Chapter 4

Energy from biomass:

4.1 Introduction:

Plant matter created by the process of photosynthesis is called as biomass. Photosynthesis in plants is an example of biological conversion of solar energy into sugar and starches. Sugar and starches are energy rich compounds; if we plant fast growing trees having high photosynthesis efficiency, we can harvest and burn them to produce steam. Such an energy plantation would be economical renewable source.

The term biomass includes trees and agricultural plants. Biomass can be obtained from forest, Woods, agricultural lands, arid land and waste land, animal and human Waste.

The ways for obtaining energy from biomass are broadly classified into:

(i) direct method (ii) indirect method.

i) Direct method:

The direct way of using biomass is to burn it. The most common fuel used for burning is Wood. The wood is one of the man's primary source of energy.In India the cooking requirement of millions of village household is met by burning wood, agricultural waste and dung cakes. Cooking is done on stove (chulas) or on open fire. Chulas are made of mud of clays. Most of traditional chulas make poor use of heat released and give out smoke in large quantity. This reduces efficiency (usually 10 %). Hence efforts have been made in recent year to improve design of chulas so that more heat is transferred to the cooking pots.

For large scale, planned use of wood, the approach of energy plantation is adopted. In this approach, particular species of trees are planted and harvested regularly so that wood is continuously available for cooking. The trees like eucalyptus, babool and casuarina are grown up for the purpose. Electric power can be produced by energy plantation approach in which wood grown in this way is being used for the boilers of a conventional power plant. Such technology is well established in U.S.A. and Europe.

ii) Indirect method:

Biomass can be used indirectly by converting it into convenient usable fuel in solid, liquid and gaseous form. Biomass conversion processes can be classified into:

1. Biological conversion,

2. Thermochemical conversion.

Biological conversion includes process like fermentation. Thermochemical

conversion includes destructive distillation, pyrolysis and gasification.

4.2 Bio-mass conversion technologies:

Biogas is the fuel produced following the microbial decomposition of organic matter in absence of oxygen. Sewage, human and animal waste are the most common organic wastes

used for biogas production. Water weed, algae and agricultural residue can also be input.

Biomass is a mixture, containing 55 to 65 % methane and 30 to 40 %g CO_2. It is a clean

combustion fuel that can be used for cooking, space and water heating, lighting. It provides

mechanical power in agricultural machinery, Water pump and as a generator of

electricity.

There are two types of biogas plant They are:

(i) Floating gas holder type biogas plant

(ii) Fixed dome type biogas plant.

It should be noted that the raw material for producing biogas in both the plants is same

it is mixture of cattle dung and water called as slurry.

4.3 Biogas Generation:

Introduction: Biogas, a mixture containing 55-65 percent methane, 30-40 percent carbon dioxide and the rest being the impurities (H_2, H_2S, and some N_2), can be produced from the. decomposition of animal, plant and human waste. It is a clean but slow burning gas and usually has a calorifïc value between 5000 to 5500 kcal/kg (20935 to 23028 kJ/kg) or 38131 kJ/m^3. It can be used directly in cooking, reducing the demand for firewood. Moreover, the material from which the biogas is produced retains its value as a fertilizer and can be returned to the soil. Biogas has been popular on the name, “Gobar Gas’ mainly because cow dung hag been the material fork its production, hitherto. It is not only the excreta of the cattle but also the piggery waste as well as poultry droppings are very effectively used for biogas generation. A few other materials through which biogas can be generated are algae, crop residues (agro-wastes), garbage kitchen wastes, paper Wastes, sea wood, human waste, waste from sugarcane refinery, water hyacinth etc., apart from the above mentioned animal wastes. Any cellulosic organic material of animal or plant origin which is easily bio-degradable is a potential raw material for biogas production.

Biogas is produced by digestion, pyrolysis, or hydrogasification. Digestion is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70°C. The container in which this digestion takes place is known as the digester.

Anaerobic digestion: Biogas technology is concerned to micro-organisms. These are living creatures which are microscopic in size and are invisible to unaided eyes. These are different types of’ micro-organisms. They are called bacteria, fungi, Virus etc Bacteria again can be classified into two type-beneficial bacteria and harmful bacteria. Compost making production of biogas, vinegur, etc. are examples of beneficial bacteria, Bacteria, causing cholera, typhoid, diphtheria are examples of harmful bacteria. This type of bacteria which causes disease both in animals and human beings is called pathogen.

Bacteria can be divided into two major groups based on the oxygen requirement. Those which grow in presence of oxygen are called aerobic while the others grow in absence of gaseous oxygen are called anaerobic. When organic matter undergoes fermentation (process of chemical change in organic matter brought about by living organisms) through anaerobic digestion, gas is generated. This gas is known as bio-gas. Biogas is generated through fermentation or bio-digestion of various wastes by a variety of anaerobic and facultative-organism. Facultative bacteria are capable of growing both in presence and absence of air or oxygen.

Aerobic and anaerobic fermentation can be used to decompose organic matter, nominally aerobic fermentation produces CO_2, NH_3 and small amounts of other gases along with a decomposed mass and evolution of heat. Anaerobic fermentation produces CO_2, CH_4, H_2 and traces of other gases along with a decomposed mass. Aerobic fermentation is used when the main aim is to render the material hygenic and to recover the plant nutrients for reuse in the fields. The residue is rich in C, N_2, P, K and other nutrients. In a biogas plant the main aim is to generate methane and. hence anaerobic digestion is used. Here the complex organic molecule is broken down to sugar, alcohols, pesticides and amino acids by acid producing bacteria. These products are then used to produce methane by another category of bacteria.

As already mentioned the treatment of any slurry or sludge containing a large amount of organic matter, utilizing bacteria and other micro-organisms under anaerobic conditions is commonly referred to as anaerobic digestion or simply digestion. This anaerobic digestion consists broadly of three phases:

(i) Enzymatic hydrolysis: Where the fats, starches and proteins contained in cellulosic biomass are broken down into simple compounds.

(ii) Acid formation: Where the microorganisms of facultative and anaerobic group collectively called as acid farmers, hydrolyse and ferment, are broken to simple compounds into acids and volatile solids,. As a result complex organic compounds are broken down to short chemical simple organic acids. In some cases, these acids may produce in such large quantities that the pH may be lowered to a level where all biological activity is arrested. This initial acid phase of digestion may last about two weeks and during this period a large amount of carbon dioxide is given off.

(iii) Methane fermentation: Where organic acids as formed above are then converted into methane (CH_4) and CO_2 by the bacteria which are strictly anaerobs. These bacteria are called methane fermentation. For efficient digestion these acid formers and methane fermenters must remains in a state of dynamic equilibrium. This equilibrium is a very critical factor which decides the efficiency of generation. It has been demonstrated that the methane formers are sensitive to pH changes. A pH value between 6.5 to 8 is the best for fermentation and normal gas production. lf organic acids are formed at a faster rate than the limited population of rnethane formers can assimilate, then the accumulated acids Will reduce the pH to levels unfavourable to methane formers.

ln controlled waste digestion the environment must be maintained suitable for the continued growth of both acid forming and methane-forming bacteria. The proper environment requires balance between the population of organisms, food supply, temperature, pH and food accessibility. Digestion processes are being improved as the conditions which influence organic metabolism are better understood and better equipment and methods are available for controlling these conditions.

Basic processes and energetics: The general equation for anaerobic digestion is .

$$C_xH_yO_z + [x-(y/4)-(z/2)]\, H_2O \longrightarrow [x/2-y/8-z/4]\, CO_2 + [x/2+y/8-z/4]\, CH_4 \quad \ldots\ldots (1)$$

For cellulose this becomes

$$(C_6H_{10}O_5)_n+nH_2O \longrightarrow 3nCO_2+3nCH_4 \text{ ………… (2)}$$

Some organic material (e.g. lignin) and all inorganic inclusions do not digest. These add to the bulk of the materia1, form a scum and can easily clog the system. ln general 95% of the mass of the material is Water. The reactions are slightly exothermic, With typical heats of reaction being about l.5 MJ per kg dry digestible material, equal to about 250 kJ per mole of $C_6H_{10}O_5$. This is not sufficient to significantly affect the temperature of the bulk material. lf the input material had beep dried and burnt, the heat of combustion would have been about 16 MJ/kg only 10% of the potential heat of combustion need be lost in the digestion process. This is 90% conversion efficiency. Moreover very Wet input has been processed to give a highly convenient and controllable gaseous fuel, Whereas drying of 95% aqueous input would have taken a further 4O MJ per kg of solid input. In practice digestion is seldom left to go to completion because of the long time involved, and 60% conversion is common. Gas yield is about 0.2 to 0.4 m^3 per kg dry digestible input at STP with throughput of asset 5 kg dry digestible solid per m^3 of liquid.

It is generally considered that three ranges of temperature favour particular types of bacteria. Digestion at higher temperature proceeds more rapidly than at lower temperature, with gas yield rates doubling at about every 5^0C increase. The temperature ranges are (1) psicrophilic, about 20°C, (2) mesophilic, about 35°C and (3) thermophilic, about 55°C. In tropical countries unheated digesters are likely to be at average ground temperature between 20 and 30°C. Consequently the digestion is psicrophilic, with retention times being at least 14 days. In colder climates the digesters have to be heated, probably by using part of the biogas output, and at temperature of about 35°C is likely to be chosen. Few digesters operate at 55°C unless the purpose is to digest material rather than produce excess biogas.

The biochemical processes occur in three stages, each facilitated by distinct sets of anaerobic bacteria:

1 insoluble biodegradable materials, e.g. cellulose, polysaccharides and fats, are broken down to soluble carbohydrates and fatty acids. This occurs in about a day at 25°C in an active digester.

2. Acid forming bacteria produce mainly acetic and propionic acid. This stage likewise takes about one day at 25°C.

3. Methane forming bacteria slowly, in about ill Clays at 25°C, complete time digestion to ~ 70% =CH_4, ~ 30% CO_2 with trace amounts of H_2 and perhaps, H_2S. H_2 may play an essential

role, and indeed some bacteria (e.g. clostridium) are distinctive in producing H_2 as the final product.

The methane forming bacteria are sensitive to pH and conditions should be mildly acidic (pH 6.6to 7.0) and certainly not below pH 6.2. Nitrogen should be present at 10% by mass of dry input and phosphorus at 2%. A golden rule for successful digester operation is to maintain constant conditions of temperature and suitable input material. As a result a suitable population of bacteria is able to become established to suit these condition.

When comparison of methane percentage from different organic matter was done for example cow dung. Poultry dropping and dairy waste scum, then best result was observed in dairy waste. 75 to 79 methane percentage found in dairy waste biogas while in cowdung, biogas was only 65 percent.

Advantages of anaerobic digestion: There are number of advantages of anaerobic digestion.

1. Calorific value of gas: One of the main benefits is the production of a biproduct the biogas which has a calorific value and can therefore, be used as an energy source to produce steam or hot water. Because in dairy industries energy source is very important for dairy use, so there is no problem of gas storage or supply, but gas can be directly useful in heat energy.

2. New sludge production: The conversion of organic matter to methane and carbon dioxide results in a smaller quantity of excess sludge.

3. Stable sludge: In the case of municipal digestion the main reason for their installation was to produce a non-putrescable and inoffensive sludge and in many cases only a proportion of the gas produced was utilised.

4. Low running cost: There is no airation in the anaerobic treatment naturally in this digestion, running costs are a quarter of the equivalent aerobic system.

5. Low odour: Since the system is enclosed the odours are contained. Compounds which are responsible for odour are broken down, during digestion. The only slight odour of hydrogen sulphide normally presents in gas. However if the gas is burnt the problem will not arise.

6. Stability: A well adapted anaerobic sludge can be presented unfed for a considerable period of time without appreciable deterioration.

7. Pathogen reduction: Work has shown that passage of he effluent through the digester reduces the number of pathogens present, so reducing subsequent disposal problems.

8. Value of sludge: The cases where aerobic sludge is treated anaerobically the resultant sludge has a. higher nitrogen content giving it increasing value as a fertilizer. It has also been reported that the sludge acts as a soil conditioner.

9. Low nutrient requirement: As consequence of the low production of the bacteria] solids the nutrient requirement is also low.

In addition using of biogas in industries will curtail the consumption of coal. If biogas is used instead of coal in boilers, it will lessen the air pollution.

Factor Affecting Bio digestion or Generation of Gas:

The following are the factors that affect generation of biogas:

1) pH or the hydrogen-ion concentration
2) Temperature
3) Total so1id content of the feed maerja1
4) Loading rate
5) Seeding

The purposes of precasting the digester are:

(j) to achieve better technical results in controlled condition;

(ii) to relieve the farmers facing lot of troubles in procuring raw materials of the plant and getting skilled mason and labours; and

(iii) to facilitate use of vibrator for compact and impermeable construction.

4.4 Factors affecting bio-digestion (list of factors):

The following are the factors that affect generation of gas:

1. pH or the hydrogen-ion concentration
2. Temperature
3. Total solid content of the feed material
4. Loading rate
5. Seeding
6. Uniform feeding
7. Diameter to depth ratio
8. Carbon to nitrogen ratio

9. Nutrients
10. Mixing or stirring or agitation of the content of the digester
11. Retentation time or rate of feeding
12. Type of feed stocks
13. Toxicity due end product
14. Pressure
15. Acid accumulation inside the digester

4.5 Working of biogas plant:

(i) Floating gas - holder type bio-gas plant:

The biogas plant consists of two parts:

(i) Digestor : It is a well containing the animal waste in the form of slurry.

(ii) Dome : Dome floats on slurry and serves as gas holder.

The digestor is normally below ground level and two pipelines lead to it's bottom. One pipeline is for feeding the animal waste slurry. Other pipeline is for the spent slurry called

sludge to come out after it has undergone fermentation. The feeding is done regularly, once a day. The sludge come out when gas pressure is build up in the dome. Sludge retains the nitrogen phosphorus and potassium originally present in animal Waste hence, it is an excellent fertilizers.

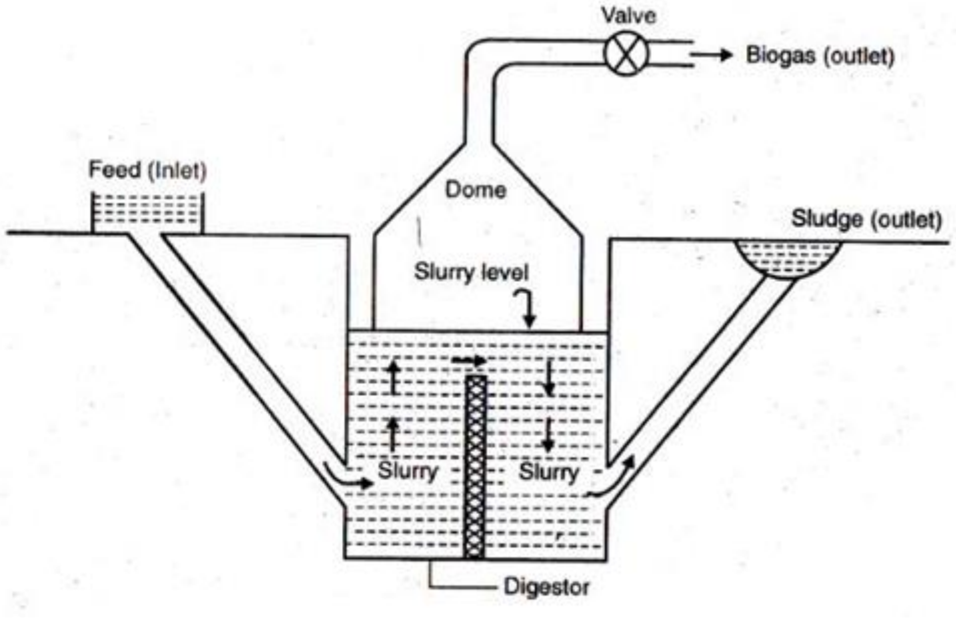

Figure 4.5.1 Floating gas-holder type biogas plant.

The diameter of digestor is about 1.2 to 6 m and its depth ranges from 3 to 6 m. There is a vertical partition wall which divides it in to two equal parts; Wall also serves to direct slurry flow.

The gas generation process takes place in two stages. In first stage, the complex, organic substances contained in the waste are acted upon by a certain type of bacteria called as acid formers. In second stage acids are acted upon by another kind of bacteria which produce methane and carbon dioxide as follows.

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

The biogas potential in India is very large." Biogas is available in different sizes. The design shown in Fig. 4.5.1is called the KVIC (Khadi and Village Industries Commission) model.

Advantages and disadvantages of Floating Drum plant:

Advantages:

1. It has less scum troubles because solids are constantly submerged.
2. No separate pressure equalizing device needed when fresh waste is added to the tank or digested slurry is withdrawn.
3. In it, the danger of mixing oxygen with the gas to form an explosive mixture is minimised.
4. Higher gas production per scum of the digester volume is achieved.
5. Floating drum has welded braces, which help in breaking the scum (floating mater) by rotation.
6. Minor problem of gas leakage.
7. Constant gas pressure.

Disadvantages:

1. It has higher cost, as cost is dependent on steel and cement.
2. Heat is lost through the metal gas holder, hence it troubles in colder regions and periods.
3. Gas holder require painting once or twice a year, depending on the humidity of the location.

4. Flexible pipe joining the gas holder to the main gas pipe requires maintenance, as it is damaged by ultraviolet rays in the sun. It may be twisted also, with the rotation of the drum for mixing or scum removal.

(ii) Chinese Digestor Mode (Fixed Dome type):

Chinese design is quite different from that KVIC, Chinese design contains a fixed dome for collection of gas. The gas is available at variable pressure. Main advantage of such design is that, cost of design is very much low and construction is easier. In floating gas holder type plant the defects in the welding of gas holder and corrosion of steel can lead to leakage of biogas. Being made of metal gas - holder has to be painted frequently. These disadvantages are removed in fixed dome type biogas plant.

Fixed dome type biogas plant consist of a well shaped underground tank called as digester, which is made of bricks and has dome shaped roof' made of cement and bricks (Fig. 4.5.2). The dome of digester tank acts as gas holder or storage tank for biogas. There is gas outlet at the top of dome.

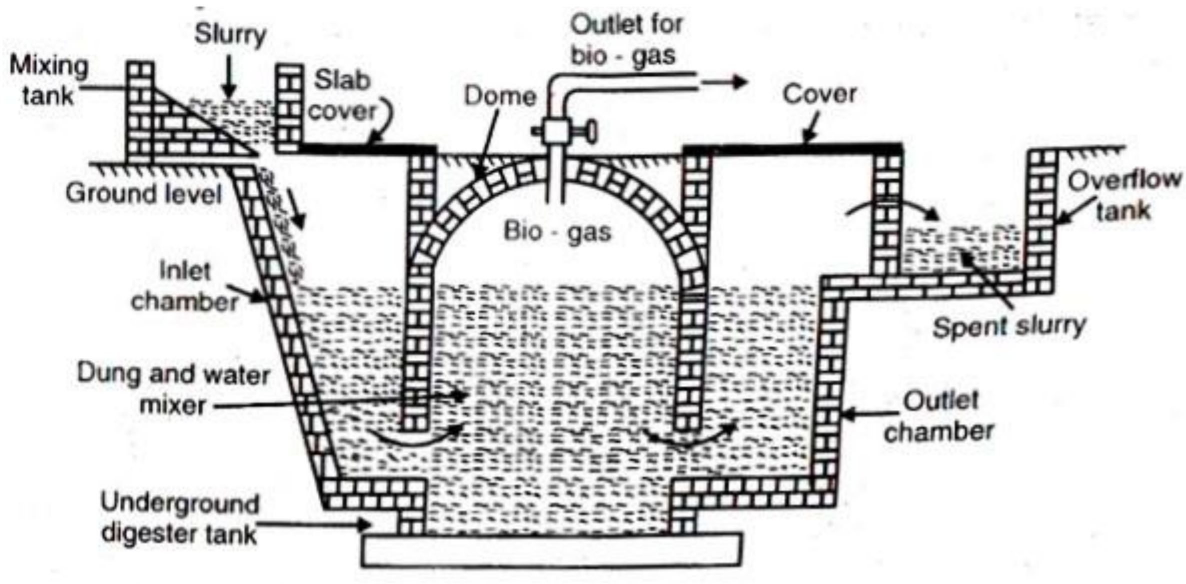

Figure 4.5.2 Fixed dome type biogas plant.

On the left side of the digester tank is a sloping inlet chamber and on right side a rectangular outlet chamber. Fresh slurry is introduced in digester through inlet chamber and whereas the outlet chamber is or taking out the spent dung slurry after extraction of biogas.

The working of this biogas is the similar as that of floating gas holder type biogas plant discussed earlier.

4.6 Advantages and disadvantage of floating and fixed dome type plant:

Advantages:

1. It has no corrosion trouble.
2. It has low cost compare to floating drum type, as it uses only cement and no steel.
3. No maintenance
4. Cattle and human excreta and long fibrous stalks can be fed.
5. In this type insulation is better as construction is beneath the ground. Temperature will be constant.

Disadvantages:

1. This type of plant needs the services of skilled masons, who are rather scarce in rural areas.
2. Gas production per cum of the digester volume is also less.
3. Scum formation is a problem as no stirring arrangement.
4. It has variable gas pressure.

4.7 Bio-gas from Plant Wastes:

The subject of biogas production from fresh-plant wastes is not new. Biogas production was a common feature even 40 years ago any European Farms, The biogas was used in kitchen oven, chicken hatching, washing machine, automobiles and other IC engines, room eating devices, refrigerators etc. These plants were essentially hatch fermentation plants which had heating systems.

The process of biodigestion as already described is carried out generally in following two recognized systems.

(1) Batch fermentation and

(2) Continuous fermentation.

In batch fermentation, the feeding is between intervals. The plant is emptied once the process of digestion is complete.

In continuous fermentation the feeding is done every day and digested slurry equivalent to the amount of feed overflows from the plant.

The continuous process may be completed in a single stage or separated into two stages.

(a) Single stage process: The entire process of conversion of complex organic compounds into biogas is completed in a single chamber. This chamber is regularly fed with the raw materials while the spent residue keeps moving out. Serious problems are encountered in a single stage continuous process. This subject is discussed separately.

(b) Double stage process: The acidogenic stage and methanogenic stage are physically separated into two chambers. This the first stage of acid-production is carried out in a separate chamber and only the diluted acids are fed into the second chamber where bio-methanation takes place and the biogas can he collected from the second chamber. Considering the problems encountered in fermenting fibrous plant waste materials the two stage process may offer higher potential of success; However appropriate technology suiting. to rural India is needed to be developed based on the double stage process.,

Wet and Dry Fermentation:

1. Wet Fermentation: In this case the digester is largely filled with water so that the dry matter generally remains less than 0%. The material similar to cow dung ferment very well in this process. However, fresh plant materials being1ight, float on water forming a scum. This scum must be broken and the materials are submerged every few hours to maintain continuity of the process. This is the0major problem encountered while fermenting agricultural waste by this process.

2. Dry fermentation: In order to prevent floatation of the plant materials on water, the amount of water in the digester is kept to it minimum which is just sufficient to keep the raw materials wet for its active fermentation. The total solids may be 25-30% with no free water.

This process is called dry fermentation. The problem of floatation and scum formation may not arise, but the accumulation of acids and entrapment of the gas in plant materials is likely to occur. The plug flow or movement of the plant material in the digester may also not take place. Thus the prob1e of pH regulation proper uniform culture, development and movement of the material pose serious problems in this process. Some of these problems may be less severe when dry fermentation is carried out in the batch fermentation process.

Problems in Straw Fermentation:

1. Scum Formation: When cow dung is mixed with equal amount of water it forms a smooth slurry which is self- buffered flows smoothly from inlet to outlet and ferments well in any simple digester. The straw material floats on water. Water is essential for fermentation but it also helps in scum formation. Even after the submergence of the straw material in the biogas digester the rising gas bubbles increase the buoyancy of the straw partj1es thereby it further helps in floatation. This scum become more compacted as the time progresses and may become sufficiently strong. When a family size plant is fully loaded with straw material, the freshly submerged scum may reappear within few hours during summer months. This phenomenon poses the greatest problem in successful straw fermentation in Continuous fermentation system. Thus suitable manual stirring device which one man (or a house wife) can operate is needed to be developed.

2. Movement in digester: Automatic movement of the charged materia1 inside the digester from its inlet to outlet due to the density gradient would be essential. While cow dung slurry moves smoothly allowing the gas bubbles to escape, the straw materials remain floating and may trap the gas. However it may move away from the feeding point as the slurry fed is daily pushed in. Since stirring (to break the scum) is essential there is a chance, that unfermented material may pass through the outlet, if the outlet is near the digester top. However, the density of the straw material approaches unity as it undergoes fermentation. It becomes less and less prone to floatation and tends to remain suspended in water. However, jt does not settle do at the bottom.

Pilot Plants Using Plant Wastes: There are many wastes such as paddy straw, or wheat straw, or water hyacinth etc. which can be utilized to generate biogas. A domestic biogas plant of 0.4 m^3 capacity was developed and fabricated at Jyoti Solar Energy Institute Vallabh Vidyanagar (Gujarat), which could be placed inside the kitchen and save 50% LPG requirements of a fami1ly. This plant uses water hyacinth (Echhonia Gassipes), a water weed, available in many parts of India. It is a very fast growing aquatic weed. Its annual productivity is about 1050 tonnes per hectare of water surface. This waste can be fed into biogas generator to generate biogas.

Physico-chemical characteristics of water hyacinth

Physical characteristics	Percentage
(i) Moisture	92.87
(ii) Total solids	7.13
(a) Volatile solids	5.82

(b) Residue	1.31

Chemical characteristics

(i) Carbon	32.51
(ii) Hydrogen	4.22
(iii) Nitrogen	1.78
(iv) Cellulose	25.00
(v) Lignin	10.99
(vi) Carbon nitrogen ratio	18.26
(vii) Specific gravity	0.25

Moisture and total solids are on wet weight basis and all other analysis are on dry wt. basis. From the above, we see that water hyacinth has a very high content of moisture and 83 per cent of its total solids are volatile. Its carbon to nitrogen ratio is 18.26 and cellulose content is 25%. Which shows that it has a good potentiality for biogas production.

The results of experiments on water hyacinth for bio-gas production are:

(j) Biogas production per kg of Wet water hyacinth	53.50 litres
(ii) Biogas production per kg of dried water hyacinth	750.61 litres
(iii) Biogas production per kg of volatile solids of water hyacinth	919.24 litres
(iv) Methane contents of the biogas generated from water hyacinth	78%

From the above result it is seen that 1 kilogramme of wet water hyacinth produced 53.5 litres of biogas with 78% of methane content, Retention period 30 days observed.

Behaviour of water hyacinth under biodegradation is different from that of cattle-dung. Cattle-dung has a specific gravity almost equal to water and remains wherever it has been fed into the digester white water hyacinth floats over Water surface when fresh and as digestion proceeds partially and fully decomposed material settles down at the bottom. So, traditional biogas plants based on cattle-dung as feed material could not be used for water hyacinth (also for other plant Wastes). It is also observed that deliberate efforts are required to bring an intimate contact of microbes with fresh and floating materia1for decomposition. The final decomposed material obtained is in powder form.

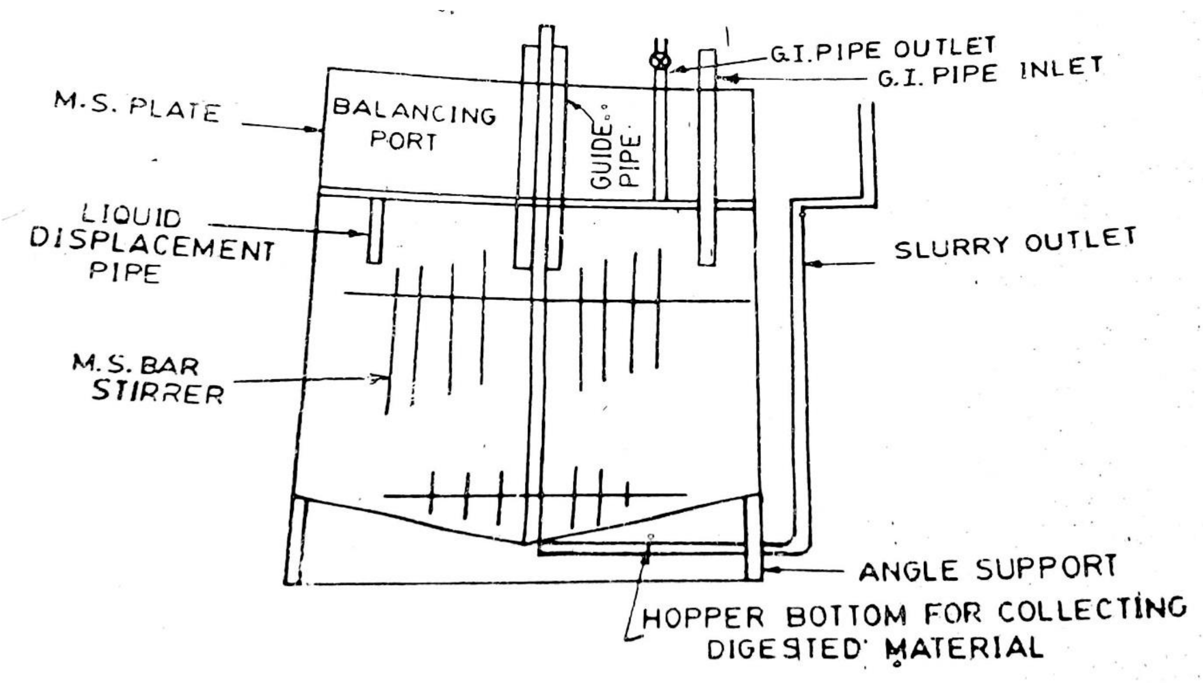

Fig. 4.7.1 A Domestic Biogas plant for water hyacinth.

The main design modifications done in traditional biogas plant being on cattle dung are:

(i) The inlet is provided near the top of the digester with proper feeding arrangement.

(ii) The slurry outlet is provided from the bottom of the digester.

The bottom should be hopper to facilitate the discharge of digested slurry.

(iji) There is a stirring (mixing) arrangement to bring the intimate contact of microbes with substrate.

In this plant, the 550 gms chopped dried water hyacinth is fed daily with 20 litres of water. 400 litres of biogas (with 78% methane content) is generated. Chopped wet water hyacinth initially mixed with digested slurry from a continuously operated gobar gas plant. It is concluded from this pilot plant that domestic biogas plant based on dried water hyacinth would be very useful for substituting the conventional fuels for cooking.

Kachra Gas Plant: A family size biogas plant (2-3 m^3 biogas per day capacity) based on continuous fermentation process was designed and tested at Gujarat Agricultural University Anand. This plant was named as "Kachra gas plant".

This is briefly described as follows,

This plant as shown is Fig. (4.7.2) all the modified arrangements as described earlier.

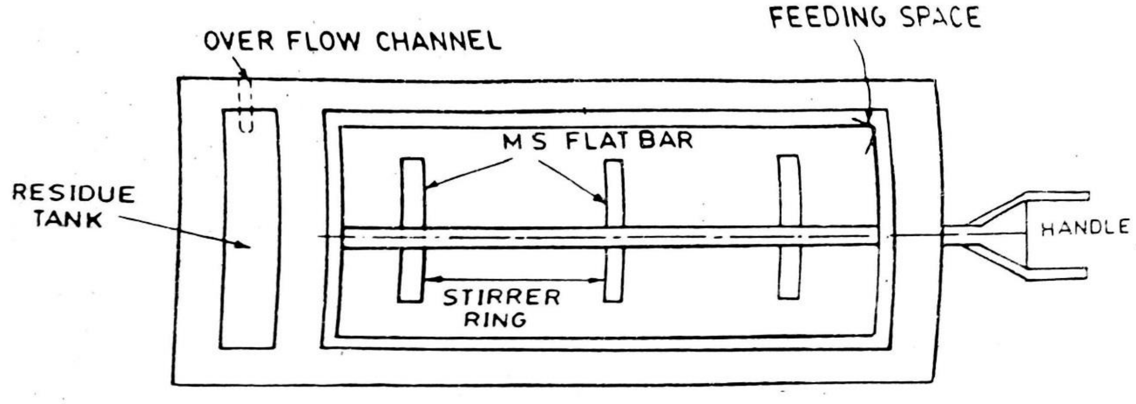

Fig. 4.7.2. Plan of a kachra gas pan.

Feeding: The feeding material must be chopped to few cm sized pieces when it consists of fresh water plant materials. Cow dung can be charged as such after breaking its clods by hand. The feeding material can be charged in any position. The plant was generally operated on singly type of materials for example, paddy straw or wheat straw or water hyacinth alone. The wheat or paddy straw was pushed air dry with a stick at the rate of 10 kg chopped material every day through the corner of the digester. Thus the problem of slurry making in the beginning is not involved.

Stirring: Stirring is the most important operation, since the material floats in a thick layer (30-40 cm). The stirring should be so designed that it should be able to submerge the floating material. In the present plant, the horizontal stirrer is provided which is mounted on a 4 cm dia. water pipe shaft.

Operation of Plant: The plant is initially filled with water in which few buckets of cow dung or dirty drain water, or well rotten compost are added. The fresh fibrous plant material is processed through the chaff cutter and about 10 kg chopped material is spread on the ground. This is frquent1y sprayed with water to keep it moist. Thus the material is charged into the digester after 10 days of decomposition. About 1 kg urea may also be added to the digester. The regularly feeding and stirring schedu1e may then be followed regularly. The evolved gas should be let out into air for about a week. During this period the gas should never be tested for burning due to possible danger of its explosion and accident.

4.8 Methods for obtaining energy from biomass:

We have seen that the photosynthetic processes of plants and certain bacteria use solar energy to in convert $C0_2$ and water into starch, cellulose or sugars with the evaluation of oxygen. Solar energy thus is biomass. The biomass energy from energy farms can be converted in to various energy forms. There an significant cost for biomass transportation. Biomass, because of its low density and low energy content per unit weight, does bear a significantly higher cost in transportation than natural gas or coal, Consequently, it would be unreasonable to expect to grow on energy crop and transport it a great distance to be converted into an end-use energy form. Instead, the biomass produced would he converted on site into electricity, synthetic natural gas, a pyrolytic char, or oil. which is more energy dense and more economical to transport. Also, on site utilization of biomass energy would allow co-generation from waste heat, overall efficiency. A most attractive concept is the location of biomass-fueled industries next to the energy farm, in this manner there are minimal cost involved in the transportation for the end user, and the fuel can he used in a more efficient end-use form, For example, the biomass can be converted through direct combustion to steam or electricity, or gasification to substitute for natural gas or as a chemical feed stock.

The processes by which the products of energy farms can be converted into various energy forms will he discussed only briefly here. (figure 4.8.1).

Combustion: One process now in commercial operation that uses biomass to produce energy is combustion. Direct combustion requires biomass with a moisture content around 15 per cent or less, so it may require drying prior to combustion for most of the crops. The combustion produces steam both for process use and for electricity. The again economies of the combustion of wood for steam production varies at the many papermills, sawmill and various other industries that utilize this technology. However, the fast that these industries have the availability of convenlional fuels such as fuel oil and coal and yet choose to use wastes, demonstrates the fact that the combination of the disposal credit for the waste material and its immediate availability makes it very competitive with existing fuels.

Electricity san also be produced by installing require capacity power plant near the industry.

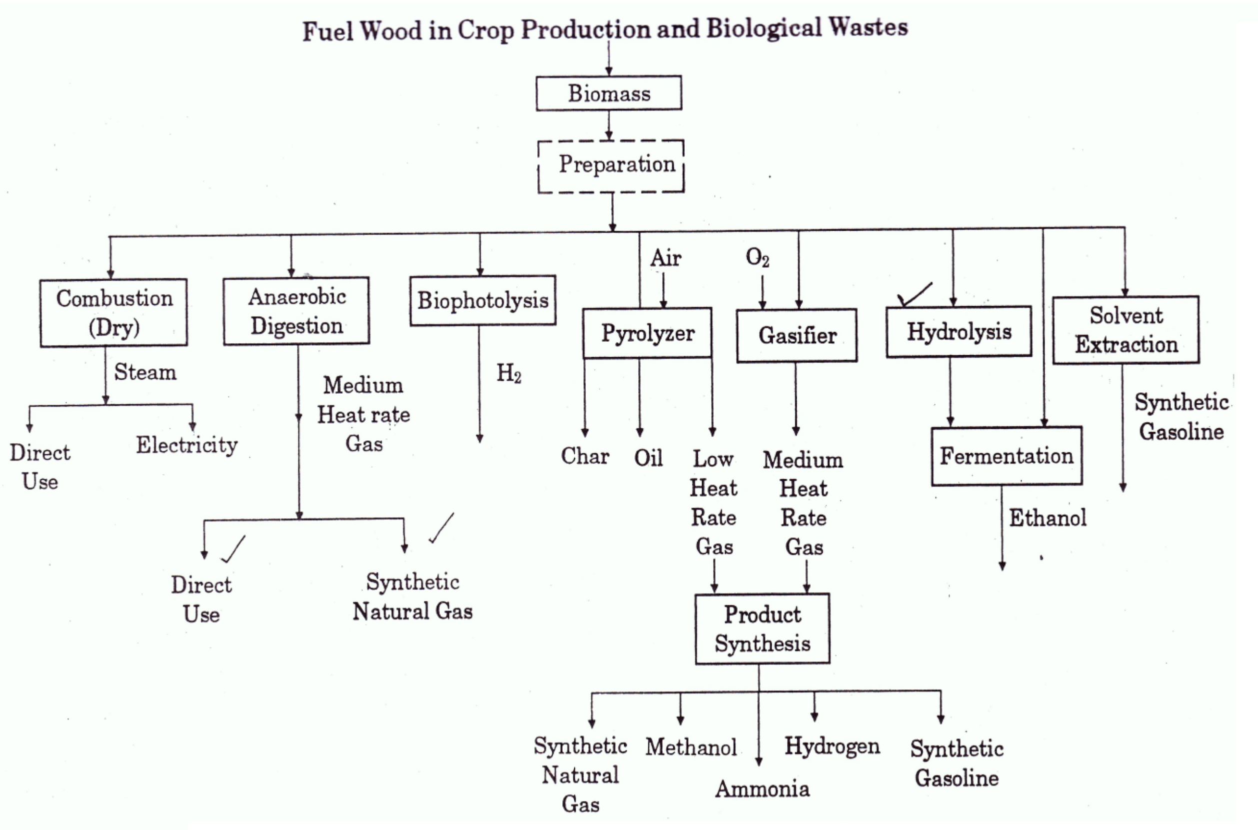

Figure 4.8.1 Possible energy conversion routes and products from biomass

Anaerobic digestion: Anaerobic digestion and combustion are probably the two most promising existing technologies because they have the longest history of use with established economics and are in current use with biomass wastes commercially. Anaerobic digestion process is described already in detail in previous sections. Anaerobic digestion plants are simple in construction with low capital outlay. Anaerobic digestion of organic wastes may constitute an effective device for pollution control in addition to energy generation. The main advantage of this biochemical process is that it utilizes biomass with water content as high as 99 per cent. Another advantage is that small units are available, which can be operated at individual farms. Furthermore, the residue has fertiliser value. The primary limitation with this process is that the large quantity of waste water is to be disposed of after digestion.

Pyrolysis: It is an irreversible chemical change caused by the action of heat in absence of oxygen. This process may yield either solid, liquid or gaseous fuel. Without oxygen the energy splits the chemical bonds and leaves the energy stored in biomass. The reactions are complex in the process. Pyrolysis of cow manure, wand-saw dust, liberates H_2, N_2, CO, CO_2, C_2H_6, C_2H_6 and C_7H_8. Hydrogen and carbon monoxide can be converted into methanol, gasoline, diesel ammonia for fertilisers, drugs. building or bonding materials and synthetic textiles.

The main advantages of pyrolysis include, compactness, simple equipment, low pressure operation, negligible waste product and high conversion efficiency' of the order of 83%.

Hydrolysis and Ethanol Fermentation:

Hydrolysis is the technology which converts cellulose to alcohols through fermentation. Ethyl alcohol can be produced from a variety of sugar by fermentation with yeasts. Molasses is diluted with water to a sugar content of about 20 percent by weight, acidified to pH 4.5 and then mixed with yeast culture (5% by volum¢) in a fermenter. Ammonia is used to produced acidity. When 8-10 percent alcohol is accumulated, then liquid is distilled, fractionated and rectified 2.5 litters of can molasses produces about one litre alcohol. Alcohol fermentation of a large variety of substrates has been obtained. They include: corn barley mashes, sugarcane, molasses and chees way, sugar beet molasses and potatoes.

Gasifier: A most promising conversion technology is pyrolysis-gasification. Considerable experience in commercial operations with this technology took place in Europe and continuous in numerous-Third-World countries for generation of low hosting value gas and electric production from biomass waste materials. Then is a considerable new research and development under way, and several commercial manufacturing operations are beginning to produce gasifiers. This technology is expected to be available within the next few yours on a commercial basis. It appears to be economically competitive with natural gas at todays prices using biomass wastes and would be economically competitive in near future if its feed stocks were dry annual energy crops.

4.9 Thermochemical process for gasification of biomass:

Thermochemical process consists of following processes:

1. destructive distillation

2. pyrolysis

3. gasification.

Here we will discuss biomass gasification in detail.

Biomass gasification is a process which permits conversion of biomass into combustible gas. The biomass is usually in the form of piece of wood or agricultural residue. The combustion is partial because the air supply is intentionally kept less than the amount required for the full combustion of biomass. As a result, gaseous mixture of CO,

CO_2, H_2 and N_2 called producer gas is obtained.

Biomass gasifier is divided into -

1. Fixed (or moving) bed

2. Fluidized bed

3. Suspended particle gasifier.

Fixed bed gasifier is also divided into:

(i) Upward gasifier

(ii) Downward gasifier.

Upward gasifier produces upto 20 % tar with gas. This restricts their use to application.

where this tar can be burnt immediately or used chemically.

Fluidized and suspended bed operates at large scale.

4.10 Working of downdraft gasifier:

Downward gasifier produces 0.1 % tar and have been widely used in small size to produce gas for vehicles or power generation.

A schematic diagram of downdraft gasifier is shown in Fig. 4.10.1. The gasifier is a vertical cylindrical vessel of variable cross section. The biomass is fed at the top at regular intervals of time. It has to go through a series of processes till producer gas and ash is produced. The ash moves slowly downwards.

The first zone of gasifier is the drying zone. In this zone, water content (moisture) in upper level of biomass is removed by evaporation. The temperature of this zone is about 120°C and acquired by heat transfer from lower zone (second zone).

The second zone is pyrolysis zone. The dried biomass moves through second zone. It is at temperature 200°C to 700°C from top to bottom. The biomass loses its volatiles when it moves through this zone. At 400°C, sustaining exothermic reaction takes place in which

structure of biomass breaks down. Thereafter water vapour, methanol, acetic acid and hydrocarbon tar are evolved. The solid products then pass to third zone.

The third zone is called as combustion (or oxidation) zone. Predetermined quantity of air is drawn into the zone through nozzles. The temperatures ranging 900°C.to 1200°C' are attained in this zone. Combustion reactions are similar to those occurring in a furnace.

Portion of char and the pyrolysed gases coming from previous zone are burnt. The main reactions taking place are exothermic and the resultant products are CO_2 and water vapours.

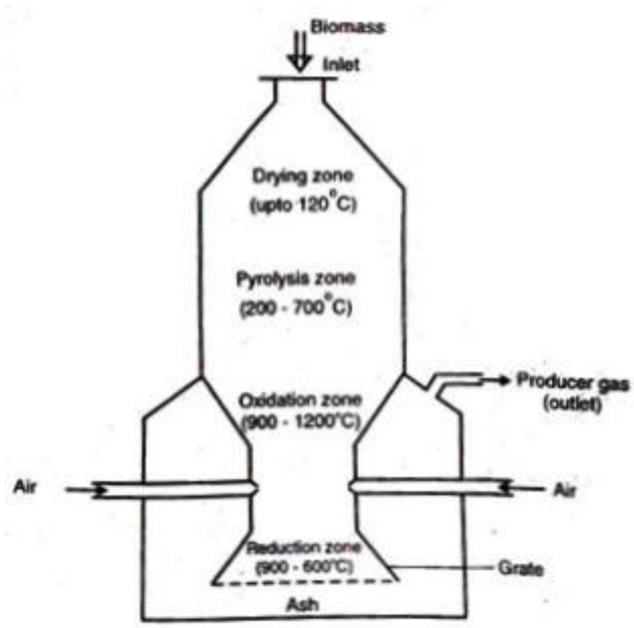

Fig. 4.10.1 Downdraft gasifier

The remaining products pass into fourth zone called as the reduction zone. This zone is at 900°C to 600°C. The highest temperature being near the oxidation zone. The principal reactions are reducing in nature and endothermic. These reactions are:

$$CO_2 + C \rightarrow 2CO$$

$$C + H_2O \rightarrow CO + H_2$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2$$

Due to endothermic nature, the temperature of zone progressively decreases. Finally, the char is fully consumed and final products are producer gas and ash.

A The producer gas produced by such method contains N_2 (45.54 %), CO (20.22 %), H_2

(15.18 %), CO_2 (9.11 %), CH_4 (2.4 %) and small quantity of tar.

The heating value of gasifier is less as compared to heating value of other gaseous fuel like natural gas. The conversion efficiency (ratio of heat content in producer gas to heat content in biomass supplied) is around 75 %.

The output of a biomass gasifier can be used for variety of applications such as cooking,

drying, heating water and generating steam. It can be used as fuel for internal combustion engines.

4.11 Advantages and disadvantages of biological conversion of solar energy:

Advantages:

1. The initial investment is comparatively low, compared to other methods of solar energy utilization, since sophisticated or expensive equipment is not needed.
2. Processing biomass for fuel sewage and wastes reduces the environmental hazards.
3. The techniques for raising such plants are simple and similar to conventional agriculture. Hence they can be readily used in the rural areas of developing countries.
4. Small units can be located near to the accumulation of waste in the forming region.
5. The by-products of such a system can be fully recycled.
6. The methods of power production are relatively low polluting.
7. Bio-gas can be distributed through GI pipes for domestic use, and
8. lt can be stored _in container which can be transported to consumers.
9. ln rural areas hygenic and sanitation conditions are improved.
10. The production of biological fuels may be coupled to the synthesis of protein.

Disadvantages or Limitations:

1. The land area required is relatively large and hence this method is ruled out for areas where land cost is high.
2. Photosynthesis efficiency or a small percentage (of the order of 0.1%) of solar radiations are converted into biomass by plants.
3. The cost of energy produced is higher than in urban areas with centralised power generation stations.
4. Relatively low concentration of biomass per unit area of land.
5. Collection and transportation of (biomass become expensive due to high moisture contents (of the order of 50---95%).

6. Since the gas cannot be liquefied ordinarily there is storage problems, it can not be bottled like LPG into cylinder.

QUESTIONS AND EXAMPLES

1. What is boimass ? Explain how energy is obtained by biomass.
2. Describe construction and working of biogas plant.
3. What is thermochemical process ? Explain how biomass is gasified by gasifier.
4. What are advantages and disadvantage of floating and fixed dome type biogas plant.
5. List the factors that affect on generation of gas.
6. State factors affecting on Bio-digestion.
7. What are the advantages of fixed dome type plant?
8. Explain the term Biogas from plant wastes.
9. What is gasifier? Explain working of 'Downdraft gasifier'.
10. Explain the applications of the gasifier.
11. State the applications of biogas.
12. What is Bio-Masss?
13. What is thermochemical pyrolysis?
14. What is biomass? What are the methods of producing energy from biomass? Explain the working of downdraft gasifier.
15. Explain the photosynthesis process in brief and give its necessary conditions.
16. Draw and explain working of 'Downdraft gasifier'.
17. What is meant by anaerobic digestion? What are the factors which affect biodigestion? Explain briefly.
18. Sate necessary condition for photosynthesis.
19. Explain biogas plant in detail with necessary diagram.
20. Explain the effect of green house on environment.
21. Explain energy plantation.

CHAPTER 5

Wind Energy and Energy Audit

5.1 Introduction

Nature of Wind

Winds are caused because of two factors (i) the absorption solar energy on the earth's surface and in the atmosphere, and (ii) the rotation of earth about its axis and its motion around the sun. Because of these factors, alternate heating and cooling cycles occur; differences in pressure are created, and Wind energy is thus an indirect manifestation of solar energy. The advantages of using wind energy are that its potential as a source of power is reasonably good and that its capture produces no pollution. The problems associated with utilizing it are the same as those associated with using solar energy directly. Firstly, the energy is available in dilute form, and secondly, the availability of the energy varies considerably over a day and with the seasons. For these reasons, the face areas of machines, which extract energy from the Wind, have to be necessarily large and a continuous supply of mechanical or electrical power cannot be obtained from them.

History:

Historically, Wind energy was used for sailing ships and for generating small amounts of mechanical power through wind mills. One of the most popular and long lasting designs was that of the horizontal axis four blade Dutch wind mill. This design was used extensively in Europe from 1200 AD onwards for a few hundred years for grinding grain and for pumping water. Dutch settlers brought the design with them to the USA around 1700 AD and over the years, by about 1850 AD, the popular horizontal axis multi-blade type evolved. A few million wind mills of this type usually generating less than 1 kW of power were in use in the United States at the beginning of this century. They were generally used to pump water or to generate electricity. With the advent of central power plants (based on hydroelectric or thermal power) and the spread of rural electrification, wind mills started to become economically unviable around 1920. Although a number of new designs were developed, wind energy ceased to be an effective means of supplying power by 1940. The new designs developed include the two or three blade propeller type design, and the Savonius and Darrieus types. ln contrast to the earlier designs, the last two were vertical axis machines. The late 1930s also saw the construction of the largest Wind machine the Smith Putnam machine built so far. This was a horizontal axis two blade propeller type of machine. It had a 175 ft. diameter rotor and generated 1250 kW of electrical power at its rated speed of 28 rpm. After a few years of intermittent operation, during which there were some major mechanical failures, the machine was finally abandoned as being economically unviable.

Recent Developments:

With the advent of the oil crisis in 1973, interest wind energy has picked up considerably. A number of research and development programmes to build and test both small and large scale wind energy conversion systems have been undertaken. As a result, many commercial models ranging in capacity from a few watts to a few hundred kilowatts are now available. In the last decade, wind energy is again becoming cost effective and the total installed capacity in the world already exceeds 2500 MW. Most of the machines installed are of the two or three blade propeller type. These machines are usually located side by side in suitable Wind swept locations, the Whole cluster being referred to as a wind farm.

Significant developments have also taken place in India in the last ten or fifteen years. Designs of small capacity multi-blade wind mills for pumping water have been standardized and hundreds of such machines have been installed across the country. ln addition, a beginning was made for producing electricity by erecting demonstration wind farms at five coastal locations. These had an installed capacity of 3 MW, about 0.5 MW being generated at each location using a number of 55 kW propeller type machines. Subsequently other wind farms using machines of larger capacity (200 kW) have been set up and the total installed capacity in the country now exceeds 100 MW, Much of this capacity is in Gujarat and Tamil Nadu. The practice followed in wind farms is to connect the machines to the electricity grid and to feed power from the machines to the grid whenever available. The average cost of installation is currently about Rs 30,000 per kW. This is considered to be reasonably cost effective and yields a payback period of 4 to 5 years at the current prices paid by the State Electricity Boards for feeding power to the grids.

5.2 Classification and Description of wind machines:

Classification:

Wind machines are generally classified in terms of the orientation of the axis of rotation of their rotors as horizontal axis machines and vertical axis machines. In a horizontal axis machine, the rotor axis is horizontal and can be adjusted so that it is parallel to the direction of the Wind stream. On the other hand, in a vertical axis machine, the rotor axis is vertical and fixed, and is perpendicular to both the surface of the earth and the wind stream.

Rotors

Various types of rotors used in wind machines are shown in Fig. 5.2.1 These are (i) multi-blade type, (ii) propeller type, (iii) Savonius type, and (iv) Darrieus type. The first two are used in horizontal axis machines, and the last two in veridical axis machines. The mule-blade rotor consists of a number of curved sheet metal blades which increase in width going outwards from the centre. The number of blades usually ranges from 12 to 20. They are fixed at their inner end to a circular rim. They are also fixed near their outer edge to a second rim, which provides support. The diameter of the rotor usually ranges from 2 to 5 m.

In contrast to a multi-blade rotor, the propeller rotor consists of only two or three blades made from glassfibre reinforced plastic. The blades have aerofoil sections with a high thickness- to-chord ratio and yield a high lift relative to the drag. The diameter of the rotor usually ranges from 2 to 25 m.

The Savonius rotor consists essentially of a hollow cylinder (approximately elliptical in shape) sliced in half, the two halves being fixed to a vertical axis with a gap in between to make an S-shape. Torque is produced by the pressure difference between the two sides of the half facing the wind.

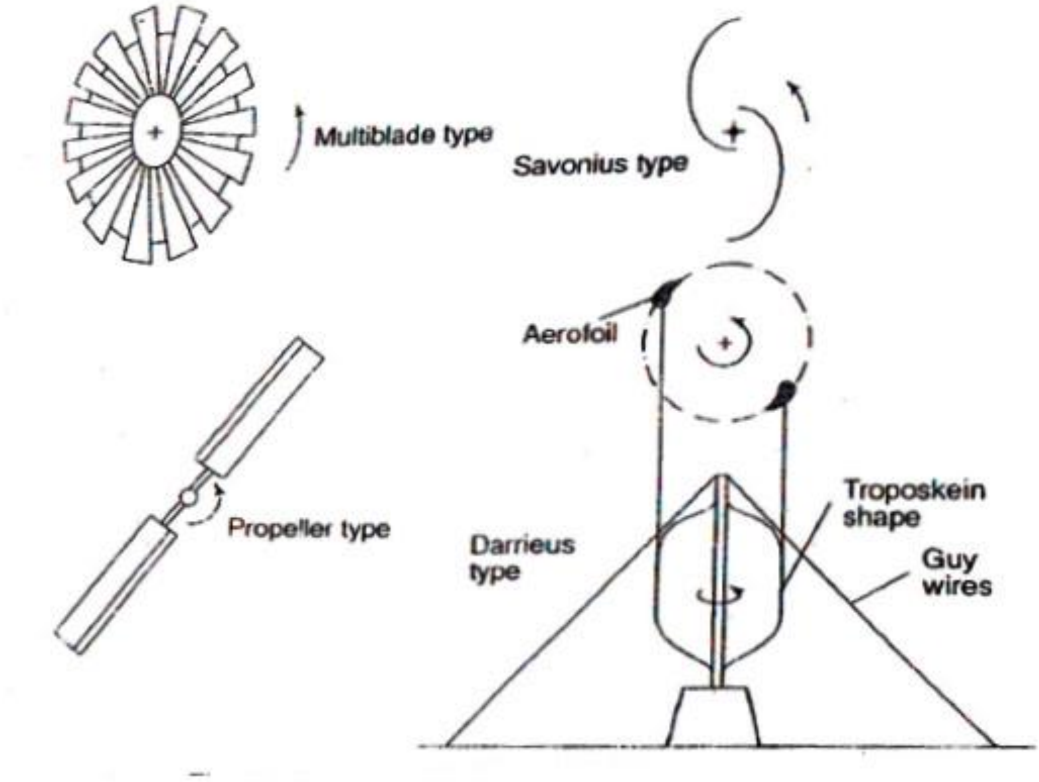

Fig. 5.2.1 is Various types of Wind Machines Rotors

The Darrieus rotor is shaped somewhat like an egg beater. It consists of two or three blades having an aerofoil cross section. Along the length, the blades are curved into a shape called a troposkein. The troposkein is the shape which a rope would take up if rotated about a vertical axis. It is to be noted that both the Savonius and Darrieus type run independently of the direction of the wind because they rotate about a vertical axis. On the other hand, horizontal axis machines have to face the direction of the wind in order to generate power.

Multi-blade Type Wind Machine:

A simplified sketch of a multi-blade type wind machine is shown in Fig. 5.2.2. The main elements are the rotor, the wind mill head (casing), the tail vane, the transmission system and the supporting structure (tower). The machine is normally used for pumping water. For this reason, an additional component at the base of the tower is a water pump. The rotor overhangs at one end of the shaft emerging from the wind mill head. The centre of the rotor is referred to as the hub. Just behind it is the front bearing of the machine.

The transmission system consists of a power shaft, a speed reducing gear drive, a crank shaft-connecting rod mechanism and a pump rod. The gear drive reduces the rotational speed by a factor of 3 or 4.

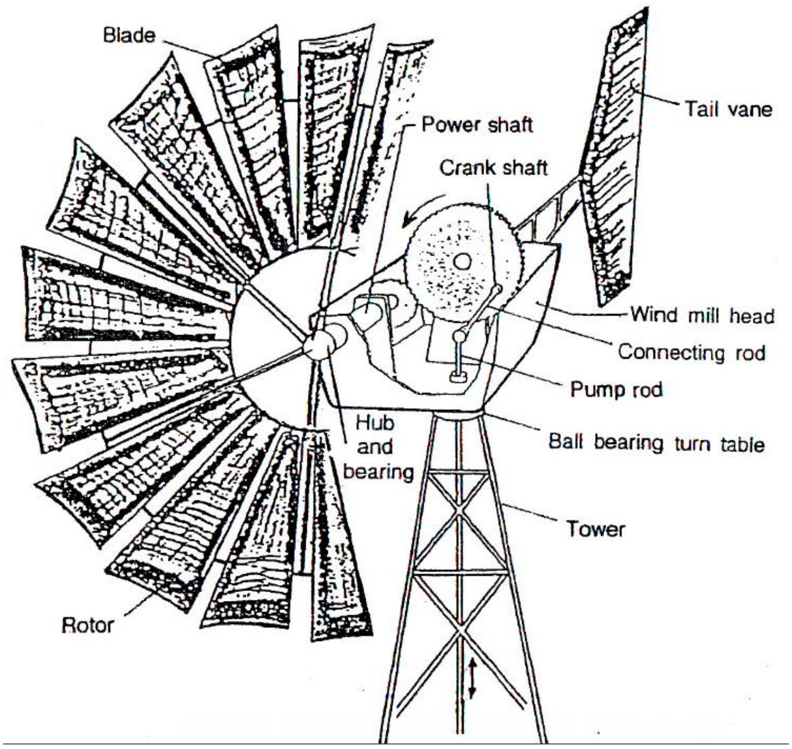

Fig. 5.2.2 Multi-blade Type Wind Machine

The rotational motion is then converted to a reciprocating motion by the crank shaft-connecting rod mechanism which in turn is connected by means of the pump rod to the Water pump. The pump rod passes through the base of the Wind mill head which sits on a ball-bearing turn table.

The tail-vane, a simple shape cut from sheet metal, is attached to the back side of the Wind mill head. It serves the purpose of aligning the rotor with the direction of the wind.

The tower is usually a steel truss construction. It serves the purpose of keeping the rotor and the wind mill head at an appropriate height from the ground where the wind speed is adequate.

Propeller Type Wind Machine:

A sketch of a propeller type wind machine is shown in Fig. 5.2.3. The machine is normally used for generating electricity, capacities ranging from a fraction of a kilowatt to a few hundred kilowatts being available. The main elements of the machine as seen from the outside are the rotor, the nacelle and the tower.

The power extracted from the wind by the blades is transmitted through the hub to a gear train and then onto a generator. The last two components, viz. the gear train and the generator are housed inside the nacelle. The nacelle also houses various control systems, These include the braking mechanism and the roller assembly linking the nacelle to the tower. The roller assembly permits rotation of the nacelle about a vertical aids and helps to align the rotor with the direction of the wind.

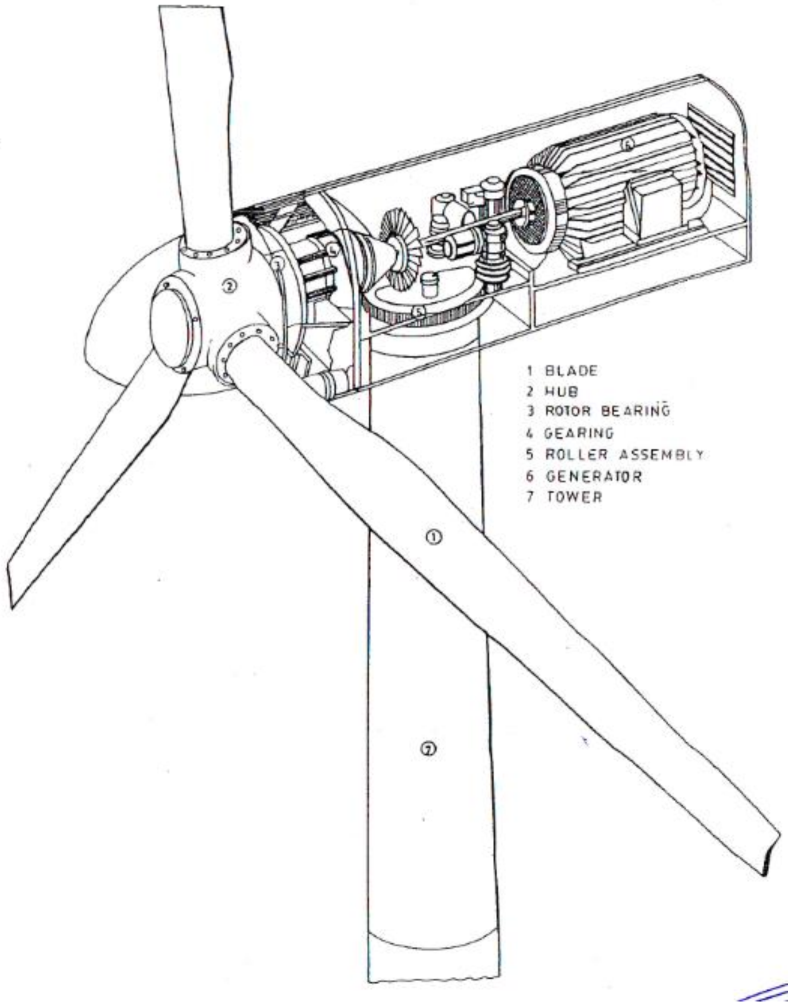

Fig. 5.2.3 Propeller Type Wind Machine

As seen in Fig. 5.2.3, the tower is of the tubular type. This design is usually adopted for large capacity machines. In some cases, the dia-meter is large enough to permit ascent through an internal staircase. For small capacity machines, a steel truss design is used.

5.3 Wind data

End velocity is vector quantity, specified by its magnitude and direction. From the point of view of extracting energy from wind, the horizontal component of the magnitude is of interest*. Hence, by convention, the value of this component is tabulated. Measurements of wind speed are made by using anemometers. The rotating cup anemometer is the most commonly used wind instrument. Various methods are used to measure the speed of rotation of the cups to which the wind speed is related. The wind velocity at any location usually varies rapidly and continuously, the variation being irregular both in terms of period and amplitude. However, for practical purposes, it is the hourly speed (the mean over one hour intervals) which is of interest and is the quantity tabulated.

Presentation of Data:

In India, measurements of Wind speed have been made for many years at various stations by the Indian Meteorological Department. These have been analyzed and tabulations showing the diurnal variation of the mean hourly Wind speed (in kmph) for each month and for the year are available for 37 stations across the country*.

It is of greater interest to know the number of hours in a month or in a year when the wind speed lies in a certain range. This information can also be computed from hourly Wind speed data, It is usually presented in the form of tables giving the mean percentage frequency distributions of hourly wind speeds in 2 kmph intervals, Values for two locations, Kandla in Gujarat and lndore in Madhya Pradesh, are given in Appendix 5. Kandla and Indore have strong Winds throughout the year and are suitable places for locating wind machines from the point of view of the energy content in the Wind.

The number of hours per month or per year during which the hourly wind speed lies in a certain range can readily be calculated by multiplying the frequency data by the total number of hours in the month or in a year. Thus, for example, from Table A5.l we see that at Kandla, the wind speed is zero for (0,012x 744 =) 8.9 h in January and for (0032 x 8760 =) 280.3 h in the Whole year. At Indore (Table A5.2), the wind speed lies in the range of 18 to 20 Kmph for (0087 x 744 =) 64.7 h in January and for (0.081 x 8760 =) 709.6 h in the whole year.

Based on the data given in Table A5.1, the annual frequency distribution of hourly wind speed for Kandla is plotted in Fig. 5.3.1. It is called the speed-frequency distribution. The distribution passes through a maximum for a particular range of speeds. For Kandla, the maximum occurs for hourly Wind speeds in the range of 18 to 20 kmph. These occur for 710 h in a year. It is also seen that there are many calm periods (zero wind speed) at Kandla adding up to 280 h in the year. The point A marked on the y-axis indicates the total extent of the calm periods. The shape of the speed-frequency distribution at most locations is similar to the one drawn in Fig.

5.3.1, Speed-frequency distributions can also be drawn on a monthly basis to study the characteristics of Wind speed available in a particular month.

An alternative way of presenting hourly wind speed data is by means of a speed-duration curve. In a speed duration curve, We plot a specified value of Wind speed against the number of hours in a month or in a year when the wind speed equals or exceeds the specified value. The usual convention is to plot the duration on the x-axis and the wind

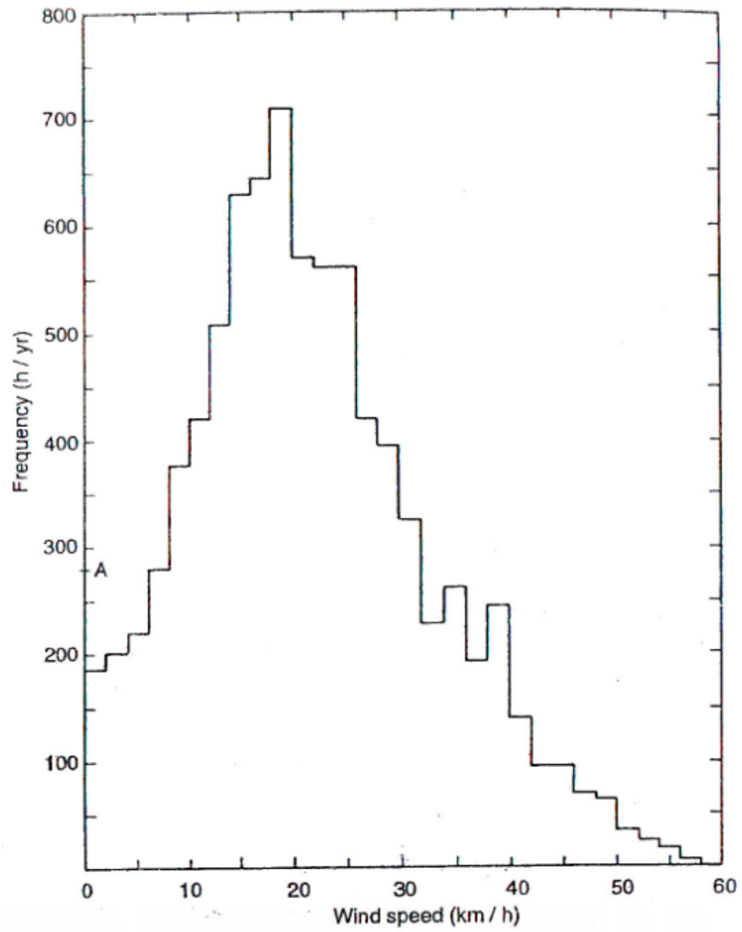

Fig. 5.3.1 Annual Speed-Frequency Distribution for Kandla with a Wind Speed Interval of 2 kmph

Fig. 5.3.1 Annual Speed-frequency Distribution for Kand|a with a Wind Speed Interval of 2 kmph*. (*Data source: A. Mani and D.A. Mooley, op. cit., p. 361.) speed on the y-axis. The annual speed-duration curve* for Kandla is plotted in Fig. 5.3.2. It is seen that the curve begins with the point having the coordinates (8760, 0), The curve coincides with the x-axis for a time period corresponding to the calm period of zero Wind speed.

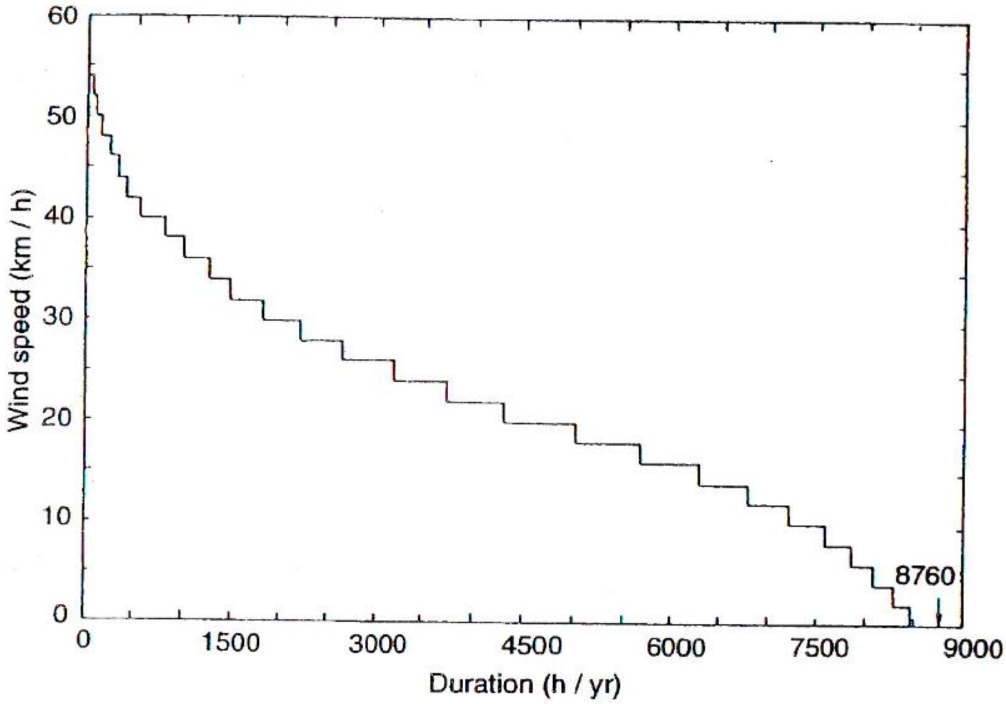

Fig. 5.3.2 Annual Speed-duration Curve for Kandla

Thereafter the curve rises to the left with decreasing slope, passes through a point of inflection and finally merges with the y-axis. Curves having a similar shape are obtained at most locations. Speed-duration curves can also be drawn on a monthly basis.

5.4 Introduction to energy audit:

Energy in the Wind:

Consider the wind flowing with a speed V, The power density (i.e. the power per unit area normal to the Wind) is the kinetic energy flowing per unit area and is given by

$$\frac{P}{A} = \frac{1}{2}(\rho V)V^2 = \frac{1}{2}\rho V^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where p = air density and V= wind speed.

The energy content of the wind per unit area for a specified period is obtained by integrating the right hand side of Eq. (1) with respect to time.

E 1

$$\frac{---}{A} = \int \frac{P}{A} \text{-----}\, dt = \frac{---}{2}\rho V^3\, dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Since the data is available in terms of the hourly wind speed, Eq. (2) is written as a summation. Thus the energy content per square metre for a month (Em/A) is given by

Em/A =

¢i'1=épi§1V§Af (10.6)

where Nm = number of hours in the month, p = density corresponding to the average air temperature for the period, Vi = hourly wind speed, and Δt = time interval of 1 hour. Similarly the energy content per square metre for a year (Eo/A) is given by

E 1 N'=

~2=- 2V?A¢ (10.7)

A zpiz,

where Nm = number of hours in a year.

A factor which needs to be considered while calculating the energy content is that the wind speed varies with the height from the ground. Generally the variation is governed by a power law of the form

$$V \propto Z^{\alpha}$$

where z is the height and or is the power law index. Thus if values of wind speed -are known at a certain height, the values at another height can be found from the relation

$$V2/V1 = (Z2/Z1)^{\alpha}$$

if the value of **α** is known. Measurements show that the power law is valid up to heights of 100-150 m and that the values of **α** range from 0.1 to 0.4. The value at a location depends on the nature of the terrain. With a smooth terrain (flat plain land with no obstructions), the value of **α** is around 0.1. With a moderately rough terrain (grass, crops), it varies from 0.1 to 0.2. With a rough terrain (rural, woods), it is around 0.2 while with a very rough terrain (urban), it varies from 0.25 to 0.40. Values of **α** for Indian locations have been given by Mani and Mooley* in the form of tables and maps. However this data is difficult to use because it gives the variation of on with the time of the day as well as with the seasons.

Example 1

Calculate the energy content of the Wind per square metre for the following situation:

- Location : Indore
- Month : May
- Height above ground : 10.9m

Take p = 1.20 kg/ma. A reasonably good estimate of the energy content can be obtained by using the data in Table A5.2 even though the interval range is 2 kmph. We take the values of Vi in Eq. (10.6) to be the average values in each interval (viz. 1, 3, 5, _ _ _ kmph) and assume that the wind speed exists at this average value for the number of hours specified in Table A5.2 for that interval. Substituting into Eq. (10.6), we have,

$$\frac{E_m}{A} = \frac{1}{2} \times 1.20 \times \frac{744}{100} \times [1.6 \times 1^3 + 0.9 + 3^3 + 1.3 \times 5^3 + 2.0 \times 7^3 + 1.3 \times 9^3 + 3.9 \times 11^3 + 6.5 \times 19^3 + 10.3 \times 21^3$$
$$+ 7.4 \times 23^3 + 8.0 \times 25^3 + 4.3 \times 27^3 + 5.1 \times 29^3 + 7.5 \times 31^3 + 4.5 \times 33^3$$
$$+ 5.7 \times 35^3 + 4.1 \times 37^3 + 1.7 \times 39^3 + 2.2 \times 41^3 + 0.8 \times 43^3 + 0.7 \times 45^3 + 0.1 \times 47^3]$$

$$= 8298622\ [(kg/m^3) \times h \times (km^3/h^3)]$$

In order to convert the value of (E_m/A) into kWh/m^2, we divide by (3.6^3 x 1000). Thus

$$E_m/A = 177.9\ kWh/m^2$$

It should be noted that a correction factor for height was not needed in this example.

The energy content in the wind can be visualized by plotting the power density duration curve. Since (P/A) $\propto V^3$, this curve is obtained from the speed-duration curve by plotting V^3 (multiplied by an appropriate constant) instead of 'V' on the y-axis. A typical annual power density-duration curve is shown in Fig. 5.4.1. It is easy to visualize that the total area under the curve represents the energy content in the wind for a year.

The energy available for the rotor of a given Wind machine is less than the total area under the curve in Fig. 5.4.1. In order to understand the reasons for this, we first define three wind speeds for a Wind machine. These are the cut-in speed, the design (or rated) speed, and the cut-out (or furling) speed. The cut-in speed for a machine is the wind speed below which the machine does not rotate and no power is produced. The design speed is the Wind speed at which a machine produces its rated output.

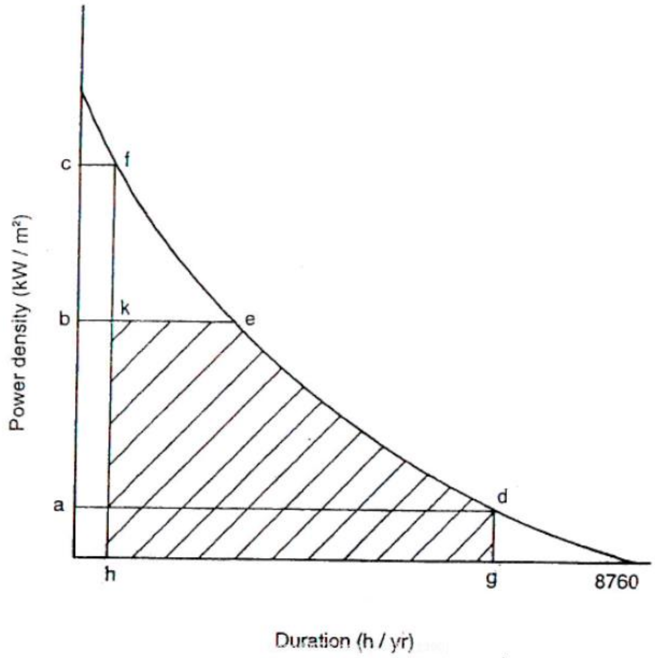

Fig. 5.4.1 Typical Power Density-duration Curve and Energy Available for a Wind Machine

Usually the output is held constant at the rated value for wind speeds greater than the design speed. This is achieved by some kind of governing mechanism. The cut-out speed is the Wind speed at which it is advisable to shut down the wind machine in order to avoid mechanical damage.

Referring again, to Fig. 5.4.1. let the points a, b and c represent the power density values corresponding to the cut-in, design and cut-out speeds respectively. We draw horizontal lines from these points to intersect the power density-duration curve at points d,e and f, and drop perpendiculars dg and fh on the x-axis. From Fig. 5.4.1, it is clear that the energy associated with the area under the curve to the right of dg is lost because of wind speeds less than the cut-in speed. Similarly the energy associated with the area to the left of fh is lost because of wind speeds greater than the cut-out speed. Also since excess of the design speed, the energy associated with the area above the line be is not used. Thus the actual energy available is given by the shaded area kedgh.

Example 2

Use the data given in Example 1 and calculate the actual energy available for a wind machine for which the cut-in speed in 14 kmph, the design speed is 36 kmph and the out-out speed is 90 kmph.

$$\frac{E_m}{A} = \frac{1}{2} \times 1.20 \times \frac{744}{100} \times [6.3\times15^3+6.2+17^3+6.5\times19^3+10.3\times21^3+7.4\times23^3+8.0\times25^3+4.3\times27^3$$
$$+5.1\times29^3+7.5\times31^3+4.5\times33^3+5.7\times35^3+(4.1+1.7+2.2+0.8+0.7+0.1)36^3]$$

$$= 76068.3\ [(kg/m^3) \times h \times (km^3/h^3)]$$

$$= 163.0\ kWh/m^2$$

It has been mentioned earlier that Kandla and Indore are both suitable places for locating wind machines from the point of view of the energy content in the wind. In general, locations having an annual energy content in excess of 1000 kWh/m^2 are considered to be suitable.

In India, many such areas have been identified along the west and east coasts, as well as on the Deccan plateau, and it is estimated that there is a potential for installing at least 20 000 MW of power from wind energy.

1. Write note on Energy Audit
2. What is the function of Wind mill?
3. What is wind energy?
4. State the principle of wind turbine.
5. What are advantages of wind energy?
6. Explain in detail axis type wind mills.
7. Which are the factors affect the nature of wind close to the surface of earth?
8. Explain vertical axis wind mills? Give its advantages and disadvantages.
9. Write advantages of wind energy.

Reference Books:

1. Non conventional Energy sources, G. D. RAI (4th edition), Khanna Publishers, Delhi.

2. Solar Energy, S.P. Sukhatme (second edition), Tata Mc.Graw Hill Ltd, New Delhi.

3. Solar Energy Utilisation, G. D. RAI (5th edition), Khanna Publishers,Delhi.

List of Experiments:

1. Fuel value of wood/charcoal.

2. Study of sensible heat storage using liquid.

3. Selective and Non-selective coatings – Determination of Selectivity ratio.

4. Thermal efficiency of liquid – flat plate collector.

5. Study of box type solar cooker.
6. Determination of instantaneous thermal efficiency of parabolic collector.