MODULE 1

MODULE-1

Energy sources, STEAM and Basics of Thermodynamics

RENEWABLE ENERGY:

Renewable energy is energy which is generated from natural sources i.e. sun, wind, rain, tides and can be generated again and again as and when required.

They are available in plenty and by far most the cleanest sources of energy available on this planet. For e.g. Energy that we receive from the sun can be used to generate electricity. Similarly, energy from wind, geothermal, biomass from plants, tides can be used to convert to another form.

NON-RENEWABLE ENERGY:

Non Renewable energy is energy which is taken from the sources that are available on the earth in limited quantity and will vanish fifty-sixty years from now. Non-renewable sources are not environmental friendly and can have serious affect on our health.

They are called non-renewable because they cannot be re-generated within a short span of time. Non-renewable sources exist in the form of fossil fuels, natural gas oil and coal.

Advantages of renewable energy resources

- Are in exhaustible.
- Can be matched in scale to the need and they can deliver required quality of energy for specific task.
- Can be built near to the required area.
- Local area energy requirement can be fulfilled.
- Pollutant free except biomass.

Disadvantages of renewable energy resources

- Intermittent nature
- Availability depends on the local atmospheric conditions.
- Concentrated only in certain regions.
- State of harnessing is not fully developed
- Requires advanced technologies for conversion- hence costlier.

Advantages of Non Renewable Sources:

- Non-renewable sources are cheap and easy to use. You can easily fill up your car tank and power your motor vehicle.
- You can use small amount of nuclear energy to produce large amount of power.
- They are considered as cheap when converting from one type of energy to another.

Disadvantages of Non Renewable Sources:

- Non-renewable sources will expire some day and we have to us our endangered resources to create more non-renewable sources of energy.
- The speed at which such resources are being utilized can have serious environmental changes.
- Non-renewable sources release toxic gases in the air when burnt which are the major cause for global warming.

FUELS

- Fuel is defined as a substance which mostly consists of carbon and hydrogen which on burning with oxygen produce a large amount of heat.

REQUIREMENTS OF AN IDEAL FUEL

- It should liberate high amount of energy per unit mass.
- Heat production should be eco friendly.
- It should be easy to store, transport and handle.
- It should be available in large quantity to meet the demand.
- Combustion should be possible to control.
- It should have low moisture content.
- It should be non toxic, non poisonous, non explosive and non volatile chemically.

COMBUSTION AND PRODUCTS OF COMBUSTION

Combustion is the conversion of a substance called fuel into chemical compounds known as products of combustion with an oxidizer. Combustion process is an exothermic chemical reaction.

HYDROGEN + OXYGEN ⟶ CARBON DIOXIDE + WATER + HEAT

- The most common oxidizer used for chemical reaction of fuel is **natural air.** "The exact quantity of air required for complete combustion of fuel is known as **stoichiometric mixture**". Normally excess air is supplied for complete combustion of fuel.
- **Weak Mixture:** A weak mixture is one in which the amount of air supplied for burning of fuel is more than the exact amount necessary for complete combustion of fuel.
- **Rich Mixture:** A rich mixture is one in which the amount of air supplied for burning of fuel is less than the exact amount necessary for complete combustion of fuel.

PRODUCTS OF COMBUSTION

Most of the chemical fuels mainly consist of compound of carbon, hydrogen and a little amount of sulphur.

The products that are formed during the combustion of the fuels are

- Carbon Dioxide
- Carbon Monoxide
- Sulphur Dioxide
- Nitrogen Oxide
- Lead
- Particulate matter (Mixture of solid particles and liquid droplets)

CALORIFIC VALUE OF FUEL

- The calorific value of fuel is the amount of heat liberated by burning the fuel. "The amount of energy produced during the complete combustion of a unit quantity of fuel is called the calorific value or heat value'. It is expressed in KJ/Kg for solid and liquid fuels and KJ/m^3 for gases.
- **Higher or Gross Calorific Value:** HCV of the fuel is the total heat produced by the complete combustion of unit quantity of fuel when the products of combustion are cooled back to the initial temperature of the fuel.
- **Lower or Net Calorific Value:** LCV of the fuel is the amount of heat produced by the complete combustion of unit quantity of fuel when the products of combustion are allowed to escape to the atmosphere.

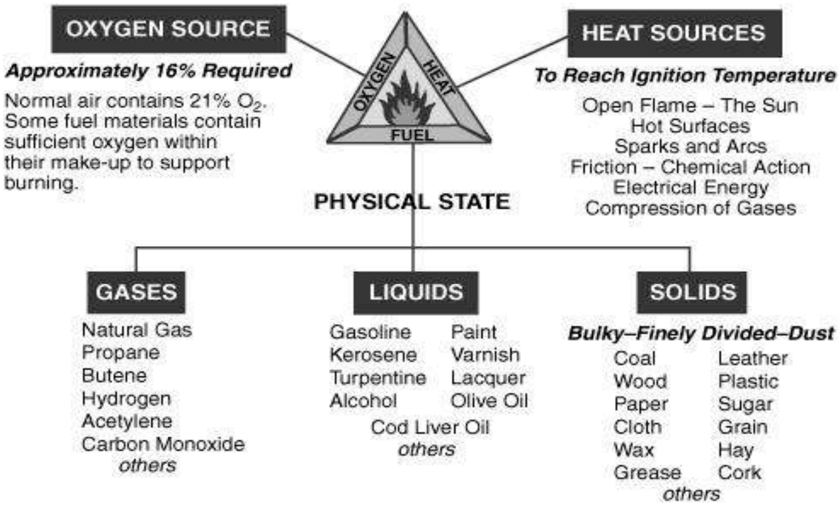
CLASSIFICATION OF FUELS

Fuels are classified according to their existence

- **Natural Fuels.**
- **Artificial Fuels.**
- Natural fuels exist in their original form such as wood, fatty oils etc. The other form of fuels is artificial or manufactured fuels. They are distillation products such as coal gas, water gas and alcohols and also prepared fuels such as coke, benzene, hydrogen gas etc.

Fuels are also classified according to their physical state as

- **Solid Fuels.**
- **Liquid Fuels.**
- **Gaseous Fuels.**



THE FIRE TRIANGLE

BIO FUELS

- Fuels that have been extracted from plants and crops are known as bio-fuels.
- It can be considered as a renewable energy source.
- Two most common types of bio-fuels used are
  - **Ethanol**
  - **Bio diesel**
- **Bio Ethanol**
  - Bio ethanol is made from carbohydrate rich crops such as corn, maize, sugarcane, wheat etc by yeast fermentation.
  - It is mostly used as a blending agent with gasoline to reduce carbon monoxide and other emissions.
  - Ethanol is most commonly used in cars, tractors and boats.
- **Bio Diesel**
  - Bio diesel can be developed from growing plants which naturally contains oil like palm, sunflower, soybean, coconut etc.
  - It can be used as an additive to reduce vehicle emissions and is a renewable alternate fuel for diesel engines.

Advantages of Bio Fuels

- Renewable source of energy.
- Low carbon emissions.
- Can be manufactured from wide range of plants.
- Decreases the nation's dependency on foreign energy.

Disadvantages of Bio Fuels

- Lower Energy Output.
- More water is required for the cultivation of bio-fuel crops.
- Bio-fuels could emit Nitrogen oxide into air.

For more information on solid, liquid & gaseous fuels, refer KRG text book

COMPARISON OF BIO-FUELS & PETROLEUM FUELS

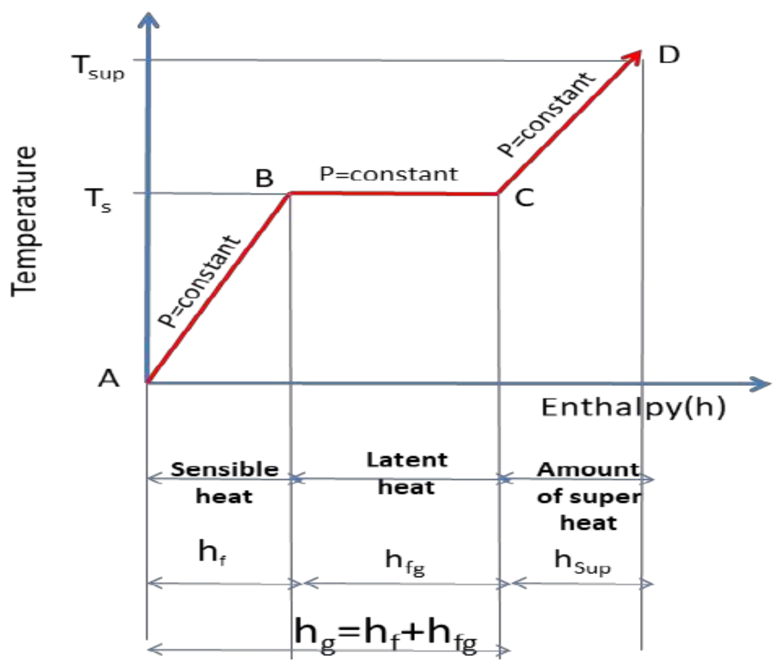
BIO-FUELS	PETROLEUM FUELS
Lower Calorific Value	Higher Calorific Value
Renewable Resource	Non-Renewable Resource
Less Emissions	High Emissions
Safe to Handle and Less Hazardous	Greater risk of fire hazards

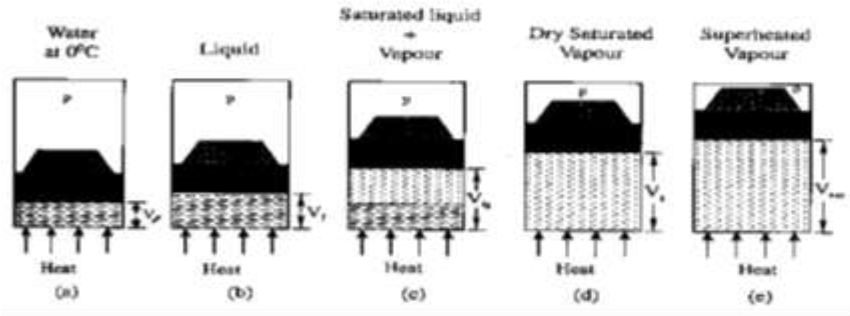
STEAM FORMATION AND PROPERTIES:

INTRODUCTION:

- **Perfect gas:** A gas which does not change its phase during a thermodynamic process.
- **Pure substance:** is a homogeneous substance which retains its chemical composition even though it undergoes a change in phase during a thermodynamic process.
- Water is one of the pure substances which can exist in three different phases
  - In solid phase as ice
  - In liquid phase as water
  - In gaseous phase as steam
- **Vaporization:** when water is heated beyond boiling point, it starts evaporating and transforms from liquid phase to gaseous phase to form steam
- The important properties of steam are
  - Pressure
  - Temperature
  - Specific volume
  - Enthalpy
  - Internal energy
  - Entropy

FORMATION OF STEAM





Formation of steam at constant pressure

To know the values of various properties of steam at a particular pressure, a steam generation experiment is conducted by heating water from 0^0c at given constant pressure.

- Consider 1 kg of water at 0^0c taken in a cylinder fitted with a frictionless moving piston as shown.
- A chosen weight is placed over the piston to get required constant pressure.
- Point A-represents water at 0^0c.
- Its temperature rises till the boiling point is reached.
- There will be slight increase in the volume of water.
- The temperature at which the water boils depends on pressure acting on it.
- Heating of water from 0^0c to Ts^{0}c is represented by the inclined line AB on the graph.
- On further addition of heat, the wet steam at point B is converted to dry saturated steam at point C without the change in temperature.
- Point D-on heating the steam further at the same constant pressure increases its temperature above the saturation temperature
- The temperature of the steam above the saturation temperature at a given pressure is called super-heated temperature.
- This process is called superheating and hence superheated steam is obtained.
- This superheating is represented by the inclined line CD

Sensible heat (h_f): The amount of heat required to raise the temperature of 1kg of water from 0^0c to Ts^{0}c at a given constant pressure is defined as **sensible heat.**

Latent heat of evaporation (h_{fg}) : The amount of heat required to evaporate 1 kg of water at saturation temperature Ts to 1 kg of dry steam at the same saturation temperature at given constant pressure is called **latent heat of evaporation or enthalpy of evaporation.**

Enthalpy of superheat (h_{sup}): The amount of heat required to increase the temperature of dry steam from its saturation temperature to any desired higher temperature at the given constant pressure is called **amount of superheat of enthalpy of superheat.**

Degree of superheat: The difference between the superheated steam and the saturation temperature is defined as degree of superheat.

Different States of Steam

- **Wet Steam**
- **Dry saturated steam**
- **Superheated steam**

1. **Wet steam**
   Two phase mixture of entrained water molecules and steam at the saturation temperature corresponding to a given pressure.

Dryness Fraction of Steam: The ratio of the actual dry steam present in a known quantity of wet steam to the total mass of the wet steam.

$$x = m_g/(m_f + m_g)$$

Where,
x – dryness fraction
m_g - *mass of dry steam in the sample quantity of wet steam*
m_f - *mass of suspended water molecules in the sample quantity of wet steam*

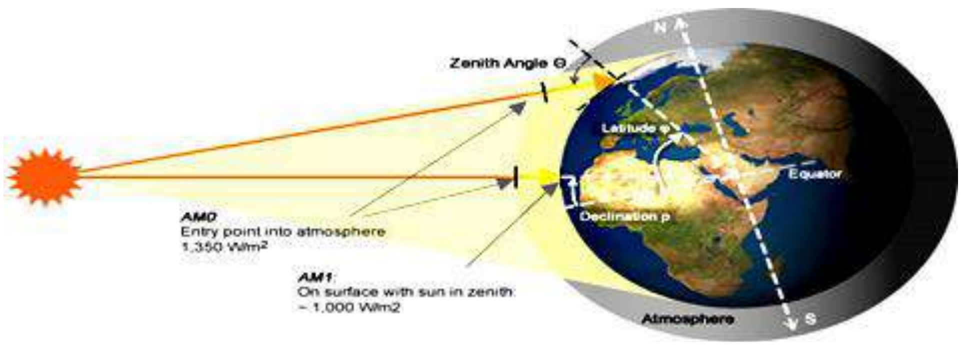
2. **Dry saturated steam**
   A saturated steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it.
3. **Superheated steam**
   The steam which is heated beyond its dry saturated state to temperatures higher than its saturated temperature at a given pressure

Advantages of superheated steam
- At a given pressure, the superheated steam possesses more heat energy compared to dry saturated steam or wet steam. Hence its capacity to do the work will be higher.
- Results in high thermal efficiency.
- While expanding in a steam turbine it reduces and in extreme cases prevents the condensation, thus giving better economy.

Disadvantages of superheated steam
- Lubrication problem due to very high temperature.
- Higher depreciation and initial cost.

<u>SOLAR CONSTANT</u>

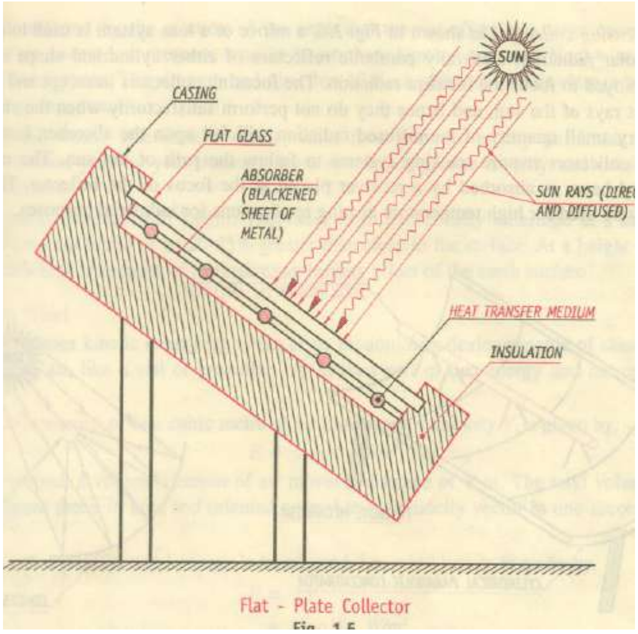
The solar constant is a measure of solar electromagnetic radiation (the solar irradiance) per unit area that would be incident on a plane perpendicular to the rays, at a distance of One Astronomical Unit (AU) from the Sun (roughly the mean distance from the Sun to the Earth). It is measured by satellite as being approximately 1.362 kW/m² at solar maximum.



Solar energy conversion:
Solar energy can be converted into other forms of energy by three primary processes.

- Heliochemical process (Photosynthesis)
- Helioelectrical process (Solar Cell)
- Heliothermal process (Liquid flat plate collector)

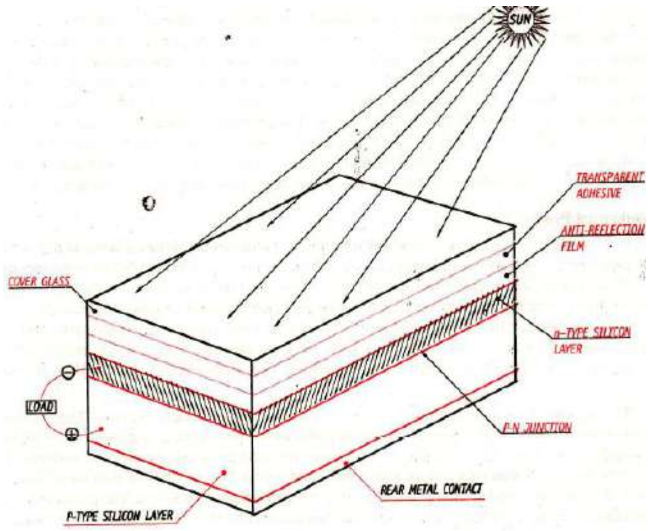
LIQUID FLAT PLATE COLLECTOR



Flat - Plate Collector

- **The flat** plate collector consists of a metal sheet (absorber surface) exposed to the solar radiation.
- This sheet absorbs both beam and diffused solar radiation. The sheet is coated with black paint.
- Fluid carrying pipes are connected to back side of the metal sheet. The liquid most commonly used is water. The lower side of metal sheet is covered with insulating material.
- The heat energy generated in the sheet of metal will be continuously transferred to the fluid.
- The transparent cover (glass) is fixed above the metal sheet, which reduces the heat loss due to convection & re-radiation.
- The flat plate collector efficiency is good at medium and maximum temperatures, but at low temperature the efficiency is very low.
- The flat plate collectors are designed for output temperatures ranging from 60^o C to 100^o C.

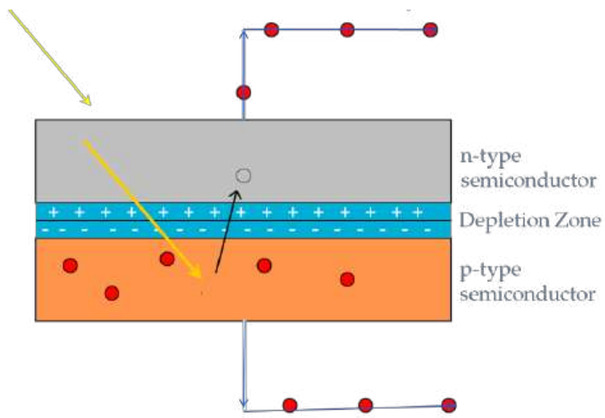
SOLAR CELL (PHOTOVOLTAIC PRINCIPLE)



- Using the principle of photovoltaic effect, the solar energy is directly converted into electrical energy. Semiconductors have the capability of generating electric power.

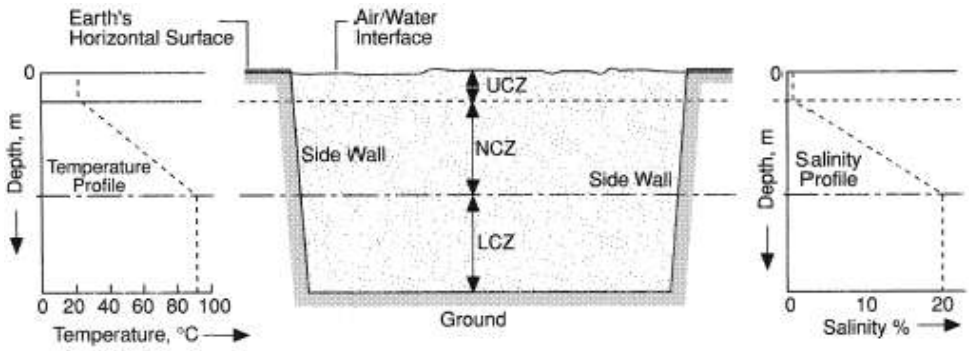
Principle:

- Semiconductors are insulators as they have no free electrons. But if very small amounts of impurities such as antimony, arsenic are added, then a few free electrons are produced.
- When photons from the sun are absorbed by a semiconductor, they create free electrons with higher energies.
- Once these electrons are created, there must be an electric field.
- **N-type silicon**
    - Silicon with added materials such as arsenic or phosphorus
    - Contains free electrons
- **P-type silicon**
    - Silicon with added materials such as boron or gallium.
    - Reduces the number of valance electrons to three (i.e one less that in the silicon.)
    - This type of atom has insufficient valance electrons to complete four valence bonds.
    - The incomplete bond results in a vacancy or hole.
    - The hole acts as positive charge and makes the silicon conductive.



SOLAR POND

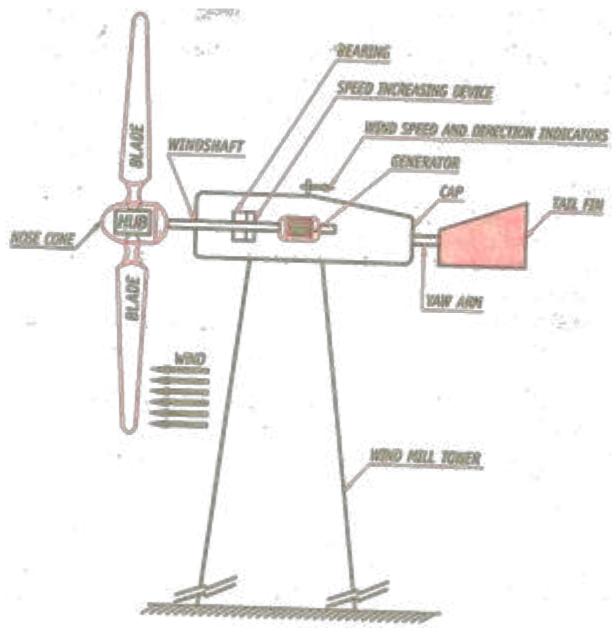
A solar pond is a pool of water in which a salt concentration gradient, a water density gradient and hence a temperature gradient can be maintained to collect solar thermal energy.



Typically a salt gradient solar pond consists of three layers.

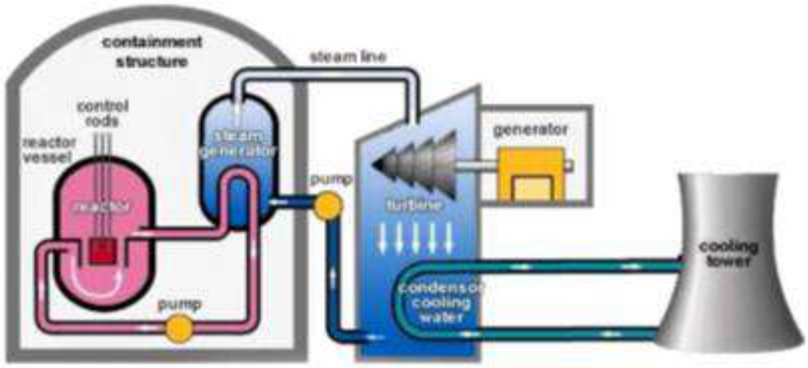
- The upper convective zone (UCZ) called surface zone of clear fresh water that acts as a solar collector. It is relatively the shallowest in depth and is at atmospheric temperature.
- The lower convective zone (LCZ) has the highest salt concentration and is the zone that collects and stores the solar energy in the form of heat. It is also called as storage zone. Salt concentration and temperature are nearly constant in this zone.
- Separating the upper and lower zones is the gradient zone or non-convective zone (NCZ). Here the salt concentration increases as depth increases, thereby creating a salinity or density gradient. Due to density gradient, the water of a layer within the zone, cannot rise or fall by natural convection. This gradient zone acts as a transparent insulator between the upper and lower zones.
- To generate electricity, the heat stored in the salty hot water, in the bottom zone is sent to the evaporator. Liquid Freon in the evaporator is heated and converted into gas. The pressure generated by the gas runs the turbine and electricity is produced by the generator.

WIND ENERGY CONVERSION



- Wind energy is the indirect form of solar energy. It is caused by the uneven heating of the earth's surface by the sun.
- In ancient times the kinetic energy of the wind was used to propel ships by sails. The wind turbines or windmills are used to convert the kinetic energy of wind into mechanical work, which may be converted into electrical energy.
- For the production of alternating current windmill must be designed to operate at a constant angular velocity over a wide rand of wind speeds in order to produce a constant frequency.
- The schematic diagram shows the horizontal axis windmill. It consists of a tall tower with a large propeller on the top.
- When the wind blows, it rotates the propeller, which turns the generator to produce electricity.
- Some of the generally used propellers for horizontal axis windmills are: multi blade type, sail tye and propeller type blades.

NUCLEAR POWER PLANTS



Nuclear fusion: Fusion energy is a form of nuclear energy released by the fusion (combustion) of two light nuclei (i.e. nuclei of low mass) to produce heavier mass.

- Deuterium and tritium are some of the fusible elements.

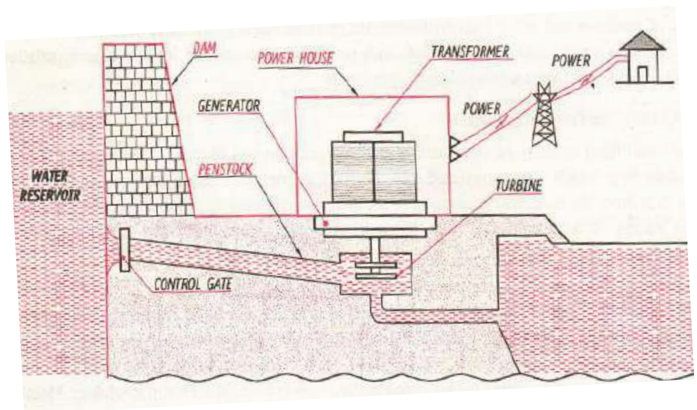
Nuclear fission is the process, where a heavy nucleus splits into two fragments of more or less of equal mass.

- Neutron + Heavy nucleus → Fission fragments + Neutrons (2 to 3) + energy
- Uranium is the main element required to run a nuclear reactor in fission.
- The energy released by fission of 1 gram of U-235 is equal to that due to combustion of 50 million tons of coal.

Nuclear reactor:

- A nuclear reactor is a device which controls the nuclear fission chain reaction to harness nuclear energy for peaceful purposes.
- A nuclear reactor which is used to generate electricity is called a nuclear power plant.
- Fuel in the form of pellets is enclosed in several tubular claddings of steel or aluminum. This is called fuel assembly. Enriched U-235 or Pu-239 is the fuel material
- Rods made of boron or cadmium which is a neutron absorber is used as control rods. The neutrons available for fission are controlled by moving the control rods in and out of the nuclear core. The rods can be used to shut down the reactor.
- A coolant is circulated through the reactor to remove the heat generated. Ordinary water is most commonly used coolant.
- Heat produced during fission process is absorbed by the coolant and is used to convert water in to steam in the heat exchanger. The steam is used to rotate the steam turbine .The steam turbine is connected to a generator which generate electricity.
- The entire reactor is enclosed in a concrete building with lead sheets covered inside to prevent radioactive radiations being released in to the environment

HYDROELECTRIC POWER PLANT



Dam

- The dam is most important component of hydroelectric power plant.
- The dam is built on a large river that has abundant quantity of water throughout the year.
- It should be built at a location where the height of the river is sufficient to get maximum potential energy from water.

Water reservoir

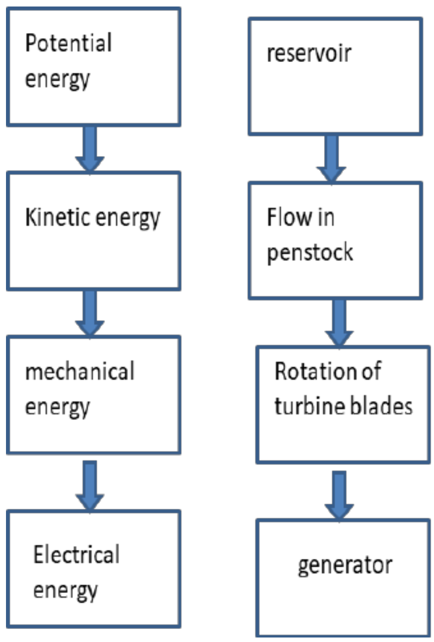
- The water reservoir is the place behind the dam where water is stored.
- It is located higher than dam structure.
- It decides how much potential energy the water possesses.

Penstock

- It is a long pipe or the shaft that carries the water flowing from the reservoir towards the power generation unit, which consists of turbines and generator.
- The water in penstock possesses kinetic energy due to its motion.

Intake/Control gates

- These are gates built inside the dam.
- The water from reservoir is released and controlled through these gates.
- When the gates are opened water flows due to the gravity and possesses kinetic energy as well.



Water turbines

- Water flowing from the penstock is allowed to enter the power generation unit, which houses the turbine and the generator.
- When water falls on the blades of the turbine the kinetic and potential energy of water is converted to rotational motion of blades of turbine and this causes the shaft of the turbine to rotate.

Generators

- Here electricity is produced.
- The up shaft of water turbine rotates in the generator, which produces alternating current in the coils of generator.
- It is the rotation of the shaft inside the generator that produces magnetic field which is converted into electricity by electromagnetic field induction.

What is Global Warming?

Global warming is the slow increase in the average temperature of the earth's atmosphere because an increased amount of the energy (heat) striking the earth from the sun is being trapped in the atmosphere and not radiated out into space.

What Causes Global Warming

- Gases released primarily by the burning of fossil fuels and the tiny particles produced by incomplete burning. Scientists call these gases "greenhouse gases" (GHGs) because they act like the wrong way reflective glass in our global greenhouse.
- The most commonly discussed GHGs are:
- Carbon dioxide
- Methane
- Nitrous oxide , NO/N2O or simply NOx is a byproduct of fertilizer production and use, other industrial processes and the combustion of certain materials.
- Fluorinated gases were created as replacements for ozone depleting refrigerants, but have proved to be both extremely long lasting and extremely warming GHGs.

Impacts of global warming:

Rising sea level: Average sea level around the world rose about 8 inches (20 cm) in the past 100 years; climate scientists expect it to rise more and more rapidly in the next 100 years as part of climate change impacts.

- Melting ice:
- Chang in Eco-systems
- Health issues
- Change in climate

OZONE DEPLETION

- Ozone is a colourless gas which is a form of oxygen. There is a layer of ozone high above the earth's surface.
- Ozone layer depletion, is simply the wearing out (reduction) of the amount of ozone in the stratosphere.

Causes:

When CFCs reach the upper atmosphere they are first degraded by the very high energy of UV (ultra-violet) radiation. Degradation of CFC leaves a free chlorine atom. The basic cause of ozone layer depletion is that this chlorine atom then breaks up ozone molecules.

- **What are the effects of ozone layer depletion?**

Depletion of the ozone layer has consequences on humans, animals and plants. This typically results from higher UV levels reaching us on earth. Research confirms that high levels of UV Rays cause skin cancer

- **There are many simple ways to save our ozone layer.**

Avoid the purchase and use of aerosol sprays containing chlorofluorocarbons (CFCs).

Avoid the use of fire extinguishers with halogenated hydrocarbon, a substance being very aggressive to the ozone layer.

Avoid buying insulating material made from CFC

BASIC CONCEPTS OF THERMODYNAMICS:

Introduction:

Thermodynamics is the science of energy transfer and its effects on the physical properties of substances. The form of energy are mechanical, thermal or heat, chemical, electrical etc.

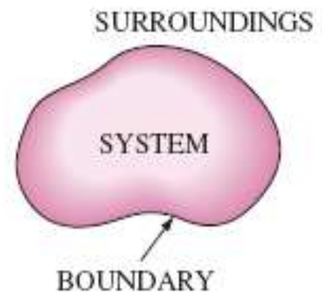
Thermodynamics deals with the behavior of gases and vapours i.e., the working substances when subjected to variation of temperature and pressure and the relationship between heat energy and mechanical energy commonly referred to as work.

Energy transformation takes place when a substance undergoes a change from one condition to another in a process. The processes are heating or cooling and expansion or compression in the cylinder or passages with or without production or supply of mechanical work.

Work producing devices	Work absorbing devices
a) Steam power plants	a) Cold storages
b) Nuclear power plants	b) Central air conditioning and heating plants
c) Petrol and diesel engines	c) Domestic refrigerators
d) Gas turbine for aircraft propulsion and power generation	d) Room air conditioners
e) Jet propulsion engines for aircrafts	e) Ice plants
f) Rocket engines	f) Food freezing and freeze-drying plants

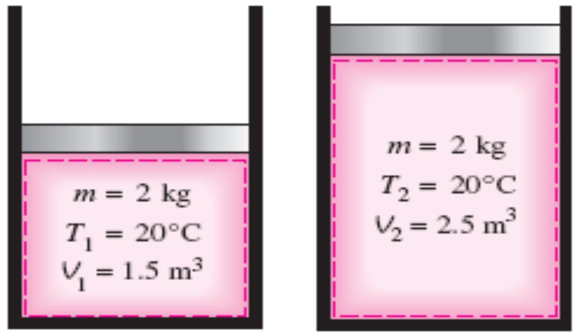
g) Fuel cells, Solar cells, thermoelectric generators etc.	g) Thermoelectric refrigerators

Thermodynamic system:



A **thermodynamic system** is defined as a quantity of matter or a region in space upon which attention is concentrated in the analysis of a problem. Everything external to the system is called the **surroundings or the environment**. The system is separated from the surroundings by the **system boundary**. The boundary may be either fixed or moving. A system and its surroundings together comprise a **universe.**

<u>Thermodynamic state of a system/substance:</u> Exact condition of a system/substance is called state.



(*a*) State 1 (*b*) State 2

<u>State diagram:</u>

This is a diagram on Cartesian coordinates with any two independent properties being represented on the X and Y axes. This diagram represents the state of a system at different instants.

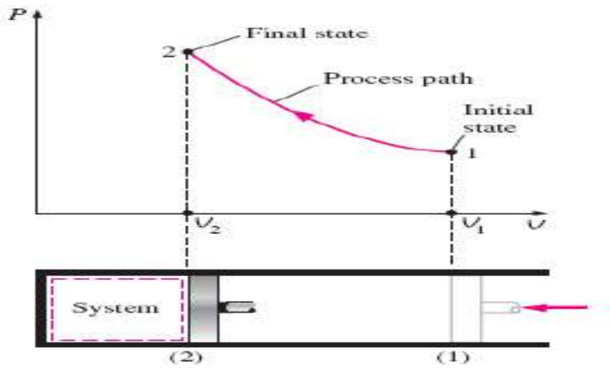
<u>State Point:</u>

This is a point on a state diagram showing the condition of a system at a given instant, in terms of the two independent properties selected for the X and Y axes.

Path:

A path is a line joining successive state points on a state diagram, during a change of state. It is a locus of series of states through which a system passes between initial and final states.

Thermodynamic process: When one or more of the thermodynamic properties of a system change, we say that there is a change of state of the system. This change of state of a system is referred to as thermodynamic process.



Definition of work in Mechanics: *The work is done by a force as it acts upon a body moving in the direction of the force.*

The action of a force through a distance is called mechanical work. The product of the force and the distance moved parallel to the force is the magnitude of the mechanical work

Thermodynamic definition of work:

In thermodynamics, work transfer is considered as occurring between system and surroundings. *Work is said to be done by a system if the sole effect on things external to the system can be reduced to the raising of a weight.* The weight may not actually be raised, but the net effect external to the system would be reduced to the raising of a weight.

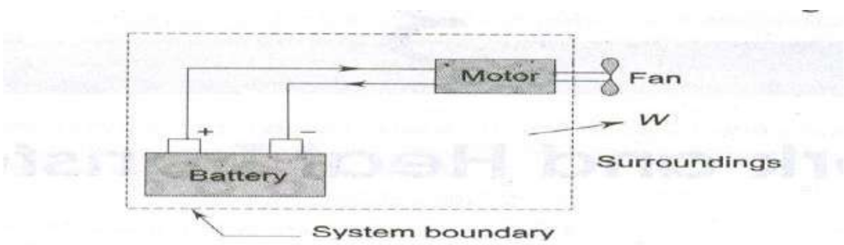
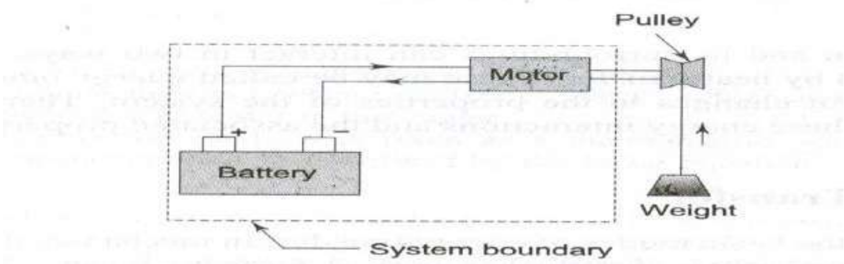
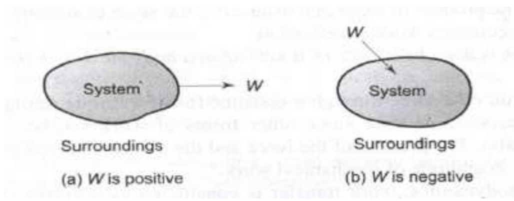


Fig. *Battery-motor system driving a fan*



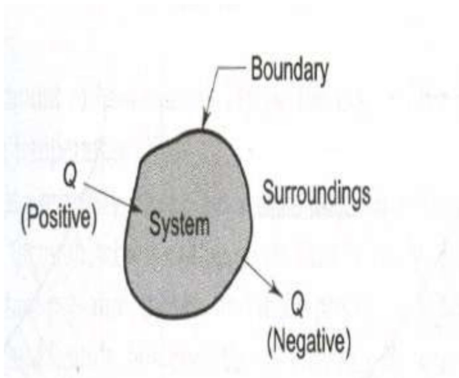
In thermodynamics by convention, the work done by a system is considered as *positive* and the work done on a system is considered *negative*.



When a system does positive work, its surroundings do an equal amount of negative work and vice versa. Thus in any process

$$W_{system} + W_{surroundings} = 0$$

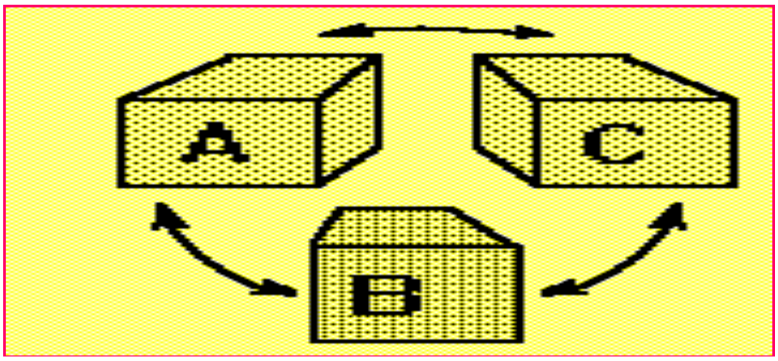
Heat transfer:



- *Heat* is defined as the form of energy that is transferred across a boundary by virtue of a temperature difference.
- The transfer of heat between two bodies in direct contact is called *conduction*.
- Heat may be transferred between two bodies separated by empty space or gases by the mechanism of *radiation* through electromagnetic waves.
- A third method of heat transfer is *convection* which refers to the transfer of heat between a wall and a fluid system in motion.
- *The direction of heat transfer is taken from the high temperature system to the low temperature system.* Heat flow into the system is taken to be *positive*, and heat flow out of a system is taken as *negative* (Fig above).
- Heat is a form of energy in transit. It occurs only at the boundary of the system.

- Energy transfer by virtue of temperature difference only is called heat transfer.
- All other forms of energy interactions may be termed as work transfer.
- Heat like work, is not a property of the system.
- A process in which no heat crosses the boundary of the system is called an *adiabatic process*. Here only work interaction takes place between the system and the surroundings.
- **Zeroth law of thermodynamics:**

- **Statement:** When two systems have thermal equilibrium with a third system, they in turn have thermal equilibrium with each other.



Thermometer and thermometric property: The Zeroth law provides the basis for the measurement of temperature. The third body 3 in Zeroth law is called the thermometer.

First law of thermodynamics:

Statement: "During a cycle, a system undergoes, the cyclic integral of heat added is equal to the cyclic integral of work done". $\oint dQ = \oint dW$

Mathematically first law may be written as

The first law is applicable to a closed system and to a thermodynamic cycle and not to a process.

$$J \oint dQ = \oint dW$$

First law for a closed system undergoing a change of state:

For a closed system during a cyclic process the sum of work transferred is equal to the sum of heat transferred.

, $\oint dQ = \oint dW$

For a closed system during non-cyclic process the work transferred and heat transferred may not be equal and this difference is accounted for by a change in *Internal Energy ΔE (OR simply energy)* of the system.

i.e., $Q = \Delta E + W$

Here Q, W and ΔE are all expressed in same units (in joules).

Second law of thermodynamics:

Kelvin-Planck Statement:

"*It is impossible for any device that operates in a cycle to receive heat from a single reservoir and produce a net amount of work*"

The Kelvin-Planck statement can also be expressed as;

"*No heat engine can have a thermal efficiency of 100%* OR as *for a power plant to operate; the working fluid must exchange heat with the environment as well as the furnace.*"

Clausius Statement:

"*It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a low temperature body to a high temperature body.*"

Third law of thermodynamics:

The third law of thermodynamics states that, "the entropy of a pure substance in thermodynamic equilibrium approaches zero as the temperature approaches zero."

Sometimes it stated as"the entropy of a system approaches a constant value as its temperature approaches absolute zero"

Internal energy: It is the energy possessed by a body or system due to its molecular arrangement and motion of the molecules. It is the sum of internal K.E and internal P.E of the molecules. It is a function of temperature and can be increased or decreased by adding or subtracting heat to or from the substance.

Absolute value of the I.E cannot be measured but change in I.E can be measured when a substance undergoes a change of state from 1 to 2. It can be expressed in general way as;

$$du = u_2 - u_1$$

Enthalpy:

Enthalpy is nothing but total heat and heat content. Enthalpy or total heat = Internal energy + Product of absolute pressure and volume.

$$h = u + pv$$

Absolute value of enthalpy cannot be measured, only change in enthalpy can be measured.

$$dh = h_2 – h_1 = (u_2 - u_1) + (pv_2 – pv_1)$$

Entropy:

It is represented by the symbol's'. Small increase of entropy 'ds' of a substance is defined as the ratio of small addition of heat dQ to the absolute temperature T of the working substance at which the heat is supplied.

$$ds = dQ/T \qquad \text{or} \qquad dQ = T.ds$$

Unit of entropy is *J/kg/K*.

Module -1 Basics of thermodynamics

Formulas used:

PdV work in various quasi static processes

1. Constant pressure process (Isobaric or Isopiestic process)
   $W_{1-2} = P(V_2 - V_1)$
2. Constant volume process (Isochoric Process)
   $W_{1-2} = 0$
3. Process in which PV=Constant
   $W_{1-2} = \int Pdv$
   $$W_{1-2} = P_1V_1 \ln\frac{P_1}{P_2}$$
4. Process in which PV^n=Constant
   $$W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}$$
5. Process in which PV^γ=Constant
   Where $\gamma = \dfrac{C_p}{C_v}$
   $$W_{1-2} = \frac{P_1V_1}{n-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

Problem-1 in an internal combustion engine, the heat rejected to cooling water during compression stroke is 50 kJ/kg and the work input is 100kJ/kg. calculate the change in internal energy of the working fluid stating whether it is a gain or loss.

Solution:

Heat rejected =Q=-50kJ/kg

Work input =W= -100 kJ/kg

Change in internal energy

$\Delta E = Q - W$

$\Delta E = -50 - (-100) \Rightarrow 50kJ/kg$

+ve sign indicates increase or gain in internal energy of the system.

Problem-2:

A closed system undergoes a change in process in which 5 kJ of heat energy is supplied to the system. Determine the change in internal energy under the following conditions i) 1 kJ of work is done on the system ii) 1.25 kJ of work is done by the system

Solution.

Heat supplied =Q=5 kJ

Case I

W= -1 kJ

$$\Delta E = Q - W$$

$$\Delta E = 5 - (-1) \Rightarrow 6kJ$$

Case II

W= 1.25 kJ

$$\Delta E = Q - W$$

$$\Delta E = 5 - 1.25 \Rightarrow 3.75kJ$$

Problem-3

A stationary mass of gas at its initial state 0.4 m^3 and 0.105 MPa was compressed at constant pressure to final state of 0.2 m^3 and 0.105 MPa. The heat transfer from the gas during the process was 42.5 kJ. Calculate the change in internal energy of the gas.

Solution

Initial condition of the gas

Volume of gas=V_1=0.4 m^3

Pressure = P_1=0.105 MPa $0.105*10^6$ N/m^2

Final condition of the gas

Volume of gas=V_2=0.2 m^3

Pressure = P_2=0.105 MPa $0.105*10^6$ N/m^2

P_1=P_2 the compression process takes place at constant pressure

Heat transfer from the gas Q= -42.5 kJ

$$\Delta E = Q - W$$

But Work=?

$$W_{1-2} = {}_1^2\int P.dv = P(V_2 - V_1)$$

$$W_{1-2} = (0.105\times10^6)\times(0.2-0.4)$$

$$W_{1-2} = -21kJ$$

$$\Delta E = Q - W$$

$$\Delta E = -42.5-(-21) \Rightarrow -21.5kJ$$

-ve sign indicates decrease in internal energy of the system

Problem-4

A gas occupies a volume of 0.1 m^3 at a temperature of 20°C and a pressure of 1.5 bar. Find the final temperature of the gas, if it is compressed to a pressure of 7.5 bar and occupies a volume of 0.04 m^3.

Initial condition of the gas

Volume of gas=V_1=0.1 m^3

Pressure = P_1=1.5 bar $1.5*10^5$ N/m^2

Temperature T_1=20°C   20+273=293 K

Final condition of the gas

Volume of gas=V_2=0.04 m^3

Pressure = P_2= 7.5 bar $7.5*10^5$ N/m^2

For a perfect gas at condition 1 and 2 we have

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(1.5\times10^5)\times0.1}{293} = \frac{(7.5\times10^5)\times0.04}{T_2}$$

$$T_2 = 587K$$

Problem -5

0.05 m^3 of air at a pressure of 8 bar and temperature 280°C expands to eight times its original volume and the final temperature after expansion is 25°C. Calculate the change in entropy of air during the process. Assume specific heat at constant pressure as 1.005 kJ/kgK and specific heat at constant volume as 0.712 kJ/kgK.

Initial condition of air

Volume of air=V_1=0.05 m^3

Pressure = P_1=8 bar $8*10^5$ N/m^2

Temperature T_1=280°C 280+273=553 K

Final condition of air

Volume of gas=V_2=8 V_1=8*0.05=0.4 m^3

Pressure = P_2= 7.5 bar $7.5*10^5$ N/m^2

Temperature T_2=25°C 25+273=298 K

Cp=1.005 kJ/kg K

Cv=0.712 kJ/kg K

To find change in entropy

$$ds = C_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{V_2}{V_1}\right)$$

Where R= gas constant =Cp-Cv

R=1.005-0.712=0.293 kJ/kg K

$$dS = 0.712\ln\left(\frac{298}{553}\right) + 0.293\ln\left(\frac{0.4}{0.05}\right)$$

dS=0.169 kJ/kg K calculated for 1 kg of air

To find mass of air

Perfect gas equation PV=mRT

Where P is in kPa

PV=mRT

$(8*10^2)(0.05)$=m*(0.293)*(553)

m=0.246 kg

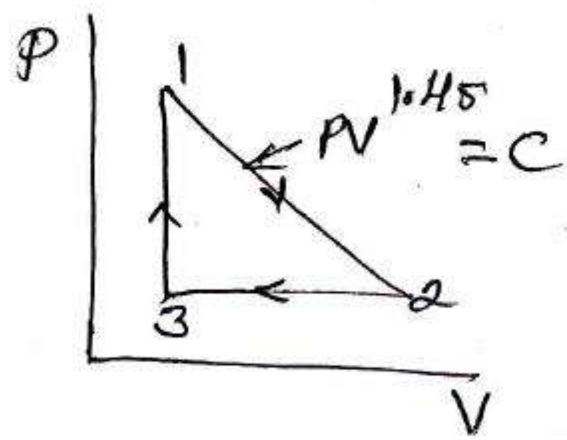
Now change in entropy dS=0.246*(0.169)

dS=0.0415 kJ/K

problem 6

A piston cylinder device operates 1 kg of fluid at 20 atm pressure. The initial volume is $0.04m^3$. the fluid can expand reversibly following the process $PV^{1.45}=C$, so volume becomes double. The fluid is then cooled at constant pressure until the piston comes back to the original position. Keeping the piston unaltered heat is added reversibly to restore it to the original pressure. Calculate work done in the cycle.

Solution



Mass of the fluid m=1 kg

P_1=20 atm pressure

P_1=20 *1.01325=20.265 bar

V_1=0.04 m^3

Process, $PV^{1.45}=C$

V_2=2* V_1

V_2=0.08 m^3

$$P_1V_1^n = P_2V_2^n = C$$

$$P_2 = P_1 \times \frac{V_1^n}{V_2^n}$$

$$P_2 = 20.265 \times \left(\frac{0.04}{0.08}\right)^{1.45}$$

$$P_2 = 7.417bar$$

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$W_{1-2} = \frac{20.265\times10^5 \times 0.04 - 7.417\times10^5 \times 0.08}{1.45-1}$$

$$W_{1-2} = 47.15kJ$$

$$W_{2-3} = P(V_3 - V_2)$$

$$W_{2-3} = 7.417\times10^5 (0.08-0.04)$$

$$W_{2-3} = -29.65kJ$$

$$W_{3-1} = 0kJ$$

Work done in cycle

$$W_{cycle} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$W_{cycle} = 47.82 - 29.65 + 0 \Rightarrow 18.17kJ$$

Problem

Find the enthalpy of 1 kg of steam at 12 bar when, a) steam is dry saturated, b) steam is 22% wet and c) superheated to 250 °C. use the steam table. Assume the specific heat of the superheated steam as 2.25 kg/kg K.

Solution

From the steam tables at 12 bar, the following values are noted

Ts=188°C

h_f=798.43 kJ/kg

h_{fg}=1984.3 kJ/kg

a) Enthalpy of dry saturated steam

$$h_g = h_f + h_{fg}$$

$$h_g = 798.43 + 1984.3 \Rightarrow 2782.73kJ/kg$$

b) Enthalpy of wet steam

When the steam is 22% wet, it will be 78% dry. Therefore, the dryness fraction x=0.78

$$h = h_f + xh_{fg}$$

$$h = 798.43 + 0.78 \times 1984.3 kJ / kg$$

$$h = 2346.18 kJ / kg$$

c) Enthalpy of superheated steam

$$h_{\sup} = h_f + h_{fg} + C_{ps}(T_{\sup} - T_{sat})$$

$$h_{\sup} = 798.43 + 1984.3 + 2.25(250 - 188)$$

$$h_{\sup} = 2922.23 kJ / kg$$

Problem

Find the specific volume and enthalpy of 1 kg of steam at 0.8 MPa a) when the dryness fraction is 0.9 and b) when the steam is superheated to a temperature of 300°C. the specific heat of superheated steam is 2.25 kJ/kg k.

Solution

From the steam tables at 0.8 MPa=8 bar, the following values are noted

Ts=170.4°C

h_f=720.94 kJ/kg

h_{fg}=2046.5 kJ/kg

h_g=2767.5 kJ/kg

v_g=0.2403 m^3/kg

v_f=0.001115 m^3/kg

a) Specific volume of wet steam

$$v = xv_g \frac{m^3}{kg}$$

$$v = 0.9 \times 0.2403 \Rightarrow 2.627 \frac{m^3}{kg}$$

b) Specific volume of the superheated steam

$$v_{\sup} = v_g \times \frac{T_{\sup}}{T_s} \frac{m^3}{kg}$$

$$v_{\sup} = 0.2403 \times \frac{(300+273)}{(170.4+273)} \frac{m^3}{kg}$$

$$v_{\sup} = 0.3105 \frac{m^3}{kg}$$

c) Enthalpy of wet steam

$$h = h_f + xh_{fg}$$

$$h = 720.94 + 0.9 \times 2046.5 kJ / kg$$

$$h = 2562.8 kJ / kg$$

d) Enthalpy of superheated steam

$$h_{\sup} = h_f + h_{fg} + C_{ps}(T_{\sup} - T_{sat})$$

$$h_{\sup} = 720.94 + 2046.5 + 2.25(300 - 170.4)$$

$$h_{\sup} = 3059.1 kJ / kg$$

Problem

5 kg of wet steam of dryness 0.8 passes from a boiler to a superheater at a constant pressure of 1 MPa abs. In the superheater its temperature increases to 350 °C. determine the amount of heat supplied in the superheater. The specific heat of superheated steam Cps=2.25kJ/kg K.

Solution

From the steam tables at 1 MPa=10 bar, the following values are noted

Ts=179.88°C

h_f=762.61 kJ/kg

h_{fg}=2013.6.5 kJ/kg

a) Enthalpy of wet steam

$$h = h_f + xh_{fg}$$

$$h = 762.61 + 0.8 \times 2013.6 kJ/kg$$

$$h = 2373.5 kJ/kg$$

b) Enthalpy of superheated steam

$$h_{\sup} = h_f + h_{fg} + C_{ps}(T_{\sup} - T_{sat})$$

$$h_{\sup} = 762.61 + 2013.6 + 2.25(350 - 179.88)$$

$$h_{\sup} = 3159 kJ/kg$$

c) Amount of heat supplied in the superheater

$$h_{\sup} - h = (3159 - 2373.5) kJ/kg$$

=785.5 kJ/kg

Total amount of heat supplied in the superheater=5*785.5

=3927.5 kJ

Problem

A mixture of saturated water and saturated steam at a temperature of 250°C is contained in a closed vessel of 0.1 m^3 capacity. If the mass of the saturated water is 2 kg. Find the mass of the steam in the vessel. Also find the pressure, specific volume, dryness fraction and the enthalpy of the mixture.

Solution

Since in the mixture in the vessel contains saturated water and saturated steam, it will be a wet steam. The pressure of the steam is found from the steam tables corresponding to Ts=250°C is p=39.77 bar.

At p=39.77 bar, the other properties are found from the steam tables:

h_f=1085.8 kJ/kg

h_{fg}=1714.6 kJ/kg

v_f=0.0012513 m^3/kg

v_g=0.05004 m^3/kg

b) mass of the steam

since the vessel contains saturated water and steam volume of the vessel

$$=m_f v_f + m_g v_g$$

$$0.1 = 2 \times 0.0012513 + m_g \times 0.05004$$

$$m_g = 1.95kg$$

Total mass of the mixture=1.95+2=3.95kg

c)dryness fraction of the steam

$$x = \frac{m_g}{m_f + m_g}$$

$$x = \frac{1.95}{3.95} \Rightarrow 0.493$$

d) Specific volume of the mixture

$$v_s = \frac{0.1}{3.95} \Rightarrow 0.02531 \frac{m^3}{kg}$$

e) Enthalpy of mixture

$$h = h_f + x h_{fg}$$

$$h = 1085.8 + 0.493 \times 1714.6 kJ/kg$$

$$h = 1931 kJ/kg$$

Total enthalpy =2*1931

=3862 kJ

Problem:

Determine the total heat content per unit mass (specific enthalpy) to water when it exists in the following state using steam tables. Asuume ambient pressure to the 100 kPa: i) 10 bar absolute and 300°C ii) 100 kPa gauge and 150°C,iii) dry saturated steam at 100 kPa absolute, iv) steam at 12 bar and 95% quality, and v) saturated water at 10°C.

Problem

A spherical vessel 0.5 m diameter contains a mixture of saturated water and saturated steam at 300°C, the saturated water occupies one-fourth of its volume and the remaining saturated steam. Calculate their masses and the dryness fraction of the mixture. Also find the enthalpy of the mixture. How much of the heat is to be added to convert the mixture into dry saturated steam at the same pressure?

Solution

From the steam tables, the pressure at the saturation temperature of 300°C is p=85.927 bar

And v_f=0.001404 m^3/kg, v_g=0.02165 m^3/kg,

Volume of the spherical vessel= $= \frac{4}{3} \times \pi r^3$

$$= \frac{4}{3} \times \pi (0.25)^3 \Rightarrow 0.06545 m^3$$

Volume of the saturated water

$$= \frac{1}{4} \times 0.06545 \Rightarrow 0.01636 m^3$$

Mass of saturated vapour

$$m_f = \frac{0.01636}{0.001404} \Rightarrow 11.65 kg$$

Volume of the saturated steam

$$= \frac{3}{4} \times 0.06545 \Rightarrow 0.049 m^3$$

Mass of saturated vapour

$$m_g = \frac{0.0149}{0.02165} \Rightarrow 2.26 kg$$

Dryness fraction of the mixture

$$x = \frac{m_g}{m_f + m_g}$$

$$x = \frac{2.26}{11.65 + 2.26} \Rightarrow 0.162$$

Enthalpy of mixture at 300°C from the steam tables

h_f=1345 kJ/kg

h_{fg}=1406 kJ/kg

h_g=2751 kJ/kg

$$h = h_f + xh_{fg}$$

$$h = 1345 + 0.162 \times 1406 kJ/kg$$

$$h = 1572.77 kJ/kg$$

Heat to be added to convert into dry saturated steam at same pressure

$$heatadded = h_g - h$$

$$heatadded = 2751 - 1572.77 \Rightarrow 1178.23 kJ/kg$$