الجامعة التكنولوجية

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Ministry of Higher Education
And
Scientific Research

University Of Technology
Chemical Engineering Department

Heat Transfer

Third Year

By

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2008-2009

University of Technology

Chemical Engineering Department **Third Year B.S.Syllabus**

Heat Transfer

Units: 7
Theoretical: 3 hr/week
Tutorial: 1 hr/week
Practical: 2 hr/week

1. **Modes of Heat Transfer:**

Conduction, Convection and Radiation .

(2 hrs)

2. **Steady State Heat Conduction in One Dimension:**

Plane wall, radial systems, heat source systems. Boundary surrounded by fluids. Overall heat transfer coefficient. Extended surface, conduction-convection systems, fins.

(24 hrs)

3. **Principles of Convection:**

Transport equations. Fluid mechanism aspect of convection. Laminar boundary layer. Thermal boundary layer. Empirical and practical relations for pipe and tube flow. Flow normal to single and tube banks.

(18 hrs)

4. **Heat Exchangers:**

Various types and their general characteristics. Fouling factor. Heat exchangers mean temperature differences. Co-current and counter-current flow.

(12 hrs)

5. **Shell and Tube Exchangers:**

Types and various specifications. Design calculations by conventional and by effectiveness (NTU) methods. Optimum design calculation.

(6 hrs)

6. **Condensation and Boiling Heat Transfer:**

Condensation of single vapors. Design calculations for condenser, condenser-subcooler and superheated condenser.

(9 hrs)

7. **Radiation and Furnace design:**

Radiation properties, shape factor, heat exchange for non black bodies, parallel planes, shields, gas tradition, boiler.

(9 hrs)

8. <u>Unsteady State Heat Transfer</u>:
Temperature as a function of time, lumped capacity system, quenching of small bodies, heating of tank reactor.

(10 hrs)

BASICS OF HEAT TRANSFER

Difference between heat and temperature in describing heat transfer problems, we often makes the mistake of interchangeably using the terms heat and temperature. Actually, there is a distinct difference between the two.

Temperature is a measure of the amount of energy possessed by the molecules of a substance. It is a relative measure of how hot or cold a substance is and can be used to predict the direction of heat transfer. The usual symbol for temperature is T. The scales for measuring temperature in SI units are the Celsius a Kelvin temperature scales.

On the other hand, heat is energy in transit. The transfer of energy as heat occurs at the molecular level as a result of a temperature difference. The usual symbol for heat is (q). Common units for measuring heat are the Joule and calorie in the SI system.

What is Heat Transfer?

"Energy in transit due to temperature difference."

1.1 Difference Between Thermodynamics and Heat Transfer

Thermodynamics tells us:

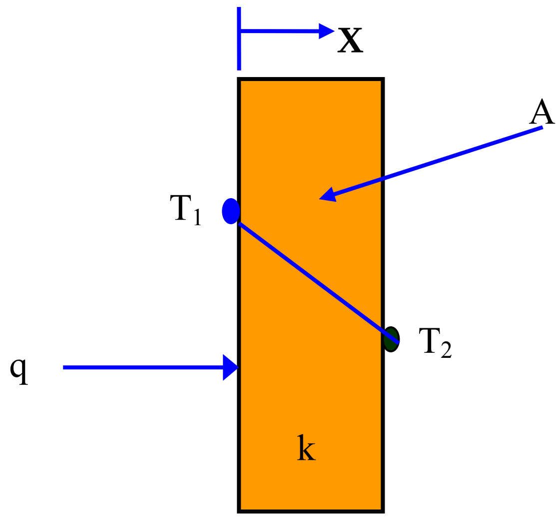
- How much heat is transferred (Q).
- How much work is done (W).
- Final state of the system.

Heat transfer tells us:

- How (with what modes) (q) is transferred.
- At what rate (q) is transferred.
- Temperature distribution inside the body.

1.2 Modes of Heat Transfer

• Conduction: An energy transfer across a system boundary due to a temperature difference by the mechanism of inter-molecular interactions. Conduction needs matter and does not require any bulk motion of matter.



Conduction rate equation is described by the Fourier Law:

$$q = -kA\frac{dT}{dx} \qquad \text{Fourier's Law}$$

Where

q: Heat transfer rate ,J/sec,W

k: Thermal conductivity,W/m.C^{o},W/m.k

A: Cross sectional area in direction of heat flow. (m^2)

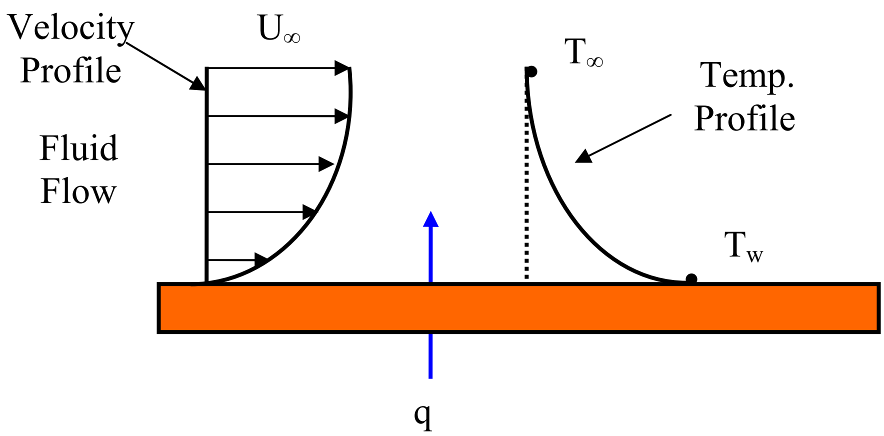
T: Temperature, C_o, k

X: Thickness ,m

$\frac{\partial T}{\partial x}$: Temperature gradient in the direction of the heat flow, C_o/m

The minus sign is inserted so that the second principle of thermodynamics will be satisfied, i.e., heat must flow downhill on the temperature scale.

• **Convection**: An energy transfer across a system boundary due to a temperature difference by the combined mechanisms of intermolecular interactions and bulk transport. Convection needs fluid matter.



To express the overall effect of convection we use Newton's law of cooling:

$$q = h\,A\,(T_w - T_\infty) \qquad \text{Newton's law}$$

Where:

q: Heat transfer rate, J/sec,W

h: Heat Transfer coefficient,$W/m^2.C^o$,$W/m^2.k$

A: Surface area from which convection is occurring, (m^2)

T_w: Temperature of surface ,C^o, k

T_∞: Temperature of fluid, C^o,

Convection: → Free or natural convection
→ Forced convection

Table 1. Typical values of h (W/m^2K)

Free convection	Gases: 2 - 25 Liquid: 50 – 100
Forced convection	Gases: 25 - 250 Liquid: 50 -20,000
Boiling/Condensation	2500 -100,000

• **Radiation**: Radiation heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of the body.

When two bodies exchange heat by radiation, the net heat exchange is then proportional to the difference in (T^4).Thus

$$q = \sigma A\left(T_1^{\,4} - T_2^{\,4}\right) \quad \text{Maxwell's law}$$

Where

q: Heat transfer rate, J/sec, W

σ: Stefan Boltzmann constant = 5.67 x 10^{-8} $W/m^2\,k^4$

A: Surface area,m^2

T_1: Absolute temperature of surface, (k)

T_2: Absolute temperature of surroundings, (k)

To take account of the (gray) nature of such surfaces we introduce another factor into Maxwell's law, called the emissivity (ε), which relates the radiation of the (gray) surface to that of an ideal black surface. In addition ,we must take into account the fact that not all the radiation leaving one surface will reach the other surface since electromagnetic radiation travels in straight lines and some will be lost to the surrounding .so that

$$q = \sigma A \varepsilon a Cos\ \theta \left(T_1^4 - T_2^4\right)$$

Where
ε: Surface Emissivity $0 < \varepsilon, a, Cos\theta < 1$
a: Absorptivity

1.3 Thermal Conductivity, k

As noted previously, thermal conductivity is a thermodynamic property of a material. From the State Postulate given in thermodynamics, it may be recalled that thermodynamic properties of pure substances are functions of two independent thermodynamic intensive properties, say temperature and pressure. Thermal conductivity of real gases is largely independent of pressure and may be considered a function of temperature alone. For solids and liquids, properties are largely independent of pressure and depend on temperature alone.

$$k = k\,(T)$$

Table2. Thermal Conductivities of Selected Materials at Room

Material	Thermal Conductivity, W/m. K
Copper	401
Silver	429
Gold	317
Aluminum	237
Steel	60.5
Limestone	2.15
Bakelite	1.4
Water	0.613
Air	0.0263

It is important that the student gain a basic perspective of the magnitude of thermal conductivity for various materials. The background for this comes from the introductory Chemistry courses. Molecules of various materials gain energy through various mechanisms. Gases exhibit energy through the kinetic energy of the molecule. Energy is gained or lost through collusions of gaseous molecules as they travel through the medium.

Solids, being are much more stationary, cannot effectively transfer energy through these same mechanisms. Instead, solids may exhibit energy through vibration or rotation of the nucleus. Another important mechanism in which materials maintain energy is by shifting electrons into higher orbital rings. In the case of electrical conductors the electrons are weakly bonded to the molecule and can drift from one molecule to another transporting their energy with them. This is an especially effective transport mechanism, so that materials which are excellent electrical conductors are excellent thermal conductors.

Example 1.1:

One face of a copper plate (3cm) thick is maintained at ($400C^o$), and the other face maintained at ($100C^o$).How much heat is transferred through the plate? Given thermal conductivity of copper is ($370\ W/m.C^o$)

Solution

$$\frac{q}{A} = -k\frac{dT}{dx} \qquad \text{Fourier's law}$$

Integrating gives

$$\frac{q}{A} = -k\frac{\Delta T}{\Delta X} = \frac{-(370)(100-400)}{(3*10^{-2})} = 3.7\ \text{MW/m}^2$$

Example 1.2:

Air at ($20C^o$) blows over a hot plate (50 by 75 cm) maintained at ($250C^o$).The convection heat transfer coefficient is ($25\ W/m^2.C^o$).Calculate the heat transfer, neglected heat transfer by radiation

Solution

$$q = hA(T_W - T_\infty) \qquad \text{Newton's law}$$

$$q = (25)(0.5*0.75)(250-20) = 2.1\ \text{kW}$$

Example 1.3:

Assuming that the plate in Example 1.2 is made of carbon steel(1%) 2 cm thick and that (300W)is lost from the plate surface by radiation, calculate the inside plate temperature Given thermal conductivity of carbon steel(1%) is (43 W/m.C^o).

Solution

The heat conducted through the plate must be equal to the sum of convection and radiation heat losses.

$$q_{Conduction} = q_{Convection} + q_{Radiation}$$

$$-kA\frac{\Delta T}{\Delta x} = hA(T_w - T_\infty) + \sigma A(T_1^4 - T_2^4)$$

$$-kA\frac{\Delta T}{\Delta x} = 2.156 * 10^3 + 300$$

$$T_1 - 250 = \frac{(2456)(0.02)}{(0.5)(0.75)(43)} = 3.05$$

$$T_1 = 3.05 + 250 = 253.05C^o$$