Elements of Mechanical Engineering [21ME1ESEME/21ME2ESEME]

SR

Module 2

Heat transfer applications

Introduction:

Heat is a form of energy that can transfer from one point to another when there is a temperature difference. Process of heat transfer continues till both points reach a state of thermal equilibrium.

Applications of heat transfer: Heat exchangers
Boilers
Condensers
Radiators
Furnaces
Refrigerators
Solar collectors etc.

Modes of heat transfer:

There are three modes of heat transfer:
1. Conduction
2. Convection
3. Radiation

1. Conduction:

Transfer of heat through molecular contact because of collisions between neighboring atoms or molecules (lattice vibrations) is called as conduction.

Conduction occurs more readily in solids and liquids, where molecules are closer together than in gases where particles are further apart.

Conduction heat transfer is governed by Fourier's law of heat conduction.

Fourier's law of heat conduction:

"Amount of heat flow through conduction is directly proportional to the area of section normal to the direction of heat flow, and temperature gradient."

Mathematically, $Q \propto A \cdot \frac{dT}{dx}$ (OR) $\boxed{Q = -KA\frac{dT}{dx}}$

where,
Q = Heat flow in Watts
K = Thermal conductivity of the material in $W/(m^\circ C)$
A = Area of heat flow in m^2
dT/dx = Temperature gradient in $^\circ C/m$

NOTE:

* Negative sign indicates the decreasing temperature along positive x direction.
* K is defined as the amount of heat energy conducted through a unit area, unit thickness and unit temperature difference in unit time.

2. Convection:

Transfer of heat through the combined effect of conduction and mixing motion is called convection.

Faster the fluid motion, the greater is the convection. Convection occurs in fluids and gases. Convection heat transfer is governed by Newton's law of cooling.

Newton's law of Cooling:

"Rate of heat loss in a body is directly proportional to the temperature difference between the body and its surrounding environment."

Mathematically, $\frac{Q}{A} \propto \Delta T$ (OR) $\boxed{Q = hA(T_S - T_\infty)}$

where, Q = Heat flow in Watts

h = Convective heat transfer coefficient in $W/(m^2\,°C)$

A = Area of heat flow in m^2

T_S = Surface temperature in °C

T_∞ = Temperature of the surrounding environment (fluid) in °C

NOTE:

* h is defined as the amount of heat energy transferred through a unit surface area, with unit temperature difference in unit time.

3. Radiation

Transfer of heat through space or matter by means of electromagnetic radiation (waves) is called radiation heat transfer.

Radiation heat transfer requires no medium for propagation. It is governed by Stefan-Boltzmann's law.

Stefan-Boltzmann's law of radiation

"Amount of radiation heat transfer in a black body is directly proportional to the fourth power of absolute temperature".

Mathematically, for a black body, $Q \propto T^4$

OR $\boxed{Q = \sigma \cdot \epsilon \cdot A (T_1^4 - T_2^4)}$

where, Q = Heat flow in Watts

$\sigma = 5.67 \times 10^{-8}\ W/(m^2 K^4)$, Stefan-Boltzmann's constant

ϵ = Emissivity of the surface

A = Area of radiating surface in m^2

T_1 = Absolute temperature of the radiating surface in °K

T_2 = Absolute temperature of the second surface in °K

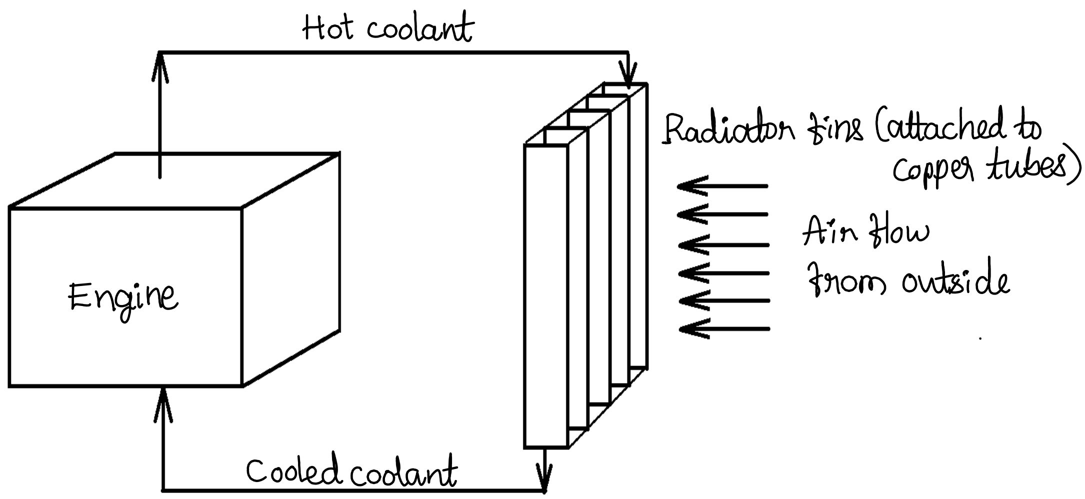
NOTE

* Body which absorbs all incident radiation is called a black body.
* A body that does not absorb all incident radiation (sometimes known as grey body) emits less total energy than a black body and is characterized by an emissivity, $0 < \epsilon < 1$
* Radiation is a nonlinear phenomenon.

Principle of heat transfer in automobile radiators

Radiator is a heat exchanging device for the purpose of cooling or heating. It is used in; (i) automobiles for cooling the engine
(ii) households to heat buildings
(iii) electronics to cool the components/circuitry

The basic working principle of radiator is convection heat transfer. It means, most of the heat is transferred by convection and only a small amount of heat is transferred by radiation.



Engines in vehicles like cars are cooled by water (or coolant) jackets. Prolonged running of the engines leads to the warming of the water in the water (or coolant) pipes which surround the engine. In order to keep the engine running, the water (or coolant) must be cooled down.

When water (or coolant) heats up, it starts to flow in the pipes which are present around the engine. When the warm water (or coolant) flows through these pipes, it is cooled down by the fans. Once the water (or coolant) cools down, it flows back into the engine. Thus convection heat transfer takes place from water (or coolant) to the surroundings with the help of fans.

Cooling of Electrical and Electronic devices:

Most of the electronic and electrical devices generate excess heat and thus require thermal management to improve reliability and prevent failures. There are several methods for cooling including heat sinks, fans, heat pipes etc. which can be classified into Active, Passive and Hybrid cooling methods.

1. Active cooling:

When additional energy is used to perform cooling, it is known as active cooling. For example, circulating coolant inside a heatpipe is cooled using a fan. Electricity is required to run the fan. This method increases the cost of the system due to more power consumption. But, this is the most common option, as it is the most safe option. Thermal management would be better in this method but requires reliable designs. (Forced convection process).

2. Passive cooling:

When additional energy is not used or very less energy is used to perform the cooling, it is known as passive cooling. For example, heat sinks attached to an electronic board without fans. Such heat sinks will have fins attached, which enhances the convective heat transfer by providing more surface area (Natural convection process). It requires less electricity and hence cheaper. As long as the temperature is low, this method works very well. Low maintenance cost and promotion of healthy environment are the other advantages. It is silent and needs additional materials (for heatsink).

3. Hybrid Cooling:

Combination of active and passive methods makes it hybrid. Combination of liquid and air cooling for high power dissipation electronics is an example. Any combination of air cooled condensers, cooling towers, surface condensers and air cooled heat exchangers is called as hybrid cooling system. Such systems are designed for better thermal management and efficiency. Designs are more complex but reliable with reduced energy consumption.

	Active cooling	Passive cooling
1.	Additional energy is used.	No additional energy (or very less energy) is required.
2.	Ex: Circulating coolant inside a heat pipe surrounding the circuit board, is cooled using a fan.	Ex: Heat sinks attached to a circuit board without fans.
3.	More power required. Increases the cost of the system.	Less power required, hence cheaper.
4.	This is the most common option as it is safe.	This is used when temperature is less.
5.	Thermal management would be better.	Thermal management is may not be efficient.
6.	Requires reliable designs.	Simple system designs.
7.	High maintenance cost.	Low maintenance cost.
8.	Additional noise due to fans.	Silent.
9.	Forced convection.	Natural convection.
10.	This is best from component perspective.	This is best from cost perspective.

Sample questions

1. Explain the modes of heat transfer with governing equations. [09 Marks]
2. Explain the the process of heat transfer in automobile radiators using a simple sketch. [06 Marks]
3. Differentiate between active and passive cooling methods. [06 Marks]
4. Explain the hybrid method of cooling. [03 Marks]