TRANSMISSÃO DE CALOR E MASSA

CAPÍTULO 13
TROCA DE RADIAÇÃO ENTRE SUPERFÍCIES

Radiation Exchange Between Surfaces: Enclosures with Nonparticipating Media

Chapter 13

Sections 13.1 through 13.4

Basic Concepts

- Enclosures consist of two or more surfaces that envelop a region of space (typically gas-filled) and between which there is radiation transfer. Virtual, as well as real, surfaces may be introduced to form an enclosure.

- A nonparticipating medium within the enclosure neither emits, absorbs, nor scatters radiation and hence has no effect on radiation exchange between the surfaces.

- Each surface of the enclosure is assumed to be isothermal, opaque, diffuse and gray, and to be characterized by uniform radiosity and irradiation.

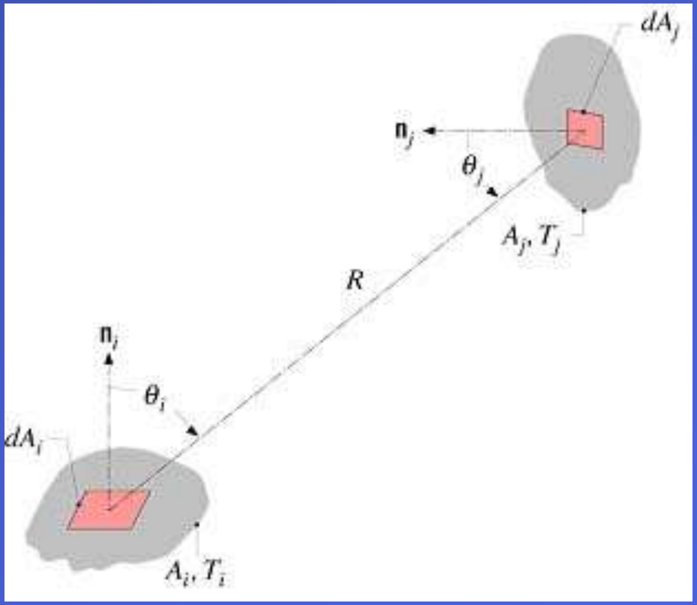
The View Factor (also Configuration or Shape Factor)

- The view factor, F_{ij}, is a geometrical quantity corresponding to the fraction of the radiation leaving surface *i* that is intercepted by surface *j*.

$$F_{ij} = \frac{q_{i \to j}}{A_i J_i}$$

- The view factor integral provides a general expression for F_{ij}. Consider exchange between differential areas dA_i *and* dA_j :

$$F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos\theta_i \cos\theta_j}{\pi R^2} dA_i dA_j$$

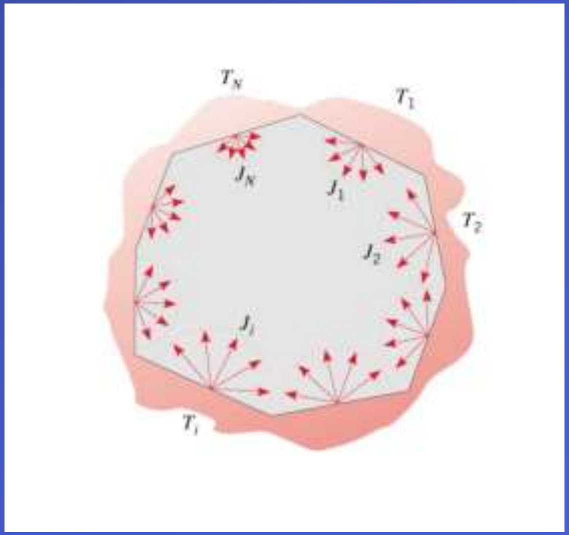


View Factor Relations

- Reciprocity Relation. With

$$F_{ji} = \frac{1}{A_j}\int_{A_i}\int_{A_j}\frac{\cos\theta_i\cos\theta_j}{\pi R^2}\,dA_i dA_j$$

$$A_i F_{ij} = A_j F_{ji}$$



- Summation Rule for Enclosures.

$$\sum_{j=1}^{N} F_{ij} = 1$$

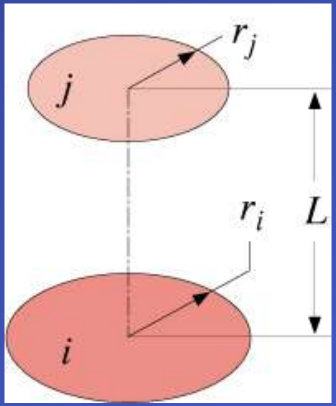
- Three-Dimensional Geometries (Table 13.2). For example,

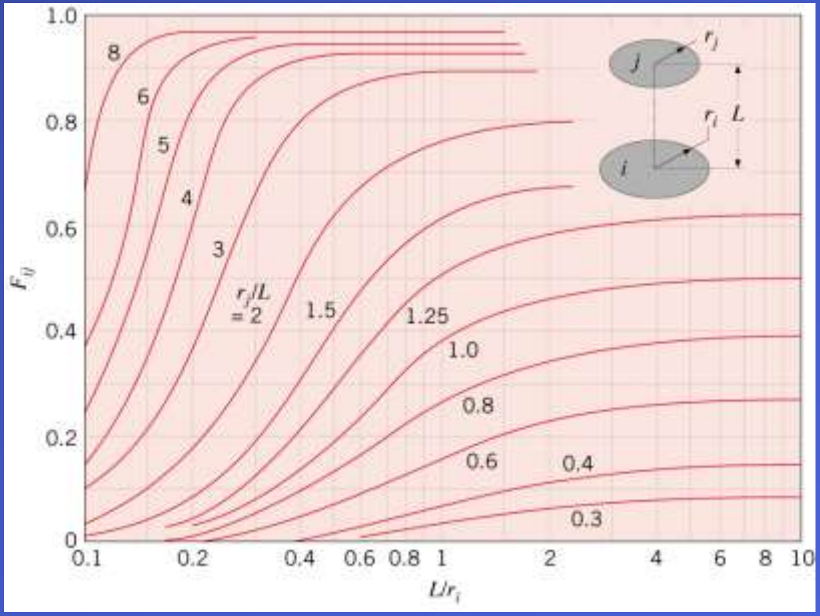
Coaxial Parallel Disks

$$F_{ij} = \frac{1}{2}\left\{ S - \left[S^2 - 4\left(r_j / r_i\right)^2 \right]^{1/2} \right\}$$

$$S = 1 + \frac{1 + R_j^2}{R_i^2}$$

$$R_i = r_i / L \qquad R_j = r_j / L$$



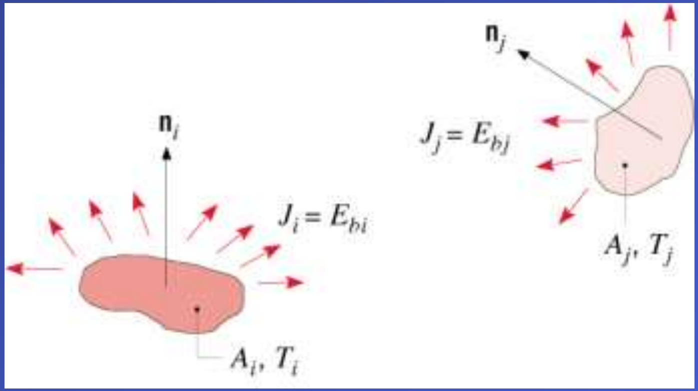


Blackbody Radiation Exchange

- For a blackbody, $J_i = E_{bi}$.

- Net radiative exchange between two surfaces that can be approximated as blackbodies $\longrightarrow$ *net* rate at which radiation leaves surface *i* due to its interaction with *j*

  or net rate at which surface *j* gains radiation due to its interaction with *i*



$$q_{ij} = q_{i\to j} - q_{j\to i}$$

$$q_{ij} = A_i F_{ij} E_{bi} - A_j F_{ji} E_{bj}$$

$$q_{ij} = A_i F_{ij} \sigma \left(T_i^4 - T_j^4\right)$$

- Net radiation transfer from surface *i* due to exchange with all (*N*) surfaces of an enclosure:

$$q_i = \sum_{j=1}^{N} A_i F_{ij} \sigma \left(T_i^4 - T_j^4\right)$$

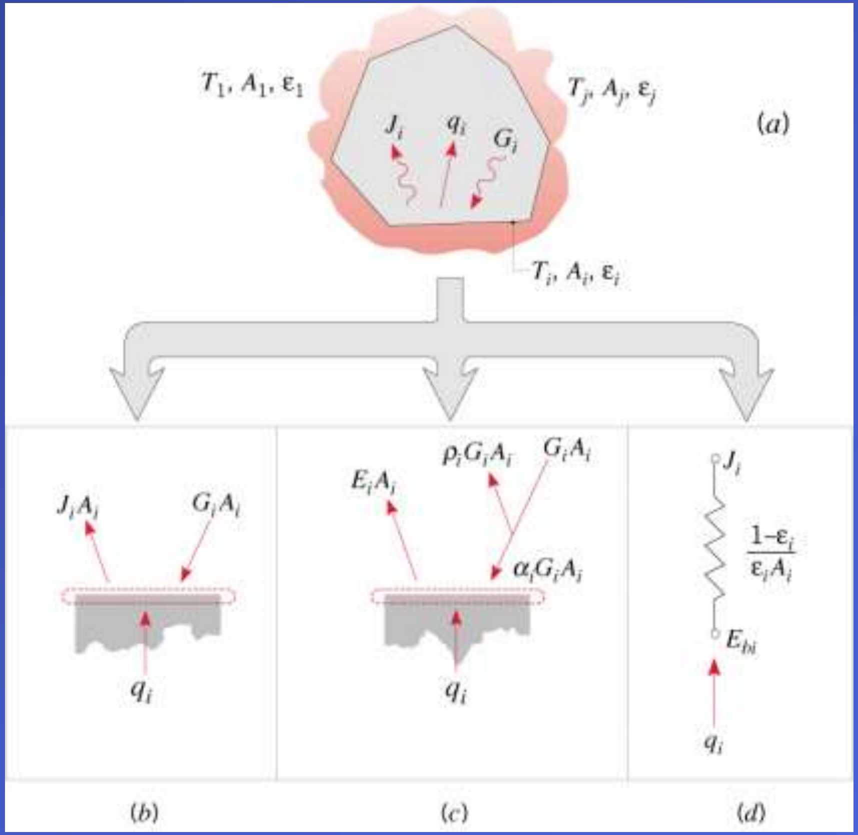
General Radiation Analysis for Exchange between the *N* Opaque, Diffuse, Gray Surfaces of an Enclosure

$$\left(\varepsilon_i = \alpha_i = 1 - \rho_i\right)$$

- Alternative expressions for net radiative transfer from surface *i*:

$$q_i = \frac{E_{bi} - J_i}{(1-\varepsilon_i)/\varepsilon_i A_i} \rightarrow \text{Fig. (d)} \qquad (3)$$

Suggests a surface radiative resistance of the form: $(1-\varepsilon_i)/\varepsilon_i A_i$



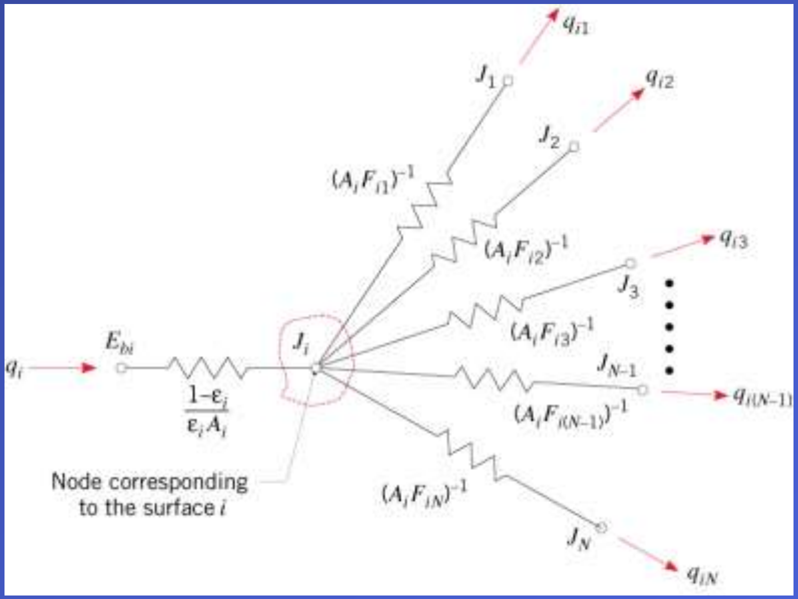
$$q_i = \sum_{j=1}^{N} A_i F_{ij} \left(J_i - J_j \right) = \sum_{j=1}^{N} \frac{J_i - J_j}{\left(A_i F_{ij} \right)^{-1}} \qquad (4)$$

Suggests a space or geometrical resistance of the form: $\left(A_i F_{ij} \right)^{-1}$

- Equating Eqs. (3) and (4) corresponds to a radiation balance on surface *i*:

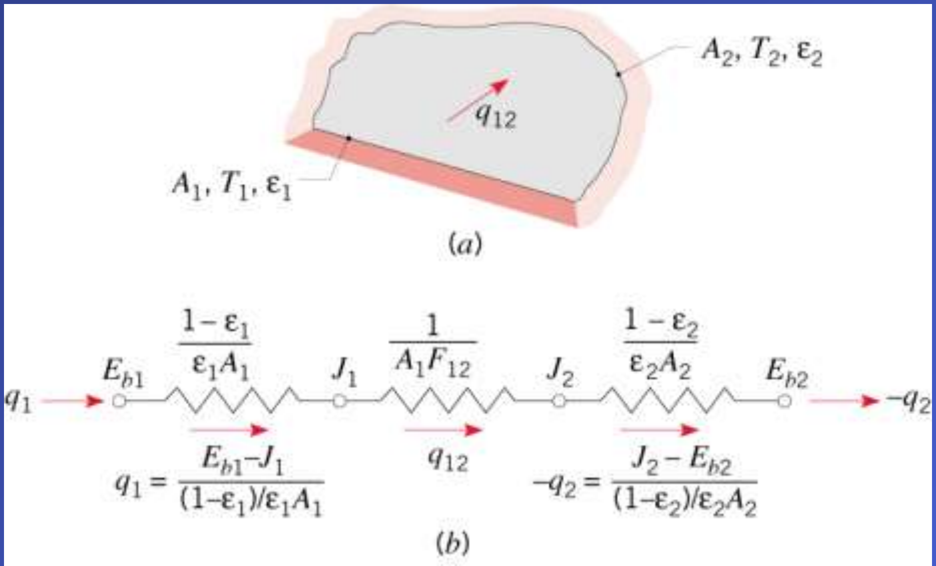
$$\frac{E_{bi} - J_i}{\left(1-\varepsilon_i\right)/\varepsilon_i A_i} = \sum_{j=1}^{N} \frac{J_i - J_j}{\left(A_i F_{ij} \right)^{-1}} \qquad (5)$$

which may be represented by a radiation network of the form



Two-Surface Enclosures

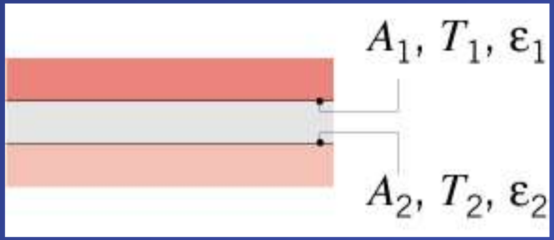
- Simplest enclosure for which radiation exchange is exclusively between two surfaces and a single expression for the rate of radiation transfer may be inferred from a network representation of the exchange.



$$q_1 = -q_2 = q_{12} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}}$$

- Special cases are presented in Table 13.3. For example,

  - Large (Infinite) Parallel Plates



$$A_1 = A_2 \equiv A$$

$$F_{12} = 1$$

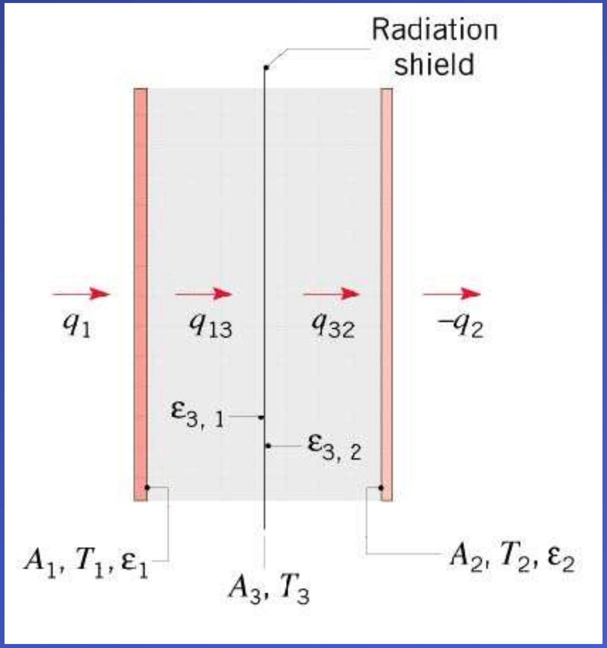
$$q_{12} = \frac{A_1 \sigma \left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

  - Note result for *Small Convex Object in a Large Cavity.*

Radiation Shields

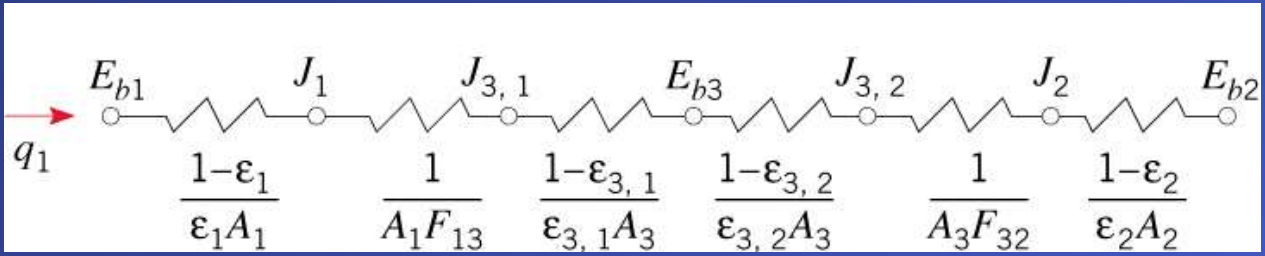
- High reflectivity (low $\alpha = \varepsilon$) surface(s) inserted between two surfaces for which a reduction in radiation exchange is desired.

- Consider use of a single shield in a two-surface enclosure, such as that associated with large parallel plates:



Note that, although rarely the case, emissivities may differ for opposite surfaces of the shield.

- Radiation Network:

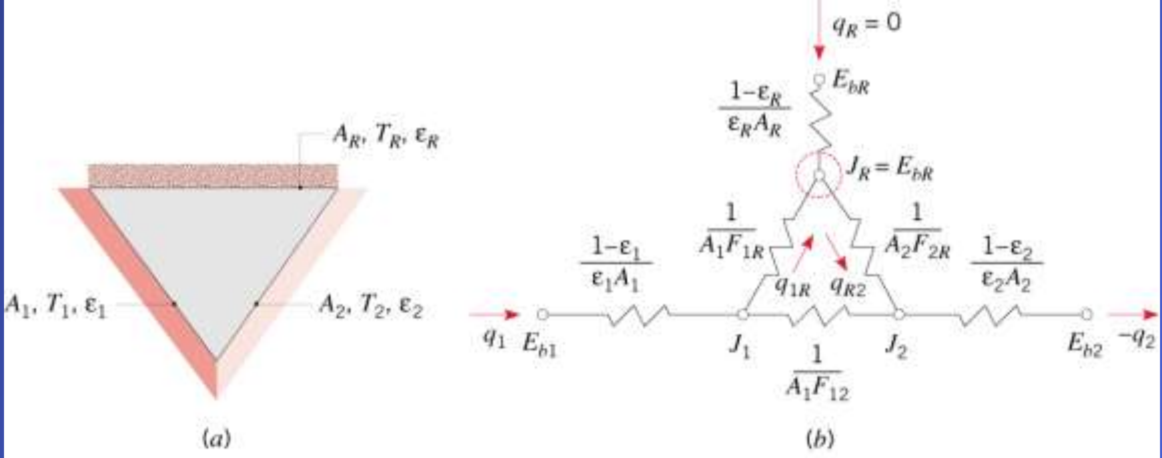


$$q_{12} = q_1 = -q_2 = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{13}} + \frac{1-\varepsilon_{3,1}}{\varepsilon_{3,1} A_3} + \frac{1-\varepsilon_{3,2}}{\varepsilon_{3,2} A_3} + \frac{1}{A_3 F_{32}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}}$$

- The foregoing result may be readily extended to account for multiple shields and may be applied to long, concentric cylinders and concentric spheres, as well as large parallel plates.

The Reradiating Surface

- An idealization for which $G_R = J_R$. Hence, $q_R = 0$ and $J_R = E_{bR}$.
- Approximated by surfaces that are well insulated on one side and for which convection is negligible on the opposite (radiating) side.
- Three-Surface Enclosure with a Reradiating Surface:



$$q_1 = -q_2 = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{12} + \left[\left(1/A_1 F_{1R}\right) + \left(1/A_2 F_{2R}\right)\right]^{-1}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}}$$