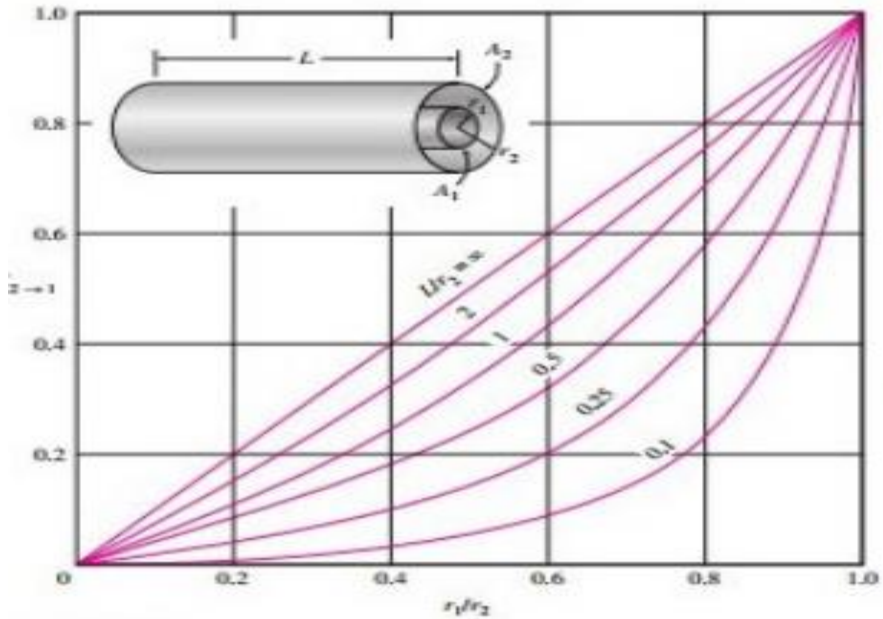
Shape Factor Between Two Aligned Parallel Rectangles of Equal Size

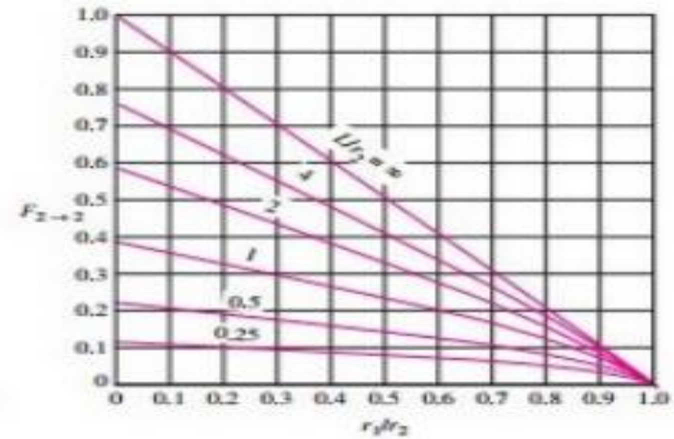


Shape Factor for Adjacent Rectangles in Perpendicular Planes Shaping a Common Edge



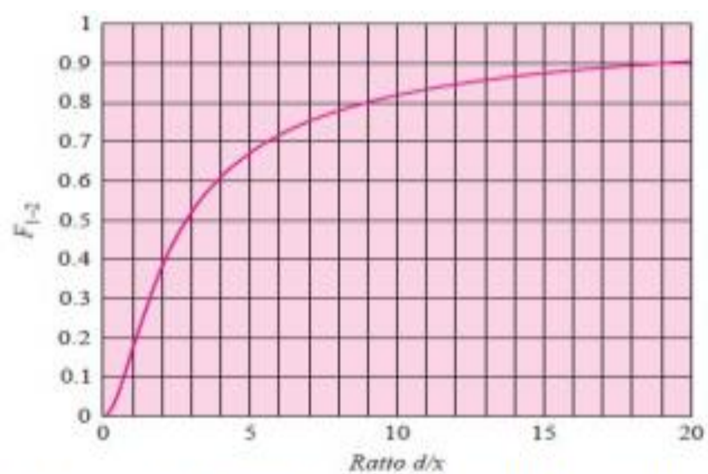
Shape Factor Between Two Coaxial Parallel Disks





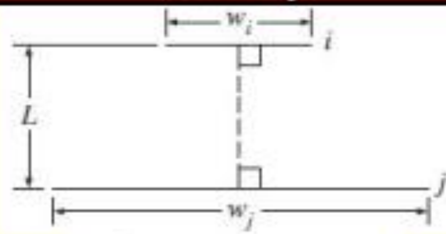
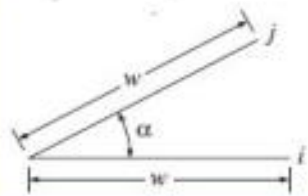
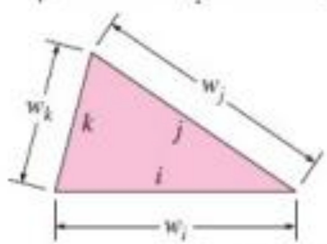
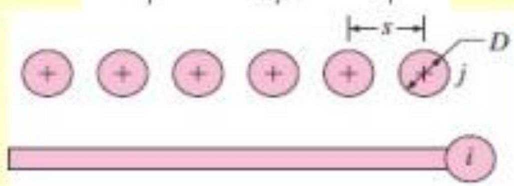
Shape Factor For Two Concentric Cylinders Of Finite Length

a) Outer Cylinder to Inner Cylinder b) Outer Cylinder to Its Self



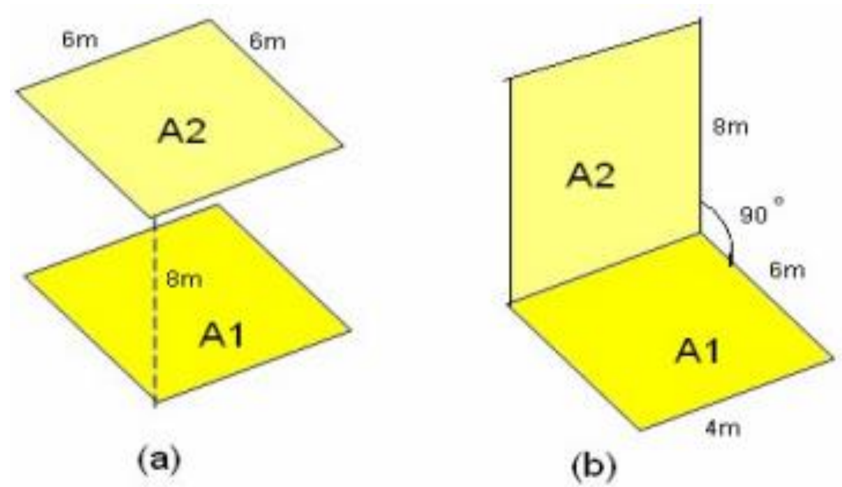
Shape Factor Between Parallel Equal Coaxial Disks

TABLE 10-2 SHAPE FACTORS EXPRESSION FOR SOME INFINITELY LONG(2D) GEOMETRIES

Specification	***Geometry***	***Relation***
Parallel Plates with a Midlines Connected by Normal Line		$W_i = w_i/L$ and $W_j = w_j/L$ $F_{i\to j} = \frac{[(W_i + W_j)^2 + 4]^{1/2} - (W_j - W_i)^2 + 4]^{1/2}}{2W_i}$
Inclined Plates of Equal Width with a Common Edge		$F_{i\to j} = 1 - \sin\frac{1}{2}\alpha$
Perpendicular Plates With Common Edge		$F_{i\to j} = \frac{1}{2}\left\{1 + \frac{w_j}{w_i} - \left[1 + \left(\frac{w_j}{w_i}\right)^2\right]^{1/2}\right\}$
Three sided enclosure		$F_{i\to j} = \frac{w_i + w_j - w_k}{2w_i}$
Infinite Plane and Row of Cylinders		$F_{i\to j} = 1 - \left[1 - \left(\frac{D}{s}\right)^2\right]^{1/2} + \frac{D}{s}\tan^{-1}\left(\frac{s^2 - D^2}{D^2}\right)^{1/2}$

<u>Example 1</u> Determine the shape factor F_{1-2} between two rectangular surfaces for arrangement shown in the accompanying Figure

Solution: The configuration in (a) two parallel plates each facing the other having equal areas (6m x 6m) and (8m) apart. The Configuration in (b) two perpendicular plates.



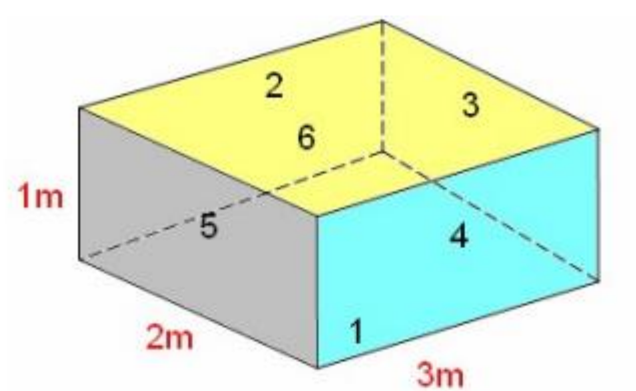
The vertical plate is (8m) height and (4m) width and the horizontal plate is of (6m) long and (4m) width. The shape factor is to be calculated for the two configurations

Assumption: There is no assumptions

Property: The radiation properties is constant Analysis: By using the shape factor charts as below For configuration (a) Y/D=6/8=0.75 and X/D=6/8=0.75 and from Fig.10.8 F_{1-2}=0.16

For configuration (b) Y/X=6/4=1.5 and X/D=8/4=2 and from Figure F_{1-2}= 0.175

Example 2. Determine the shape factor from the floor face of the furnace of size(1m x 2m x 3m) to the surfaces of the all sides and the roof surface.



Solution: A room of Dimensions (1m x 2m x 3m) as shown in Fig. . The shape Factors between the floor and all the sides and roof are to be determined. F_{1-2}, F_{1-3}, F_{1-4}, F_{1-5}, and F_{1-6}.

Assumption: There is no assumption Property: Radiation properties are constant

Analysis: Firstly to find the shape factor between the floor 1 and the side 2 by using the chart to perpendicular adjunct side walls. y/x=2/3=0.667, and z/x=1/3=0.333 and $F_{1-2} = F_{1-4}$ =0.15 and from the floor and the side 3. y/x=3/2=1.5 and z/x=1/2=0.5 then

$F_{1-3} = F_{1-5}$=0.1. then

F_{1-6}=1-($F_{1-2} + F_{1-3} + F_{1-4} + F_{1-5}) = 1$ $-$(0.15+0.1+0.15+0.1)=0.5 Or by using the chart of shape factor between two parallel rectangular planes: y/D=2/1=2, and x/D=3/1=3 and F_{-6} =0.5

- **THERMAL RADIATION EXCHANGE** The radiation exchange among the surfaces of enclosure analysis is complicated spastically when the surfaces are not black. The radiation leaving a surface may be return back by reflection and fronts for several times among the surfaces with partial absorption occurring at each reflection.
- Therefore analysis of these problem properly must include the effects of these multiple reflections. Also to simplify the analysis, we will assume a given enclosure is divided into several zones as shown in Figure. The following conditions are assumed to hold for each of the zones i=1, 2, 3, …., N in such a manner

1- The properties of radiation (reflectivity, absorptivity and emissivity) are independent of direction and frequency and are uniform.

2- The surfaces are as diffuse emitters and also diffuse reflectors

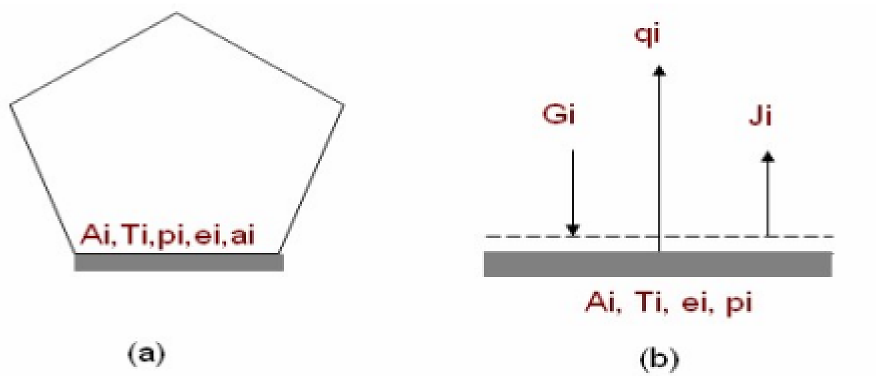
3- The surface is of uniform radiation heat flux leaving.

4- Uniform irradiation is over the surface in each zone

5- The surface are opaque ($\alpha+\rho=1$).

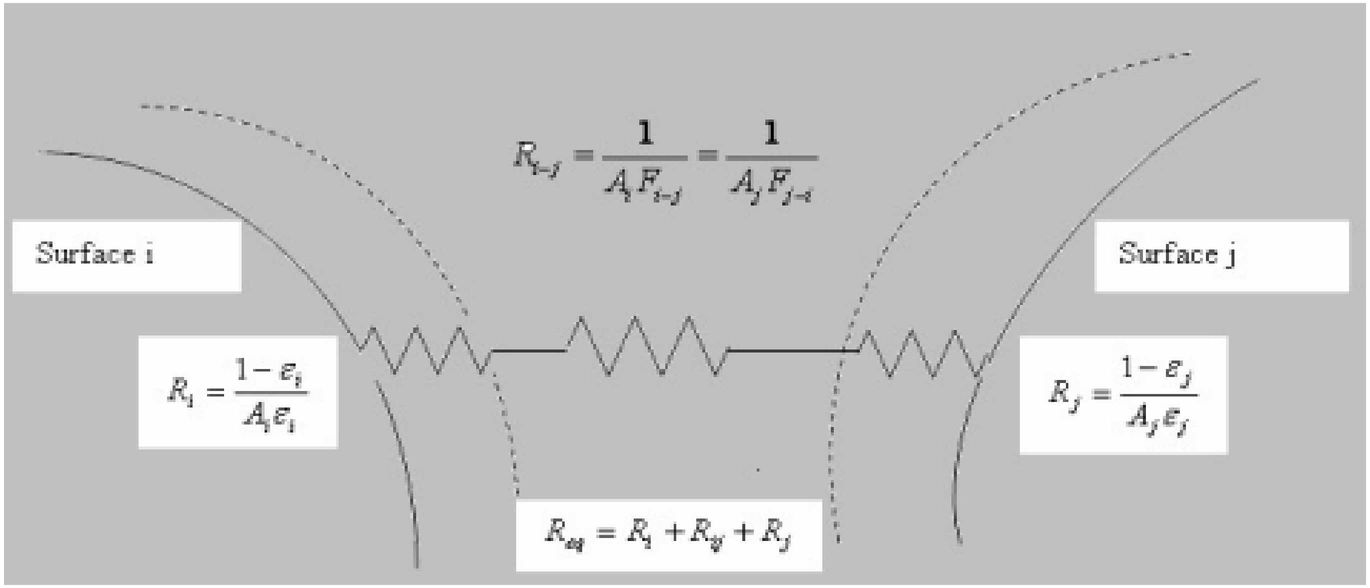
6- The surfaces are prescribed either a constant surface temperature or uniform heat flux.

7- The enclosure if filled with a nonparticipating medium



(a) The Enclosure That Filled With medium of a Nonparticipating
(b) A Balance of Energy per Unit Area of Zone i

Radiation Resistance Across Two Surfaces Let two surfaces A_i and A_j of emissivity's ε_i and ε_j, and are maintained at uniform different temperature T_i and T_j respectively as shown in Figure. Let $\dot{Q}_{i-j}$ be the net heat transfer by radiation from zone i to zone j.



Various Resistance To Radiation In The Path Of Heat Flow Between Surfaces Ai and Aj

- The balance of energy for heat transfer by radiation between the two zones can be written as:

$$\dot{Q}_{i-j} = \frac{E_{bi} - E_{bj}}{R_i + R_{i-j} + R_j} = \frac{\sigma\left(T_i^4 - T_j^4\right)}{\frac{1-\varepsilon_i}{A_i\varepsilon_i} + \frac{1}{A_iF_{i-j}} + \frac{1-\varepsilon_j}{A_j\varepsilon_j}} = \frac{5.67\left(\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4\right)}{\frac{1-\varepsilon_i}{A_i\varepsilon_i} + \frac{1}{A_iF_{i-j}} + \frac{1-\varepsilon_j}{A_j\varepsilon_j}}$$

- And for black bodies where $\varepsilon_i = \varepsilon_j = 1.0$

- $\dot{Q}_{i-j} = A_iF_{i-j} \times 5.67\left[\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4\right]$

- When the radiating bodies are infinite parallel bodies here $A_i = A_j$, and $F_{i-j} = F_{j-i}$=1

$$\dot{Q}_{i-j} = \frac{A_i \sigma \left(T_i^4 - T_j^4\right)}{\frac{1-\varepsilon_i}{\varepsilon_i} + \frac{1}{1} + \frac{1-\varepsilon_j}{\varepsilon_j}} = \frac{A_i (5.67) \left(\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4 \right)}{\frac{1}{\varepsilon_i} + \frac{1}{\varepsilon_j} - 1}$$

- When the radiation bodies are concentric bodies Here F_{i-j}=1 and $A_i < A_J$

$$\dot{Q}_{i-j} = \frac{A_i (5.67) \left(\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4 \right)}{\frac{1}{\varepsilon_i} + \frac{A_i}{A_j} \frac{1-\varepsilon_j}{\varepsilon_j}}$$

- When a small body lies in a large enclosure Here, $F_{i-j} = 1$, $A_i \ll A_j$ so that $A_i / A_i \rightarrow 0$

$$\dot{Q}_{i-j} = \frac{A_i (5.67) \left(\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4 \right)}{\frac{1-\varepsilon_i}{\varepsilon_i} + 1}$$

Example.1 Determine the heat transfer rate per area by radiation between the two long cylinder surfaces of radii (120mm) and (60mm) respectively. The smaller cylinder is placed in the larger. The axis of the cylinders are parallel to each other and separated by a distance (10mm). The temperatures of the surfaces of inner and outer cylinders are ($127^{o}C$) and ($77^{o}C$) respectively. Take the emissivities of both the surfaces are (0.5).

Solution: Two cylinders of r_i =60mm=0.06m, r_o=120mm=0.12m. The smallest one in the larger one. The cylinders axis are parallel and separated by a distance (d=10mm=0.01m). The temperatures are (Ti=127oC=400K) and (To=77oC=350K).

Assumption: The two cylinder is very long and radiation take place between them only (F_{io} =1). The heat transfer is by radiation only

Property: the emissivities of the cylinder surfaces are equal and they are ($\varepsilon_i = \varepsilon_o$ =0.5).

Analysis: by using the equation of heat transfer by radiation between the two surfaces

$$\dot{Q}_{i-o} = \frac{A_i(5.67)\left(\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_o}{100}\right)^4\right)}{\frac{1}{\varepsilon_i} + \frac{A_i}{A_o}\frac{1-\varepsilon_o}{\varepsilon_o}}$$

And we know that $F_{i-o} = 1.0, \frac{A_i}{A_o} = \frac{\pi L d_i}{\pi L d_o} = \frac{d_i}{d_o} = \frac{r_i}{r_o} = \frac{0.06}{0.12} = 0.5$

$A_i = 2\pi L r_i = 2\pi \times 0.06 \times 1 = 0.377 m^2$. By substituting these values in previous relation.

$$\dot{Q}_{i-o} = \frac{(0.377)(5.67)\left(\left(\frac{400}{100}\right)^4 - \left(\frac{350}{100}\right)^4\right)}{\frac{1}{0.5} + \frac{1}{2}\frac{1-0.5}{0.5}} = 90.58 W/m$$

- **Example.2** Two large parallel planes are at temperatures (1200K) and (800K). Determine the heat exchange between these two surfaces per unit area. (i) If surfaces are black, (ii) if the hot one has an emissivity of (0.8) and the cooled one (0.5).
- **Solution:** Two Large parallel surfaces at temperatures (Ti=1200K) and (Tj=800K) and emissivities (ε_i =0.8)and (ε_j=0.5). The heat exchange between the two surfaces is to be determined in the case of black body assumption and of the emissivities as given
- **Assumption:** The surfaces are very large so that F_{i-j}=1
- **Property:** The emissivities are as given in the example that ε_i=0.8, ε_j=0.5
- **Analysis:** For the case (i) When the two bodies are black where $\varepsilon_i = \varepsilon_j$ =1, and F_{i-j}=1

$$\dot{Q}_{i-j} = F_{i-j} A_1 (5.67)\left[\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4\right]$$

$$\dot{Q}_{i-j} = 1.0(1.0)(5.67)\left[\left(\frac{1200}{100}\right)^4 - \left(\frac{800}{100}\right)^4\right] = 94.35 kW/m^2$$

For the case (ii) when (ε_i=0.8)and (ε_j=0.5), then

$$\dot{Q}_{i-j} = \frac{A_i (5.67)\left(\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4\right)}{\frac{1}{\varepsilon_i} + \frac{1}{\varepsilon_j} - 1}$$

$$\dot{Q}_{i-j} = \frac{1.0(5.67)\left(\left(\frac{1200}{100}\right)^4 - \left(\frac{800}{100}\right)^4\right)}{\frac{1}{0.8} + \frac{1}{0.5} - 1} = 41.933 kW/m^2$$