

1. Thermal Energy storage:-

- i) sensible heat storage
 - a) water storage
 - b) pebble bed storage.
- ii) Latent heat storage.

2. Electrical storage:-

- i) capacitor storage
- ii) inductor storage
- iii) Battery storage

3. Chemical storage:-

- i) chemical
- ii) thermochemical

4. Electromagnetic Energy storage

5. Mechanical Energy storage

- i) pumped hydroelectric storage
- ii) compressed air
- iii) Flywheel.

Limitations of solar Thermal Energy:-

- * cost is very high as the power generated is about 100 mw and more.
- * These systems can only be built in places where solar radiation is high.
- * They require more space and large land area.
- * solar thermal energy is completely dependent on climate and therefore, the process is inconsistent.
- * They should be replaced by gas thermal plants, if there is no sun or in case of bad weather conditions.

Phase change materials of latent heat storage system:-

In a latent heat storage system, heat is stored in material when it's phase changes. Hence, such materials are called phase change materials. The phase change materials may be divided into three types as,

1. organic materials
2. Hydrated salts
3. Inorganic materials.

The most suitable phase change material under the category of organic materials is paraffin wax. They are suitable for space heating and cooling applications.

Hydrated salts such as, Sodium sulphate decahydrate is used for solar applications.

Properties required for a phase change materials are,

- * melting point should be in the range of working temperature of the application.
- * High latent heat of fusion.
- * negligible volume change during the phase change.
- * high thermal efficiency of the material.

Solar cooling:-

Most of the air conditioning and refrigeration systems are utilising solar energy. There are two such systems, that are using solar energy for producing refrigeration effect.

They are,

- i) Vapour compression system.
- ii) Absorption system.

i) Vapour compression system:-

In this, a heat pump converts the solar energy into mechanical energy, which in turn drives the compressor. Thus, the compressed vapour refrigerant is condensed and sent to the expansion valve. The expanded refrigerant absorbs the heat from the evaporator at low pressure, to give cooling effect.

ii) Absorption system:-

This system uses a refrigerant, that is mixed with the absorbent. The primary purpose of the absorbent is to dissipate the heat during generation and to absorb it during evaporation. Due to this, the cooling effect is produced.

where T_1 and T_2 denotes the temperature limits of cycle, mass inside the storage is m kg and specific heat is c_p . The system operates between the minimum of the requirements of the process and the vapour pressure of the liquid. (14)

The capacity of heat storage depends up on the product of c_p and m . most commonly used materials for storage are,

- a) water
- b) Rock and gravel
- c) Iron shot
- d) Iron, red-oxide and iron-ore
- e) Refractory materials like silicon oxide, magnesium oxide and aluminium oxide.

Water storage:-

Water is abundantly and cheaply available material with high thermal energy storage capacity. The energy is accumulated, when high temperature water is stored in an insulated tank. The characteristics of water as storage medium are,

- i) less expensive and readily available.
- ii) High thermal storage capacity
- iii) cost of pumping water less
- iv) no undesired temperature losses.

Electrical storage:-

It is further classified as

Capacity storage:-

capacitors are employed for the storage of large amount of electrical energy for long period. The energy stored is given by

$$W = \frac{1}{2} \epsilon V E^2$$

where, ϵ = constant

V - Dielectric volume

E - Electric field strength.

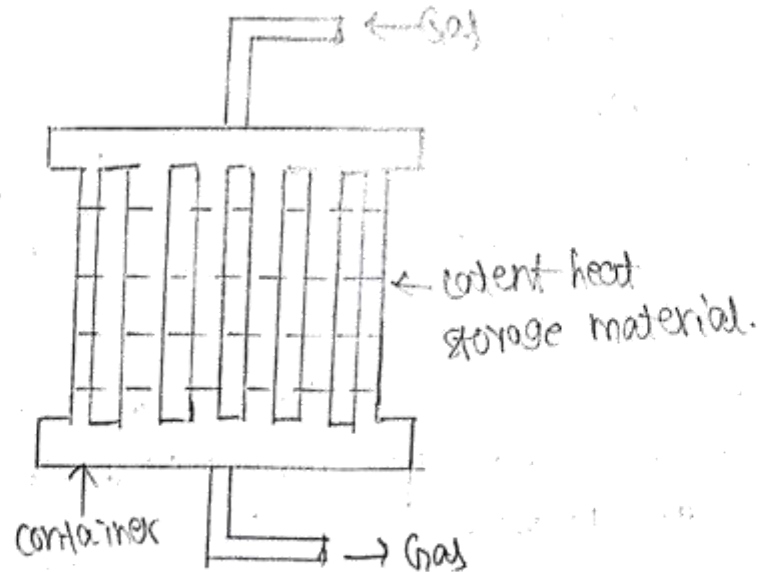
Electric field strength is dependent on the material and is limited to the breakdown strength (E_b) for the dielectric. The electric energy, thus invariable becomes limited for a material.

Latent Heat storage:-

In this, energy is stored by heating a material which undergoes a phase change. The energy storage capacity in this case is a function of mass and the latent heat of Fusion of the material.

The heat is stored in a material, when it melts and obtained from the material, when it solidifies or freezes. Hence, such materials are called phase change materials.

The major advantage of latent heat storage system is that it is compact in size, compared to a sensible heat storage system. However, the principle of working is complex, as it involves heat transfer between a fluid and storage material. First solidification of the heat transfer surface. Hence, the thermal resistance to the flow of heat keeps on increasing as heat is extracted from the storage. In order to prevent the excess thermal resistance the storage material is placed in long containers and the gas is passed through narrow space between the tubes.



merits of solar furnace:-

- * Solar furnace provides instantaneous heating and cooling.
- * It provides very high temperatures. (15)
- * The heat produced is free from contamination.
- * The various properties can be measured in an open pattern.
- * The pattern of furnace is provided by heating desired atmospheric conditions.

Demerits of solar furnace:-

- * The cost of the equipment is high.
- * Solar furnace can be used only on sunny days and for short period of duration.

Features of solar energy:-

Irrigation water pump utilizes the power generation by solar energy for water pumping useful for irrigation.

There are some features of solar energy that are attractive in utilizing the irrigation pumping. The greatest need for pumping occurs during the summer months when solar radiation is high.

During periods of low solar radiation, the need of pumping decreases, as there is less vapourization of water from crops.

Hence, an inexpensive pumped storage can be provided in the form of ponds, during the period of requirement.

The major disadvantage of utilizing the solar irrigation system is high capital cost. If the cost of solar pump can be reduced then solar irrigation could become economical.

Solar distillation:-

It is the process in which solar energy is used to convert saline water into distilled water. The pure water can be obtained by distillation in the simplest solar still, generally known as the 'basin type solar still'. This solar still mainly consists of a black basin and an airtight cover. The blackened basin contains saline water at a shallow depth and the space is totally covered by a transparent airtight cover usually made of glass or plastic, is sloped

towards a collection through. The solar radiation incidents on the black surface through cover which is converted into heat. The solar energy converted into heat vapourized the water and this vapour is condensed to purified water on the cooler interior of the roof. The condensed water is collected in the troughs at the bottom.

Applications of solar dryer:-

- * It is used for drying agricultural products.
- * Natural convection or direct type solar dryer is used in drying feed products.
- * mixed mode type solar driers are used for drying rice.
- * solar driers are used in both medium scale and large scale systems.

Advantages and disadvantages of solar cooker:-

Advantages:-

- * cost of fuel is eliminated.
- * solar cookers helps in conserving 3 or 4 LPG cylinders per year, if used regularly.
- * It ensures better and nutritious food because of the slow process for cooking.
- * It can be used for long durations.
- * simple in operation.

Dis-Advantages:-

- * It can work only on sunny days
- * It takes more time to cook the food.

Electrical Storage:-

(16)

large amount of rise in electrical energy is stored in capacitors. mostly batteries and capacitors are used to store energy. The expression for the total energy storage is given as

$$H_{cap} = \frac{1}{2} V \epsilon E^2$$

where

V - volume of the dielectric

ϵ - constant

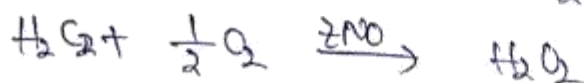
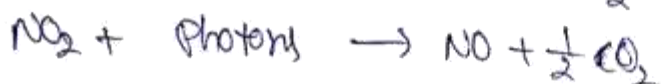
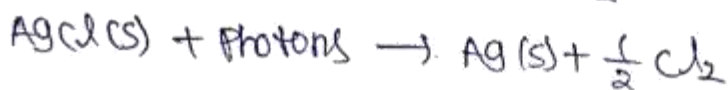
E - Electric field strength.

Chemical storage:-

It is classified into two types they are

i) Storage in the form of fuel:-

In this, the reactant in the battery is generated by a photochemical reaction promoted by solar radiation. The photochemically charged battery discharges electrical energy whenever needed. The photochemical reaction is shown below



ii) Thermo-chemical Energy Storage:-

In this type of storage, some reversible chemical reactions are used for storage of high temperatures. In forward reaction heat is absorbed and stored in the form of products and heat is liberated in the reversible reaction.



Mechanical Energy storage:-

This is classified into three types

i) Pumped hydroelectric storage:-

In this, the pumped water at higher heads is allowed to flow through a hydraulic turbine, which drives an electric generator.

ii) Compressed air storage:-

In this, air is pumped into a suitable pressurized storage tank and used, when the wind is unavailable. This air drives an air turbine, which in turn drives a generator.

iii) Flywheel storage:-

In this, the rotation of the flywheel can be used to operate a generator to produce electricity, whenever required.

Electromagnetic Energy Storage:-

In this, super conducting materials at lower temperature are used because they possess low resistance at lower temperature and they can carry storage electric currents with negligible loss. Due to the flow of electric current, an electromagnetic field is produced which can store energy.

Solar Energy Storage Methods:-

The few storage methods of solar energy are as follows,

1. Thermal energy storage.
2. Electrical storage.

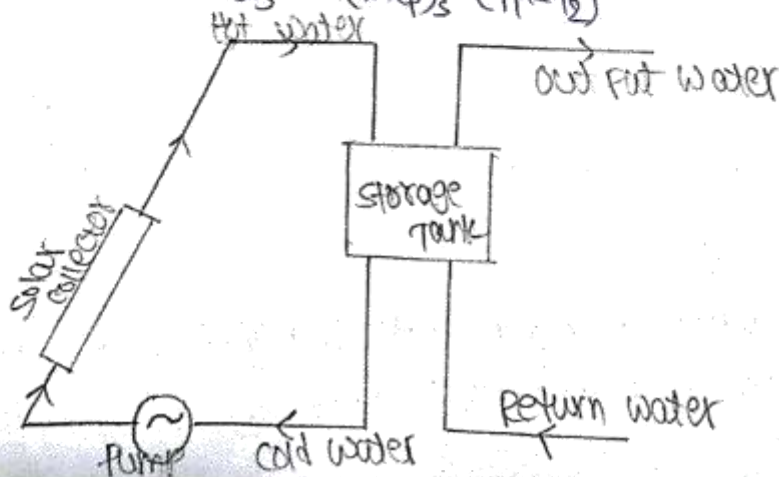
1. Thermal Energy Storage:-

It is further classified as follows,

Sensible Heat Storage:-

The material involved in the process undergoes no change in phase over the temperature range to which it is subjected in the storage unit. The equation for energy storage with respect to a fixed temperature difference is given as,

$$Q_s = (mcp)_s (T_1 - T_2)$$



Characteristics of Wind Energy :-

17

- * It is readily available in nature and does not cause any pollution.
- * It is clean and mostly available in many off shore, onshore and remote areas.
- * Desired winds are available only in few locations away from cities, forests etc.
- * Wind energy is unsteady, irregular, intermittent and erratic.
- * Direction of wind continuously changes.

Sources of Wind :-

The sources of winds are classified into two categories.

1. Planetary winds or global winds
2. Local winds.

1. Planetary or Global Winds :-

Planetary winds are those winds which usually blow under the influence of permanent or planetary belts.

2. Local Winds :-

Local winds are the winds which blow in accordance to local pressure gradient conditions. These originate from local weather conditions and blow for shorter period of time.

Controlling methods of Windmill :-

* The controlling arrangements required for operation of windmill are as follows

1. Direction control
2. Power control
3. Speed control
4. Pitch control of blades.

Methods used to overcome the fluctuating power generation of wind mill are,

1. one-site domestic unit with battery storage.
2. system with mechanical and solar storage.
3. power direct feed to main bus-bar.

Dis-Advantages of Large Wind Power Generators:-

- * Extremely high stresses are caused, during storms and gales.
- * Installation and maintenance are difficult.
- * Complex in design.
- * It involves mechanical, metallurgical and aerodynamic control problems, due to complexity in design.
- * Large units requires high technology.
- * Large land area is required.
- * Manufacturing of the system is expensive.

Applications of Wind Energy:-

The energy extracted from the wind is mechanical motion and it can be directly used for some applications or can be converted to electricity, heat or fuel.

Pumping applications:-

The typical application is pumping of irrigation water and other applications include the pumping of water for aqueducts or for pumped hydro storage of energy.

Direct heat applications:-

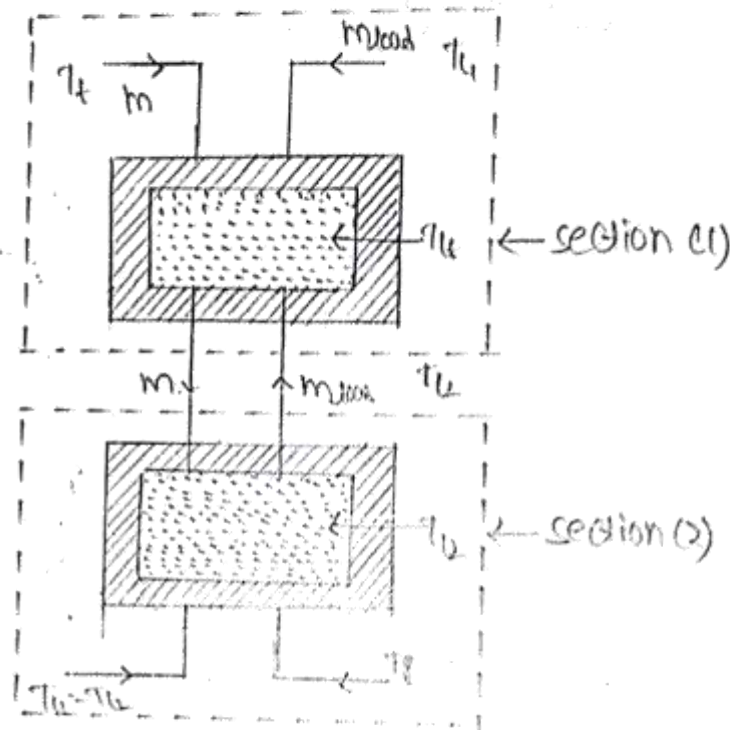
Mechanical motion derived from wind power can be used to drive a heat pump or to produce heat from the friction of solid materials or by the churning of water or other fluids or in other cases by the use of centrifugal or other types of pumps in combination with restrictive orifice that produce heat from friction and turbulence when the working fluid flows through them.

Thermal Energy storage:-

Thermal energy rise in can be stored in two ways that is sensible heat storage and latent heat storage. In sensible storage, heat is accumulated by the rise in temperature of the metal and in the latent heat storage, the heat energy is stored, when the medium undergoes a phase transformation.

It is quite difficult to analyse the thermally stratified tank as it considers the temperature profile to be solved, as a function of time. However, this issue is not considered practically in one dimensional, since the heat is conducted through the walls of storage tank.

The analysis of thermally stratified sensible heat liquid storage tank is shown in figure below.



Thermally stratified heat can be analysed by considering storage tank with various well-mixed sections of different temperatures and by writing energy balance equation for each section. For example assume that the storage tank with two well mixed sections having a temperature T_1 and T_2 respectively. The energy balance on these sections is given by

for section (1),

$$(PVc_p) e_1 \frac{dT_1}{dt} = m c_p (T_h - T_1) - m_{load} c_p (T_1 - T_h) - (UA) T_1 (T_1 - T_h) \dots (1)$$

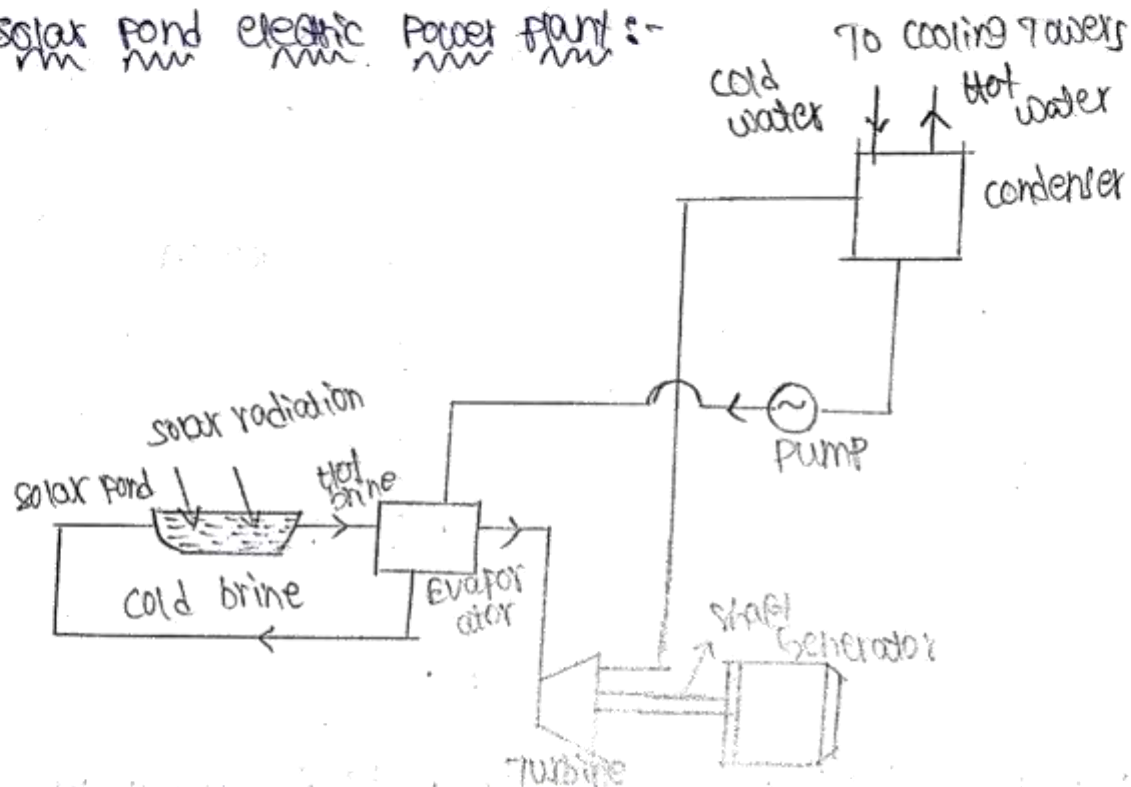
for section (2),

$$(PVc_p) e_2 \frac{dT_2}{dt} = m c_p (T_h - T_2) - m_{load} c_p (T_2 - T_h) - (UA) T_2 (T_2 - T_h) \dots (2)$$

The above equations are written based on the assumption that the flow enters the tank at section (1) only. This can be possible only when $T_0 > T_n$. If $T_0 < T_n$ then there is no existence of flow.

Then, by combining the differential equations (1) and (2), the value of T_n and T_h can be determined. The above equation can be solved by expressing them in finite difference form and selecting a specific time period.

Solar Pond Electric Power Plant :-



The above figure shows the solar pond electric power plant.

The solar pond is used for lower thermal electric power production. The solar pond receives and ~~low~~ absorbs the direct radiation from sun, thereby collect the heat. It can absorb about 50% radiation, which drops to 20% due to heat loss. Its lower layer of pond reaches above 60°C, then the generated heat is utilized to run the Rankine cycle heat engine. The organic exchanger and cooled by the condenser, thus, results in the pressure difference. Thus, the gas is vapour at this pressure is passed to turbine, where it expands and rotated the blades of the turbine. The generator set is connected to the turbine through shaft, thus producing electric energy.

The cycle is repeated by condensing the exhaust gas vapour in a condenser and pumping the fluid back to evaporator.

Applications of solar pond:-

19

The various applications of solar pond are as follows

1. Heating and cooling of buildings
2. Production of power.
3. Industrial process heat
4. Desalination
5. Drying crops on farms
6. Heat for biomass conversion.

Solar applications:-

The various solar applications are

1. Solar thermal applications
 - i) water heating
 - ii) space heating
 - iii) space cooling
 - iv) solar distillation
 - v) solar drying.
2. Photovoltaic applications
 - a) Industrial applications
 - i) Telecommunications
 - ii) cathodic protection
 - iii) Aircraft applications
 - iv) Alarm system
 - v) defence equipment
 - vi) Emergency equipment.
 - b) Electrical power generation
 - c) Consumer applications.

Passive solar space heating system:-

Passive solar space heating (CSSH) is generally adopted for heating of the houses and buildings. Based on the physical structure the solar space heating systems are classified as follows.

- a) Direct gain system
- b) Attached sun space system.
- c) Thermal storage wall system.
- d) Thermal storage roof system.
- e) Convective loop system.

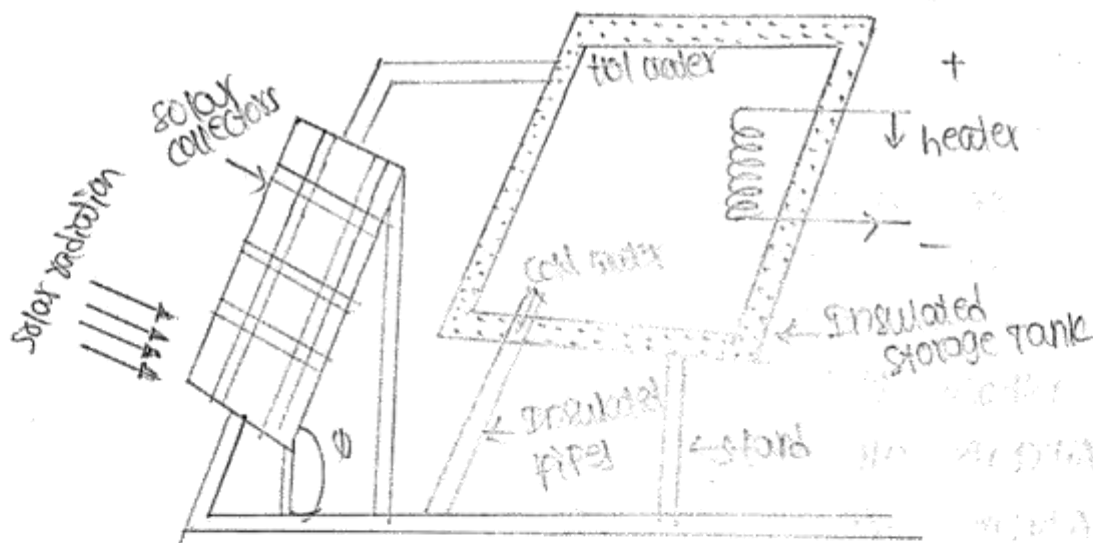
Natural circulation of solar water heating systems:-

This system is divided into two types. They are,

- a) Pressurized solar water heating system.
- b) Non pressurized solar water heating system.

a) Pressurized solar water heating system:-

The system works on the principle of thermo siphoning. It consists of collectors, insulated tanks, auxiliary heaters, insulated pipes, storage etc as shown in figure.

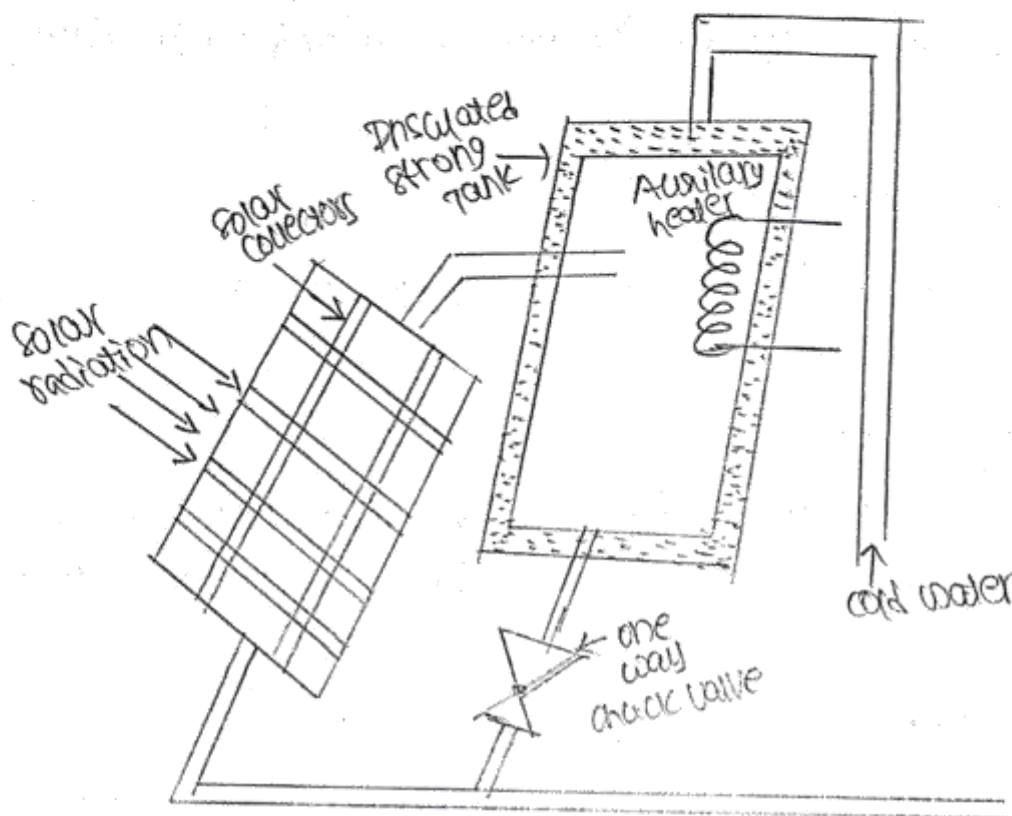


As the solar radiation falls on the collector it absorbs the heat from the panels and transfer the heat to the fluid i.e. water flowing in the tubes. The insulated tubes supply the hot water to the insulated storage tanks that are situated at height of 0.3 m from the bottom surface. The cold water is simultaneously sent from bottom portion of the tank. This circulation of water is carried by natural circulation and it is due to the difference in density of the cold water. This system can be used in cloudy and rainy days by providing an auxiliary heater in the storage tank.

6) non-pressurized solar water heating system:-

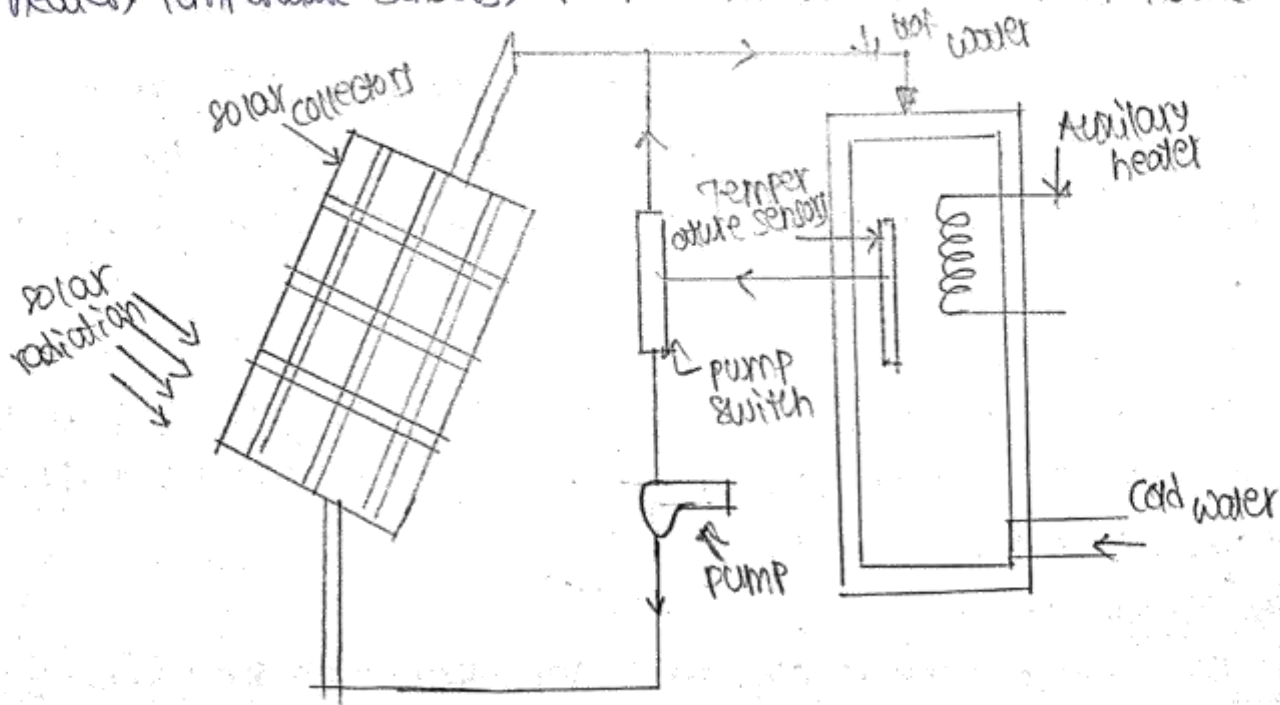
(20)

The non pressurized system consists of all the components of pressurized system except the one way valve situated near the collector as shown in figure. In this system water circulation is carried by the gravitation force.



forced circulation of solar heating system:-

This system consists of a solar collector, pump, storage tank, auxiliary heater, temperature sensors, pump switch etc as shown in figure.



In this system, as the solar radiation falls on the solar collector, the working fluid extracts the heat energy and heats the water. The water is pumped directly to the storage tank. When the temperature is retained, the hot water supply is closed due to the temperature sensor and pump switcher. There is a cold water inlet provided at the bottom position of the tank for simultaneous balancing of hot & cold water in collector. The auxiliary heater is provided for the cloudy and rainy days in the system.

Design of solar water heating system:-

The various parameters to be considered for the design of solar water heating systems are as follows.

1. Availability of Area:-

The area should be large for the installation of solar power plant. The solar water heater system with a capacity of 100 litres requiring a floor area of 3 m^2 .

2. Collector orientation:-

It is an important parameter for achieving maximum efficiency of a solar system. The collector should be faced to true South direction for absorbing maximum solar radiation.

3. Collector Tilt:-

The collector tilt position should be correlated to latitude of location as to allow maximum energy collection. In winter the collector tilt is equal to latitude $+15^\circ$ and in summer it is equal to latitude -15° .

4. Collector Area:-

The load carrying capacity of roof should be considered as the each collector area is large. The area of 2 m^2 collector approximately weighs 50 kg.

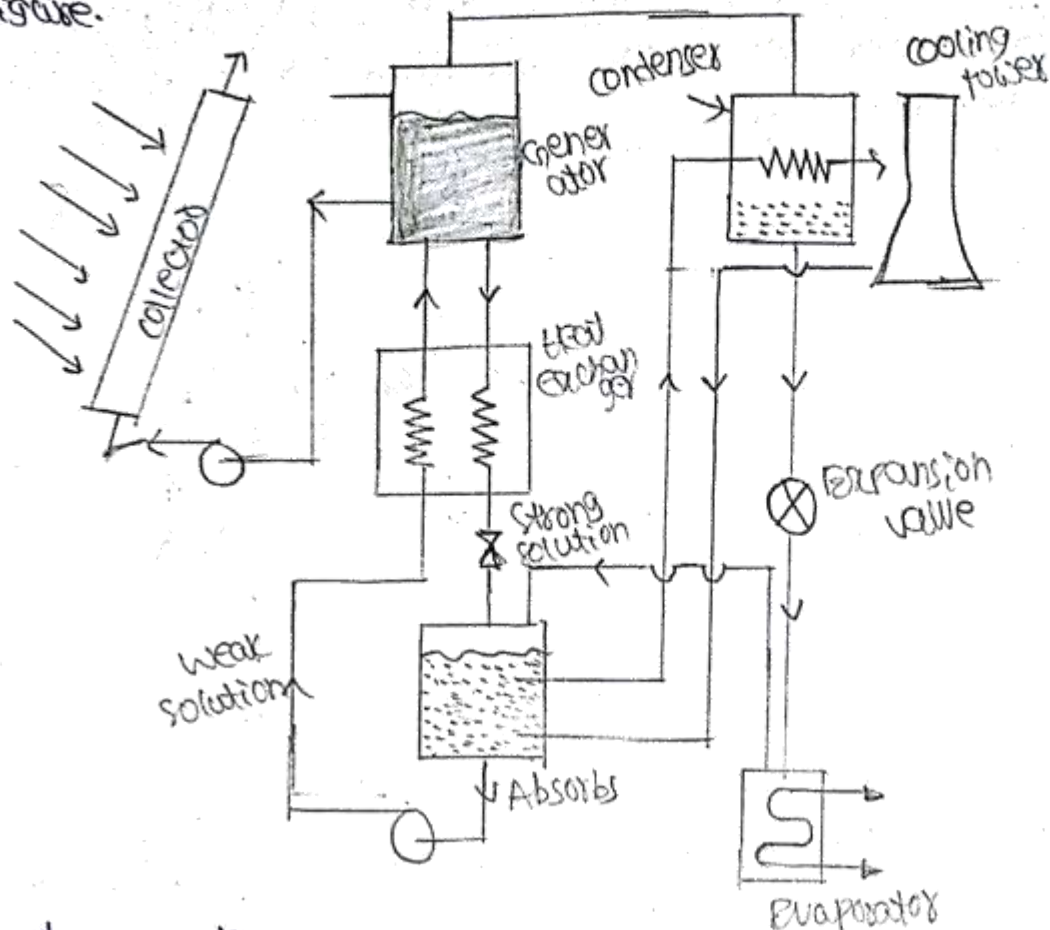
5. Storage Tank:-

The size of tank is considered depending up on the usage of hot water.

Continuous solar cooling system :-

(21)

The main components of the absorption cooling system are shown in figure.



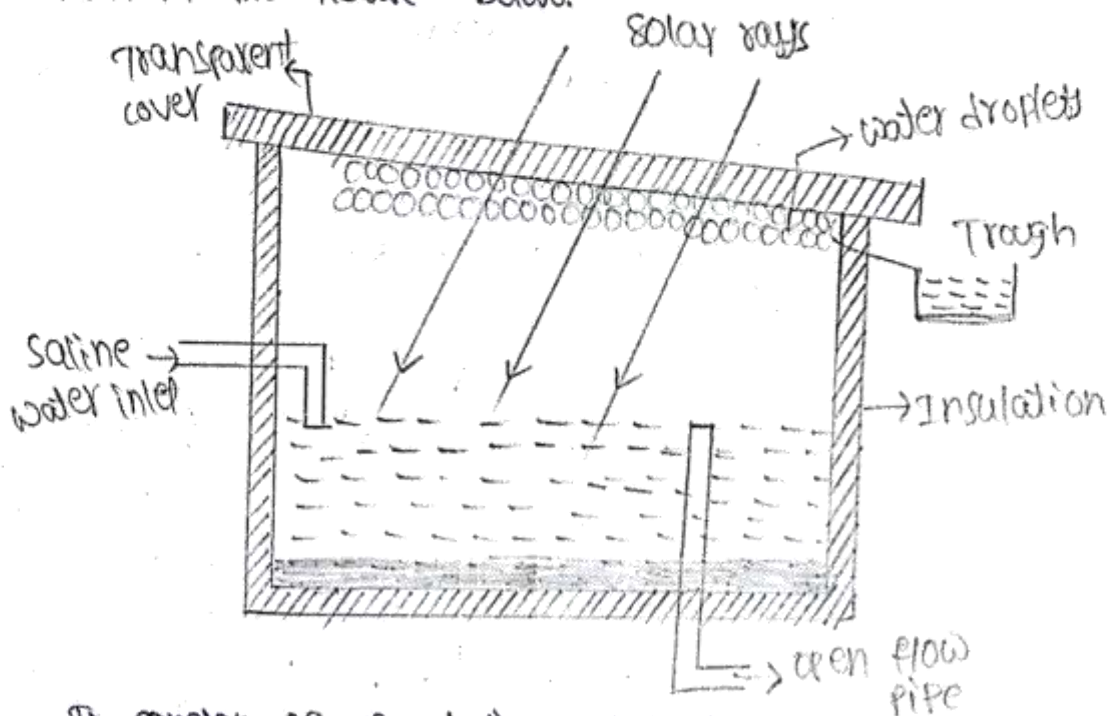
The generator of absorption cooling system is supplied with the heat produced by the flat plate collector, which is used to raise the temperature of water. Cooling water from cooling tower is used to condense the vapour formed in the generator. The condensed liquid from condenser is supplied through expansion valve to evaporator. The function of the expansion valve is to reduce the pressure of the refrigerant. Heat produced in the vapour evaporator is absorbed through the low temperature refrigerant or water. To avoid the crystallization of lithium bromide, the generator temperature is maintained between 75°C to 100°C .

Advantages :-

1. Other than the motor pump, the cooling system has no moving part.
2. There is no noise pollution.
3. Less wear
4. Low cost of maintenance
5. It is compact in size.

Solar distillation :-

Solar distillation is the process of converting the saline water into distilled or pure water, by the use of solar radiations. For this purpose a device called solar still is used. The basin type solar still is shown in the figure below.



It consists of a basin, which is made shallow and is coated with a black lining called basin liner, an overflow pipe, transparent glass cover, inlet for saline water and trough for collecting distilled water.

In this process, the solar rays are made to pass into the basin through a transparent cover. The evaporated water through vapour is condensed into water by the inner surface of the glass cover, which is at lower temperature.

Advantages :-

1. The operation is simple, as no chemicals are used.
2. The amount of energy consumed is less.
3. Highly skilled labour is not required, as the operation is easy.
4. Maintenance cost is low.

Power Generated by a wind mill from first principle:-

(22)

Power coefficient (C_p) for the wind mill is the ratio of maximum power to total power.

Consider incoming air between 'i' and 'a' as thermodynamic system. The general energy eqn is

$$\frac{P_i}{\rho} + \frac{V_i^2}{2} = \frac{P_a}{\rho} + \frac{V_a^2}{2}$$

$$P_i + \frac{\rho V_i^2}{2} = P_a + \frac{\rho V_a^2}{2}$$

The potential energy remains constant and there is no addition or removal of heat or work because of which potential energy terms, heat terms or work terms are not considered in energy eqn. Similarly, considering the air between b-e in exit region, the general energy eqn is

$$\frac{P_e}{\rho} + \frac{V_e^2}{2} = \frac{P_b}{\rho} + \frac{V_b^2}{2}$$

$$P_e + \frac{\rho V_e^2}{2} = P_b + \frac{\rho V_b^2}{2}$$

$$V_i > V_a, \quad V_b > V_e$$

$$\text{And } P_a > P_i \text{ and } P_b < P_a$$

Subtracting equation (2) from eqn (1)

$$\left[P_i + \frac{\rho V_i^2}{2} \right] - \left[P_e + \frac{\rho V_e^2}{2} \right] = \left[P_a + \frac{\rho V_a^2}{2} \right] - \left[P_b + \frac{\rho V_b^2}{2} \right] \quad \text{--- (3)}$$

As wind pressure returns to ambient pressure,

$$P_e = P_i \quad \text{--- (4)}$$

$$V_a = V_b \quad \text{--- (5)}$$

Substitute eqn 4, 5 in eqn 3,

$$\frac{\rho V_i^2}{2} - \frac{\rho V_e^2}{2} = P_a - P_b$$

$$P_a - P_b = \frac{\rho}{2} (V_i^2 - V_e^2)$$

Axial force on the turbine wheel area $\perp$ to stream is

$$F_x = (P_a - P_b) \times A = \frac{\rho}{2} (V_i^2 - V_e^2) \times A$$

$$= \frac{\rho A}{2} (V_i^2 - V_e^2)$$

i) cut in speed:-

cut in wind speed is the minimum wind speed at which the brakes are released and the prime mover starts rotating. The generator thus starts generation of power. It is the lower wind speed limit. Wind speed limit for the turbine to operate safely.

ii) cut out speed:-

cut out wind speed is the maximum wind speed above which the turbine or the prime mover runs at a speed beyond their limit. Wind speed above the cut out speed ~~will~~ affect the mechanical capacity, which may be hazardous.

iii) yaw controls:-

yaw control is the rotates according to the direction of wind, by controlling the nacelle about the vertical axis. In small wind turbines, the yaw control is achieved using a tail vane and in large turbines, a servo mechanism operated by a wind direction sensor is adopted.

iv) Co-efficient of performance of a wind mill:-

co-efficient of performance of a wind mill is the ratio of rotor output power to the maximum wind power available. Coefficient of performance,

$$C_p = \frac{\text{Rotor output power (P)}}{\text{maximum wind power available (P}_w)}$$

$$C_p = \frac{P}{\frac{1}{2} \rho A v^3}$$

where

ρ - is the density of the air

A - swept area (m^2)

v - velocity of the wind (m/s)