Al.Mustaqbal University

College of engineering and technology

chemical and petroleum industrial Department

class –three   Term-1

Heat transfer – Code No. UOMU0102051

week-1 Introduction on Heat transfer

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- **INTRODUCTION**
  Temperature scales
  Conduction Heat Transfer
  Thermal Conductivity
  Convection Heat Transfer
  Radiation Heat Transfer

INTRODUCTION

- **Energy:** energy can be exit is different forms (types). They are thermal energy, chemical energy, mechanical energy, potential energy, kinetic energy, electrical energy, magnetic, energy, nuclear energy and etc.
- **Specific heat of gases, liquids and solid:** The specific heat is defined as the energy to rising the temperature of unit mass of material one degree ^{o}C

There are two specific heats for the gases. They are: Specific heat at constant pressure which is denoted as Cp, and specific heat at constant volume Cv.

INTRODUCTION

The change in internal energy of system is

$\Delta U = mCv(T_2 - T_1)$ kJ

Where: ΔU= the change in internal energy of the system, m=mass of the system, Cv=specific heat at constant volume, T_1, T_2 are initial and final temperature of the system

- The change in enthalpy of the system is
- $\Delta H = mCp(T_2 - T_1)$ kJ
- Where ΔH= the change in enthalpy of the system, Cp= specific heat at constant pressure.

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The relations between Cp and Cv are

$$Cp - Cv = R, \quad k = \frac{Cp}{Cv}$$

Where R= gas constant, and k specific heat ratio

The unit of specific heat is [kJ/kg.K]

In general liquids and solids are considered incompressible material. They have only one specific heat denoted as C or Cp so the change in internal energy and enthalpy of liquids and solids can be expressed as:

INTRODUCTION

$$\Delta U = \Delta H = mC\Delta T$$

The heat transfer to the system is the change in enthalpy for constant pressure process or the change in internal energy for constant volume process.

$Q = \Delta H = mCp(T_2 - T_1)$ For constant pressure

$Q = \Delta U = mCv(T_2 - T_1)$ For constant volume

For liquids and solids

$Q = mC(T_2 - T_1)$

INTRODUCTION

- Ex.1. **5kg of air is heated at constant volume in the tank of rigid volume from 20°C to 80°C. Find the heat transfer to the air if Cv=0.718kJ/kg.K**
- **Solution**: air m=5kg, T_1=20°C, T_2=80°C, Cv=0.718kJ/kg.K . It is heated at constant volume.
- **Requirements**: heat transfer Q
- **Analysis**
- $Q = mCv(T_2 - T_1) =$
- $=5 \times 0.718(80 - 20) = \mathbf{215.4}\boldsymbol{kJ}$

INTRODUCTION

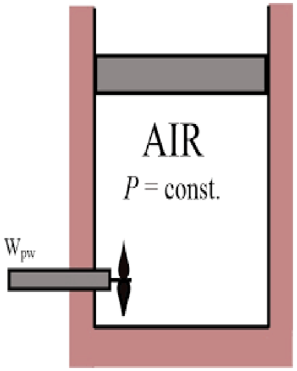
Ex.2. **5kg of air is heated in piston cylinder device at constant pressure from 20°C to 80°C. Find the heat transfer to the air if Cp=1.005kJ/kg.K**

Solution: air m=5kg, T_1=20°C, T_2=80°C, Cp=1.005kJ/kg.K. It is heated at constant pressure

Requirements: heat transfer to the air at constant pressure

$$Q = mCp(T_2 - T_1)$$

$$= 5 \times 1.005(80 - 20) = \mathbf{301.5}\boldsymbol{kJ}$$



INTRODUCTION

Ex.3. **5kg of water is heat in the vessel from 20^{o}C to 80^{o}C. Find the heat transfer to the water if C=4.2kJ/kg.K**

Solution: water, m=5kg, T_1=20^{o}C, T_2=80^{o}C, C=4.2kJ/kg.K

Requirements: heat transfer to water

$$Q = mC(T_2 - T_1)$$

$$= 5 \times 4.2(80 - 20) = \mathbf{1260kJ}$$

INTRODUCTION

- **Heat Transfer:**

There two mechanisms for energy to transfer from or to the system. They work and heat.

In thermodynamic we will study how energy transfers as a work in different types of processes. Energy transferred due to temperature difference is heat transfer. Which is denoted as Q. heat transfer per unit time is called heat transfer rate (or rate of heat transfer) and is denoted as $\dot{Q}$.

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$$Q = \int_0^{\tau} \dot{Q} d\tau \quad \text{or} \quad Q = \int_{\tau_1}^{\tau_2} \dot{Q} d\tau$$

- If $\dot{Q} = constant$
- Then $Q = \dot{Q}(\tau - 0) = \dot{Q}\tau$

  or $Q = \dot{Q}(\tau_2 - \tau_1) = \dot{Q}\Delta\tau$
- The unit of rate of heat transfer is [J/s] or [W] or sometimes kW
- Heat flux: the rate of heat transfer per unit area normal to direction of heat transfer is called $\dot{q}$ and it is: $\dot{q} = \frac{\dot{Q}}{A}$

INTRODUCTION

- **Ex.4. A copper ball of diameter 10cm is to be heated from a temperature 20°C to a temperature 70°C in 30minutes. The average specific heat and density of copper in this range of temperature are 0.395kJ/kg.K and 8950kg/m^3, respectively. Determine: (i) The heat transfer to the ball. (ii) The rate of heat transfer to the ball. (iii) The heat flux.**
- Solution: copper Ball D=10cm=0.1m, T_1=20°C, T_2=70°C, τ=30min=1800sec,
- Properties: density of copper ρ=8950kg/m^3, specific heat C=0.395kJ/kg.K,

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Analysis: the heat transfer to the ball is

$Q = mC(T_2 - T_1)$

m is the mass of the ball

$$m = V \times \rho = \frac{4}{3}\pi r^3 \times \rho = \frac{4}{3}\pi\left(\frac{0.1}{2}\right)^3 \times 8950 = 4.686kg$$

$$Q = mC(T_2 - T_1) = 4.686 \times 0.395 \times (70 - 20) = 92.55kJ$$

The rate of heat transfer

$$Q = \dot{Q}\tau \rightarrow \dot{Q} = \frac{Q}{\tau} = \frac{92.55}{1800} = 0.0514kW = 51.4W$$

The heat flux is $\dot{q} = \frac{\dot{Q}}{A}$

Where A=surface area of the ball,

$$A = 4\pi r^2 = 4\pi\left(\frac{0.1}{2}\right)^2 = 0.0314m^2$$

$$\dot{q} = \frac{\dot{Q}}{A} = \frac{51.4}{0.0314} = 1636.1W/m^2$$

INTRODUCTION

- **Temperature Scale**

The temperature is the measurement of how much the body hotness or coldness. The temperature is measured by to system of temperature measurement

1. Clauses system of temperature measurement in which

- Temperature of freezing of water is $T_f=0^oC$
- Temperature of boiling of water is $T_b=100^oC$

2. English (Fahrenheit) system of temperature measurement in which

- Temperature of freezing of water is $T_f=32^oF$
- Temperature of boiling of water is $T_b=212^oF$
- The relation between these two systems of temperature scales is

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°C	0	100
°F	32	212

- $\frac{F-32}{212-32} = \frac{C-0}{100-0} \rightarrow F - 32 = \frac{180}{100}C$
- $F = 1.8C + 32 = \frac{9}{5}C + 32$
- Or $C = \frac{1}{1.8}(F - 32) = \frac{5}{9}(F - 32)$
- The absolute Temperature with Clauses is Kelvin and is denoted as K
- K=273+°C

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Ex.5. **Convert 100ºF to ºC, and find the temperature that equal in the two scales**

Solution: to convert 100ºF to ºC

$$C = \frac{1}{1.8}(F - 32) = \frac{1}{1.8}(100 - 32) = 37.778^{o}\text{C}$$

The temperature which is same in the two systems.

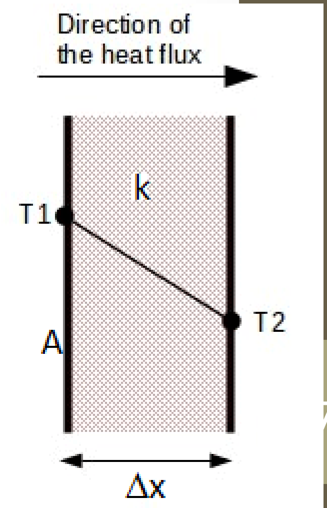
We can use any one of the upper relation and put the C=F

- $F = 1.8C + 32 \rightarrow F = 1.8F + 32$
- $-0.8F = 32 \rightarrow F = \frac{-32}{0.8} = -40^{o}\text{F}$

INTRODUCTION

- Heat Transfer Mechanisms
- The heat is transferring by the mechanisms:
- 1. Conduction, 2. Convection, 3. Radiation

Conduction: The rate of heat transfer by conduction through a medium depends on the geometry of the medium, its thickness, the material of the medium, as well as the temperature difference across the medium. As we show in the figure



$$rate\ of\ heat\ conduction \propto \left(\frac{(area)(temperature\ difference)}{thickness}\right)$$

$$\dot{Q}_{cond} \propto \left(\frac{A\Delta T}{\Delta X}\right)$$

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- $\dot{Q}_{cond} = -k\left(\frac{A\Delta T}{\Delta X}\right)$

$$\dot{Q}_{cond} = -kA\frac{(T_2 - T_1)}{\Delta x} = kA\frac{(T_1 - T_2)}{\Delta X}$$

Where k is the proportionality constant is defined as the thermal conductivity of the material which is the measure of the ability of the material to conduct heat. It is a property of the material. The upper equation can be written in a differential form as

$$\dot{Q}_{cond} = -kA\frac{dT}{dx}$$

This is heat conduction law. It is called Fourier's law.

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Ex.6. A wall of brick is of thickness 25cm, and cross-sectional area 10m^2. The temperature of inside surface of the wall is 24^{o}C and the temperature of the outside surface of the wall is 48^{o}C. Find the rate of heat transfer by conduction if the thermal conductivity of the brick is 0.78W/m.^{o}C

Solution: A wall, Δx=25cm=0.25m, A=10m^2, T_1=48^{o}C, T_2=24^{o}C, k=0.78W/m.K.

Requirement: the rate of heat transfer $\dot{Q}_{cond}$

Analysis: the rate of heat transfer by conduction is

$$\dot{Q}_{cond} = kA\frac{(T_1 - T_2)}{\Delta X} = 0.78 \times 10\,\frac{(48-24)}{0.25}$$

$$= 748.8W = 0.7488kW$$

INTRODUCTION

- Thermal Conductivity: It is a property of material. The material of high thermal conductivity is good conductance. The material of low thermal conductivity is insulations. The gases usually have very low thermal conductivity and metals have high thermal conductivity. Some materials have very low conductivity like wood, glass wool. The values of thermal conductivity change by 10^4 between different substances like in the following table.

Material	K, W/m.K	Material	K, W/m.K
Aluminum	237	Iron	80.2
Brick	0.78	Mercury (Liquid)	8.54
Copper	401	R-12	0.026
Diamond	2300	Rigid foam	0.72
Gold	317	Silver	429
Glass	0.78	Soft rubber	0.13
Glass fiber	0.043	Water (liquid)	0.613
Helium(gas)	0.152	Wood(oak)	0.17
Human Skin	0.37	Air (gas)	0.026

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Convection: It is a mode by which energy transfer between a solid surface and the adjacent liquid or gas that is motion and it involves the combined effects of fluid motion and conduction.

Convection is of two types. They free and forced convection. Free (natural) convection is occurred when the fluid motion is caused by forces of buoyancy that are induced due to differences of density by the temperature variation of the fluid. Forced convection is occurred when the fluid is flow under force over the surface by external mechanisms such as fan, pump, or the wind.

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- The rate of heat transfer by convection is observed that proportional to temperature difference and the heat transfer area:

$$\dot{Q}_{conv} \propto A(T_s - T_\infty)$$

- And by using the proportionality constant, it becomes

$$\dot{Q}_{conv} = hA(T_s - T_\infty)$$

- Where h is defined as the coefficient of heat transfer by convection of unit [W/m^2.^{o}C]. A is the area of the surface through which convection of heat transfer take place. T_s, T_∞ are the surface temperature and the fluid temperature that far from the surface with sufficient distance.

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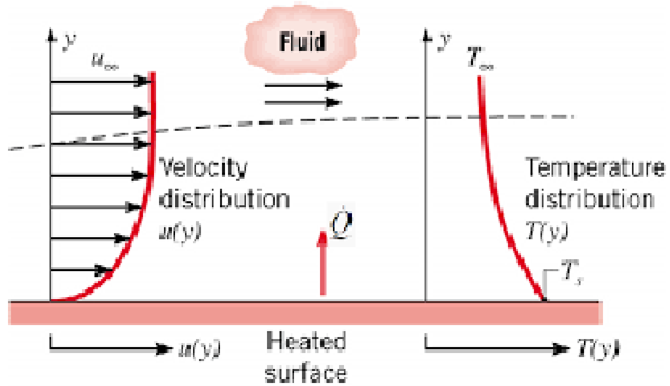

Coefficient of heat transfer by convection, h is not property of the fluid. It is a parameter which is determined experimentally. It is function of geometry of the surface, nature of fluid, properties and velocity of fluid. The following table gives typical coefficient of convection heat transfer.

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Type of Convection	h, $W/m^2.^oC$
Gases, Free Convection	2-25
Liquids, Free Convection	10-1000
Gases, Forced Convection	25-250
Liquids, Forced Convection	50-20000
Condensation and Boiling	2500-100000

- **Ex.7. determine the rate of heat transfer by convection from a surface with area of $2m^2$ and temperature of 100^oC to the air of temperature 25^oC. The convection heat transfer coefficient is $20W/m^2.^oC$.**

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- **Solution:** heat transfer from surface to air, $A=2m^2$, $T_s=100^oC$, $T_\infty=25^oC$, $h=20W/m^2.^oC$.
- **Requirement**: heat transfer rate by convection
- **Analysis:** $\dot{Q}_{conv} = hA(T_s - T_\infty) = 20 \times 2(100 - 25) = 3000W = 3kW$

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- **Radiation:** Radiation is energy that emitted by a matter in the form of electromagnetic waves (photons) as a result of the change in the electronic configuration of the atoms or molecules. Not same as that in conduction and convection, the energy transfer by radiation does not require the existence of medium. In fact, energy transfer by radiation is faster (its speed is the light speed) and doesn't effect by vacuum. This is exactly how the energy transfers from the sun to reach the earth.
- The calculation the exchange of heat between two surfaces of absolute temperatures T_1 and T_2 respectively by radiation by the following relation.

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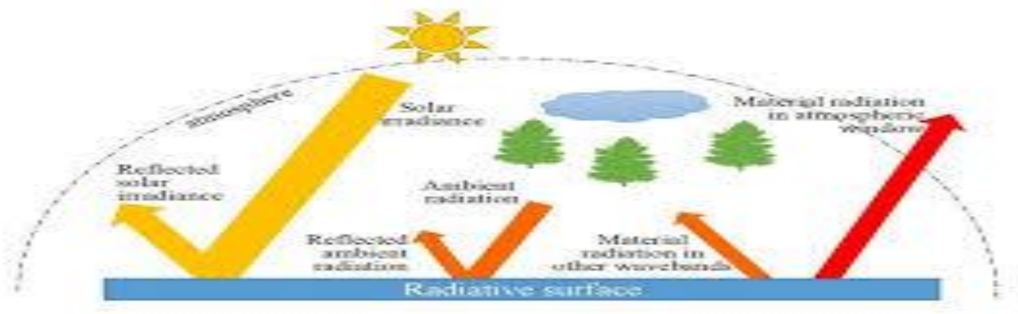

- $\dot{Q}_{rad} = \varepsilon \sigma A (T_2^4 - T_1^4)$
- Where: ε is emissivity of the surface and is less than unity.
- σ is Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8} W/m^2.K^4$
- A is the surface area that emits heat
- T_1, T_2 are the surfaces temperature in K (adding 273)

INTRODUCTION

- **Radiation heat transfer Coefficient**
- It is very useful to put the heat transfer by radiation relation in form look like that of heat transfer by convection:
- $\dot{Q}_{rad} = \varepsilon\sigma A(T_2^2 + T_1^2)(T_2 + T_1)(T_2 - T_1) = h_r A(T_2 - T_1)$
- $h_r = \varepsilon\sigma(T_2^2 + T_1^2)(T_2 + T_1)$

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- Ex.7. A plate at temperature 127°C with area of 1.2m^2 and emissivity of 0.92 exchange heat by radiation with a wall of room at 27°C. Find the heat transfer coefficient of radiation between plate and the wall, and the rate of the heat transfer by radiation.
- Solution: two surfaces A=1.2m^2, T_2=127°C=400K, T_1=27°C=300K, ε=0.92
- And we know that σ=5.67x10^{-8}W/m^2.K^4
- Requirements: heat transfer coefficient of radiation h_r, heat transfer by radiation $\dot{Q}_r$.
- Analysis:
- $h_r = \varepsilon\sigma(T_2^2 + T_1^2)(T_2 + T_1) =$ $0.92 \times 5.67 \times 10^{-8}(400^2 + 300^2)(400 + 300) = 9.128 W/m^2.{}^{o}C$
- $\dot{Q}_{rad} = Ah_r(T_2 - T_1) = 1.2 \times 9.128(127 - 27) = 1090.444W$