FDE449
Physical Properties of Foods
Thermal properties of foods

Content
***Heat transfer**
-Conduction
-Convection
-Radiation

Introduction

- Thermophysical properties are necessary for the design and prediction of heat transfer operation during handling, processing, canning, and distribution of foods.

- Design and operation of processes involving heat transfer requires special attention, due to the heat-sensitivity of foods.

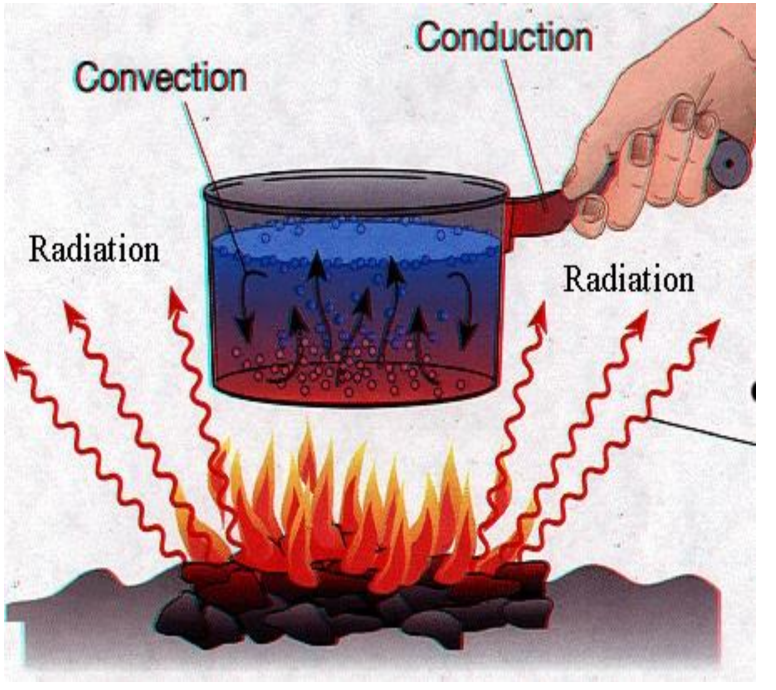
Heat transfer

- Heat transfer involves the transfer of heat into or out of a food.

three ways that heat can be transferred:

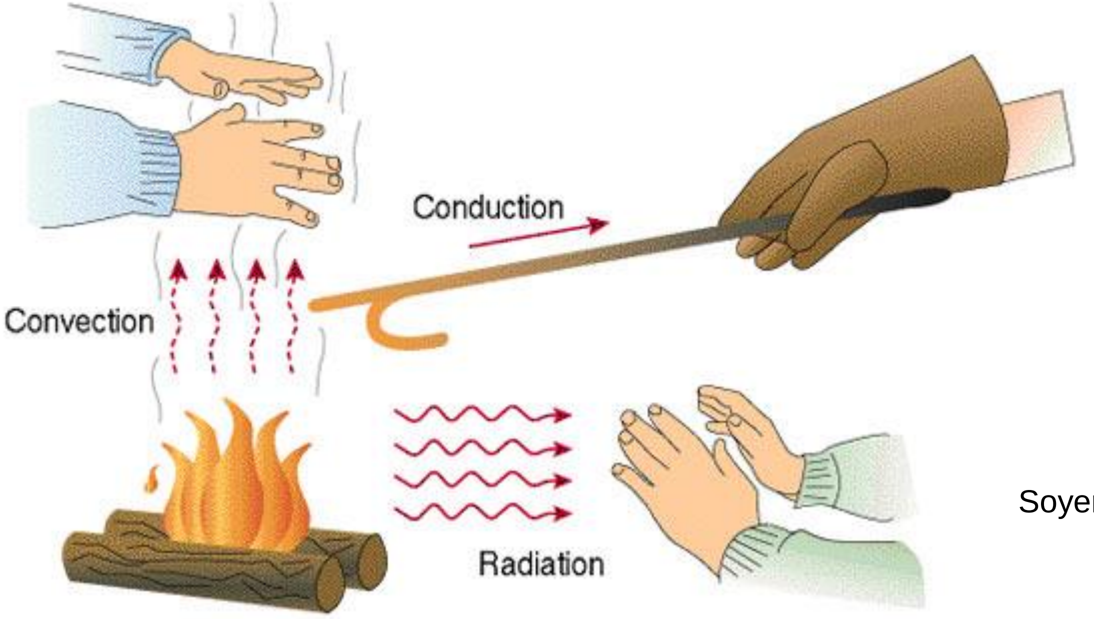
- radiation,
- conduction,
- convection.

Heat transfer



Heat transfer by:

- Conduction
- Convection
- Radiation



Soyer,A. Thermal properties of Foods

Heat transfer by conduction

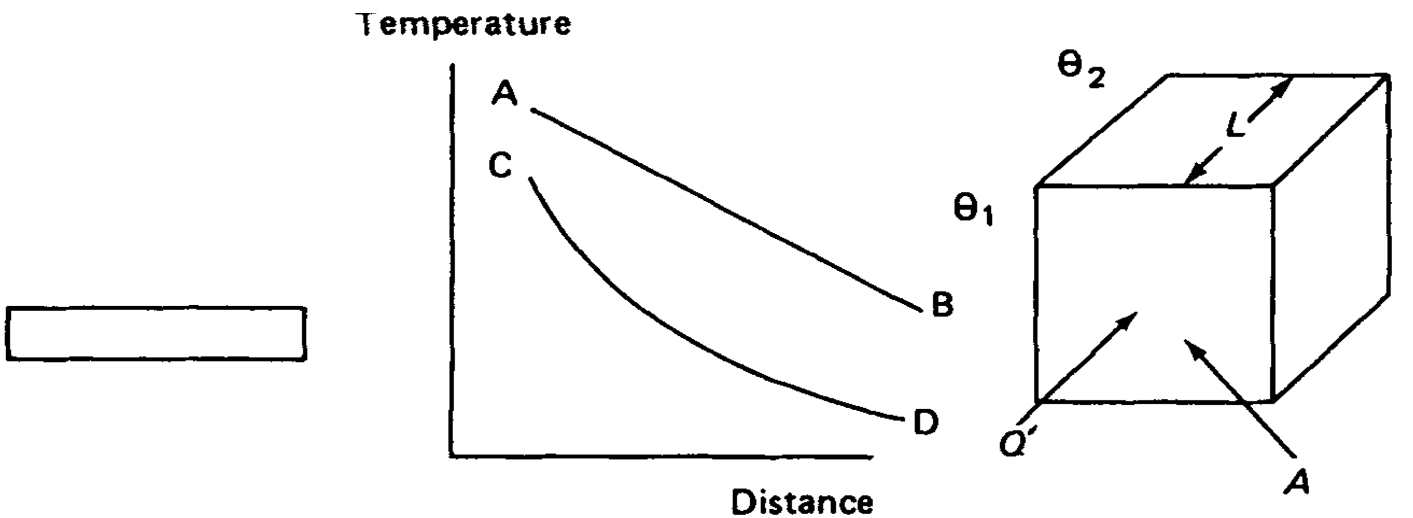
- If one end of a metallic bar is heated, the kinetic energy of the molecules increases and the temperature rises. A temperature gradient will be set up and heat will be transferred along the bar.

- Materials differ in their capacity to conduct heat, metals being

- generally much better conductors than non-metals. The property used to quantify the ability of a substance to conduct heat is known as **thermal conductivity**.

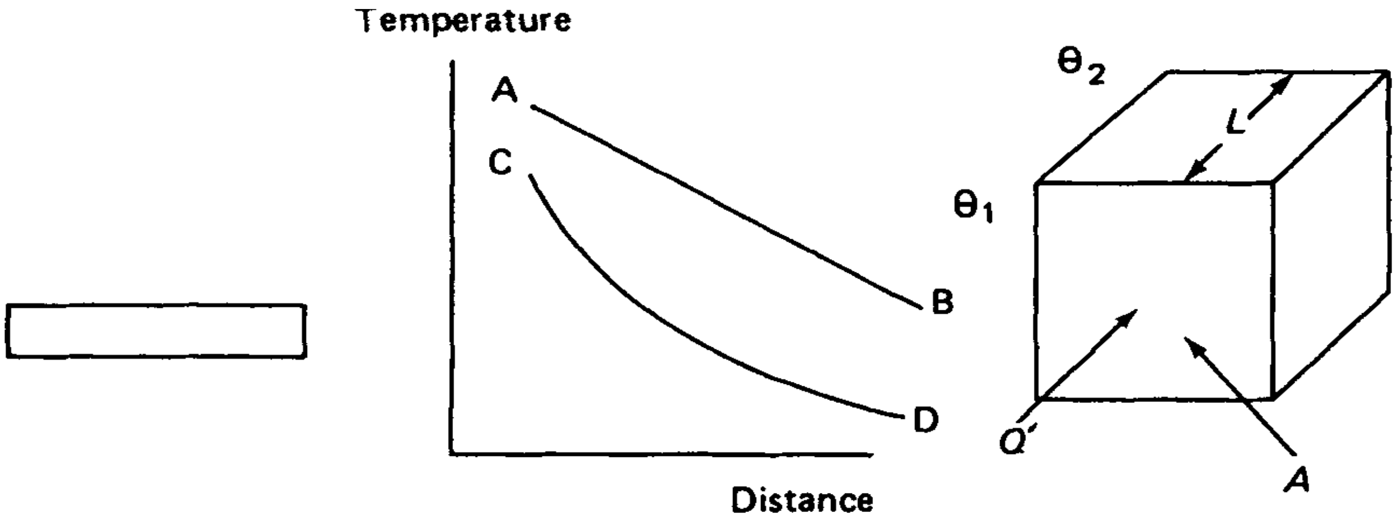
- Thermal conductivity provides a means of quantifying the heat transfer properties of a solid material.

Steady- and Unsteady-state Heat Transfer



(a) (b)

Steady- and Unsteady-state Heat Transfer



(a) (b)

FOURIER'S LAW OF HEAT CONDUCTION

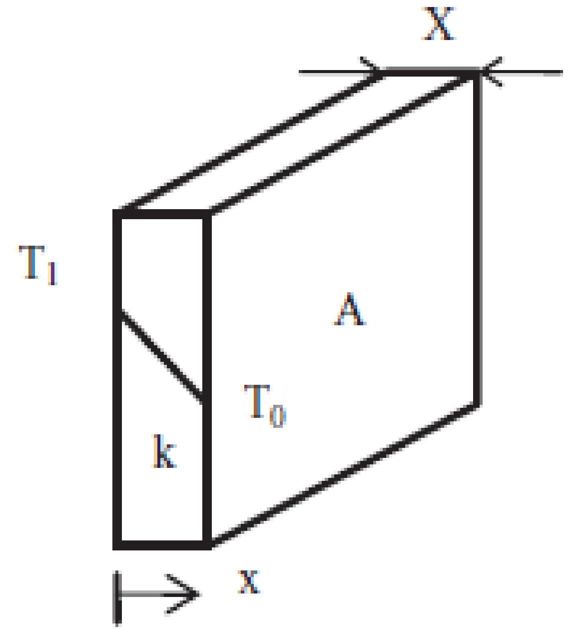
- We need a driving force to overcome a resistance in order to transfer a property. For any kind of molecular transport processes (momentum, heat or thermal energy, and mass) the general equation can be written as follows:

- Rate of a transfer process = $\frac{\text{Driving force}}{\text{Resistance}}$

- Finally, linear steady-state temperature distribution is achieved as shown in Fig.
- The driving force for the heat transfer to occur is the temperature difference:

  Driving force = $T_1 - T_0$
- When the steady-state condition has been reached, the rate of heat flow (Q) through the wall can be written:

$$Q = kA\,\frac{T_1 - T_0}{X}$$



Steady-state heat transfer through the wall.

This equation in differential form gives Fourier's law of heat conduction:

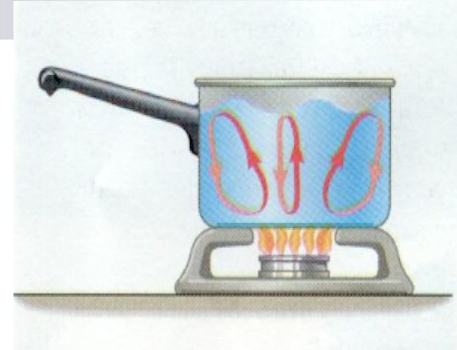
$$Q_x = -kA\,\frac{dT}{dx}$$

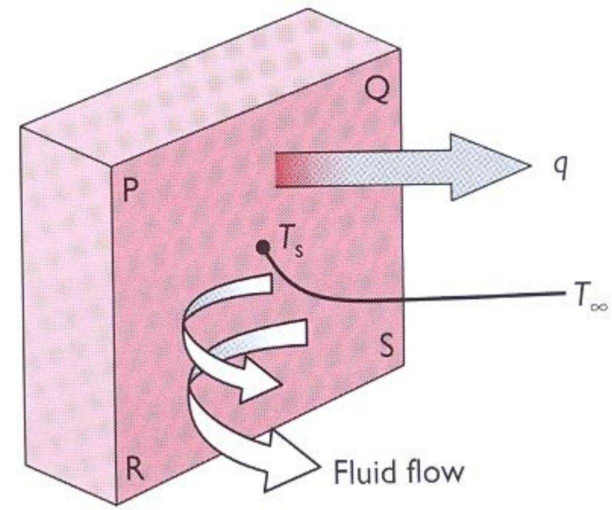
Q_x : The rate of heat flow in the x-direction, W
k : Thermal conductivity, W/m K
A : The heat transfer area, m2
dT: Temperature difference, K
x: The thickness of the wall, m

Example 1. One surface of a 20 cm thick brick wall is kept constant at 35^oC and the other surface at 10^oC. Since the thermal conductivity coefficient of the brick is 0.7 W/m K, calculate the amount of heat transferred from 1 m^2 wall area.

Heat transfer by convection

- Convective heat transfer is the transfer of heat between two bodies by currents of moving gas or fluid.
- As the fluid flows over a solid surface, a heat exchange always takes place as long as there is a temperature difference between the fluid and the solid surface.
- During the heating and cooling of gases and liquids, the movement of the fluid changes heat at the solid surface by convection.



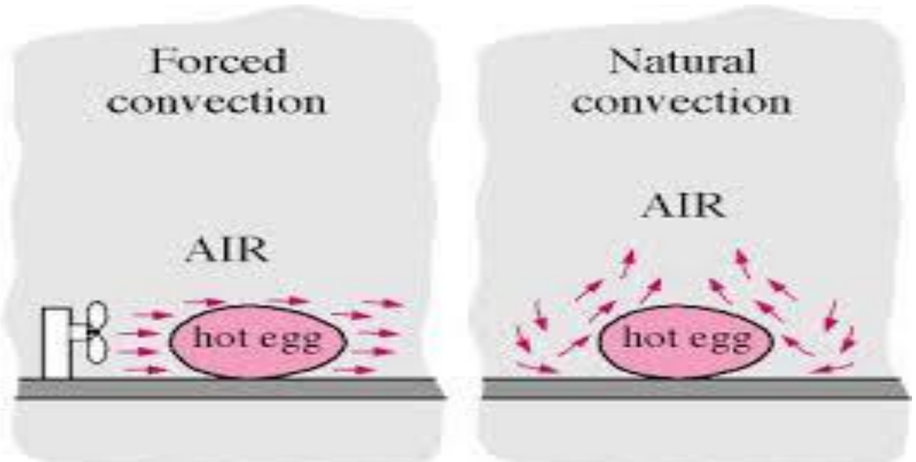


Convective heat flow from a flat surface

Types of Convection

1. Forced convection
2. Natural convection

- Forced convection: when the fluid is forced to flow over the surface by external means such as a fan, pump or wind.
- Natural (or free) convection: when fluid flow is caused by buoyancy forces that are introduced by density differences due to variation of temperature of the fluid.

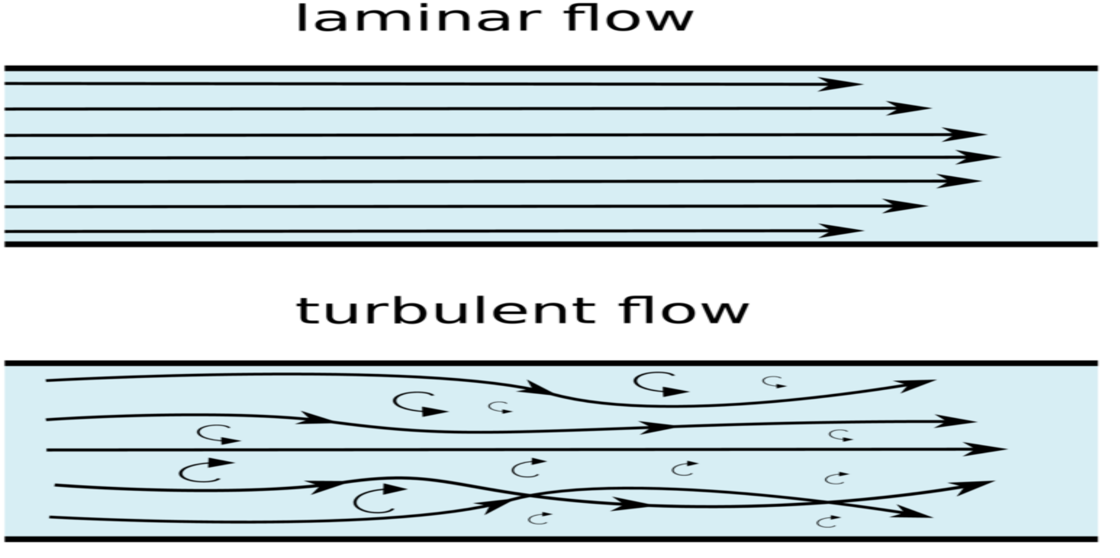


Flow regimes

- Laminar flow
- Turbulent flow

Laminar flow: If the flow is smooth and if the layers in the flow do not mix macroscopically then the flow is called laminar flow. In laminar flow layers will glide over each other without mixing.

Turbulent flow: Fluid layers mix macroscopically and the velocity/temperature/mass concentration at any point is found to vary over a time period.



Convective heat transfer mechanism

- Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate).

The rate of convection heat transfer is expressed by Newton's law of cooling:

$$Q_{conv} = h\, A_s\, (T_s - T_\infty)$$

Q_{conv}= Transfer olan ısı, W

h=The convection heat transfer coefficient, W/m^2 ^{o}C

A_s= Heat surface area, m^2

T_s = The temperature of solid surface, ^{o}C

T_∞= The temperature of fluid, ^{o}C

$(T_s - T_\infty)$= temperature gradient

Convective heat transfer mechanism

- Convective Heat Transfer Coefficient
- As can be seen, the constant of proportionality will be crucial in calculations and it is known as the convective heat transfer coefficient, h.
- The convective heat transfer coefficient, h, can be defined as:

The rate of heat transfer between a solid surface and a fluid per unit surface area per unit temperature difference.

$$h = \frac{q}{\Delta T}$$

where

q is the local heat flux density [$W.m^{-2}$]

h is the heat transfer coefficient [$W.m^{-2}.K$]

ΔT is the temperature difference [K]

Convective heat transfer

- The convective heat transfer coefficient h strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent).

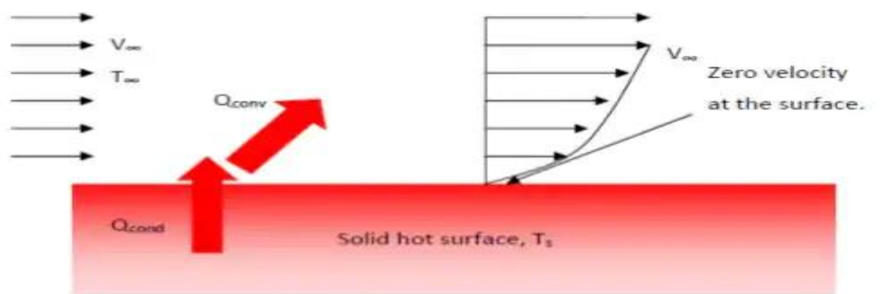


fig. Forced convection

- It is assumed that the velocity of the fluid is zero at the wall, this assumption is called **no-slip** condition.

- As a result, the heat transfer from the solid surface to the fluid layer adjacent to the surface is by pure conduction, since the fluid is motionless.

Convective heat transfer values

Typical values of the convective heat transfer	
Process	h $(W/m^2 \cdot K)$
Free convection	
Gases	2 - 20
Liquids	50 - 1000
Forced convection	
Gases	25 - 300
Liquids	100 - 40,000
Convection with phase change	
Boiling or condensation	2500 - 100,000

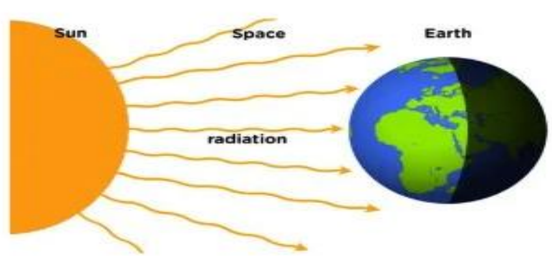
Heat transfer by radiation

- Energy of radiation transferred in the form of electromagnetic waves.

- Radiation mode of heat transfer is independent of medium.
- It occurs more effectively in vacuum.

Radiation continues....

- We can feel the heat of the Sun, although it is 150 million km away from the Earth.
- Because no particles are involved while reaching the heat from sun to earth.



Heat transfer by radiation

- Some type of materials will emit radiation when they are treated by external agencies.

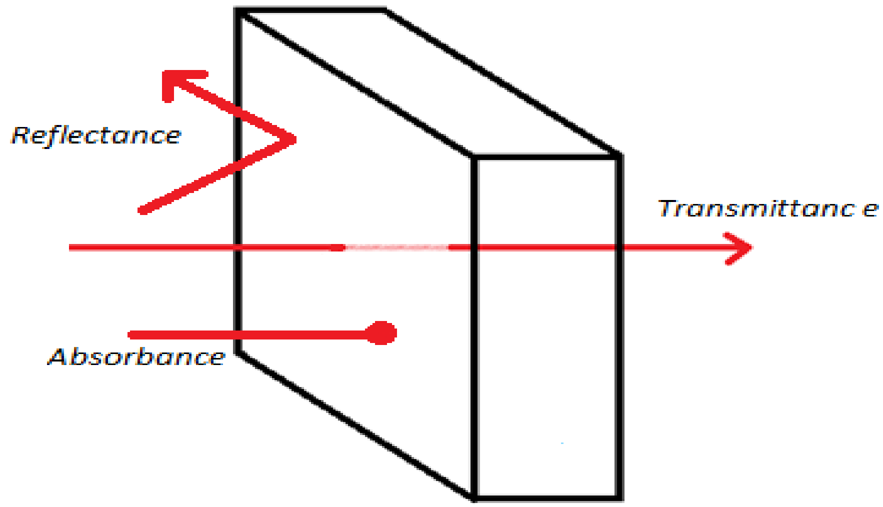
- All substances at temperatures above absolute zero emit radiation that is independent of external agencies.

- Radiation that is the result of temperature only is called

«thermal radiation»

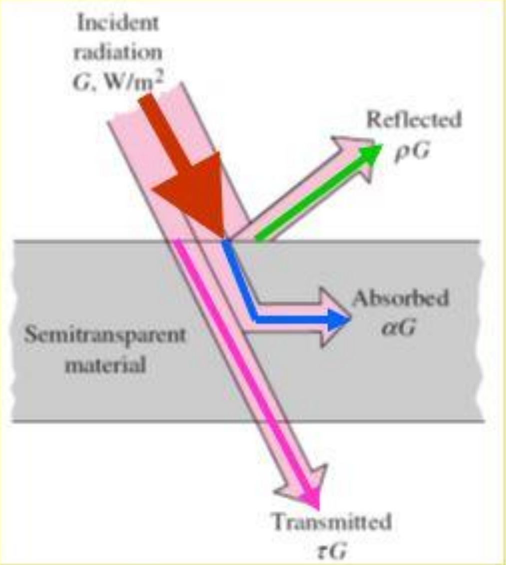
Some definitions:

- The fraction that is absorbed is called absorptivity.
- The fraction that is transmitted is called transmissivitiy.
- The fraction of the radiation falling on a body that is reflected is called reflectivity



Absorptivity, Reflectivity, and Transmissivity

- When **radiation** strikes a surface, part of it:
  - is absorbed (**absorptivity**, α),
  - is reflected (**reflectivity**, ρ),
  - and the remaining part, if any, is transmitted (**transmissivity**, τ).



- *Absorptivity:* $$\alpha = \frac{\text{Absorbed radiation}}{\text{Incident radiation}} = \frac{G_{abs}}{G} \quad \textbf{(12-37)}$$
- *Reflectivity:* $$\rho = \frac{\text{Reflected radiation}}{\text{Incident radiation}} = \frac{G_{ref}}{G} \quad \textbf{(12-38)}$$
- *Transmissivity:* $$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}} = \frac{G_{tr}}{G} \quad \textbf{(12-39)}$$