

# Renewable Energy Technology



**DR. P. SUBRAMANIAN**

**DR. A. SAMPATHRAJAN**

**Renewable Energy Technology**  
**-: Course Content Developed By :-**

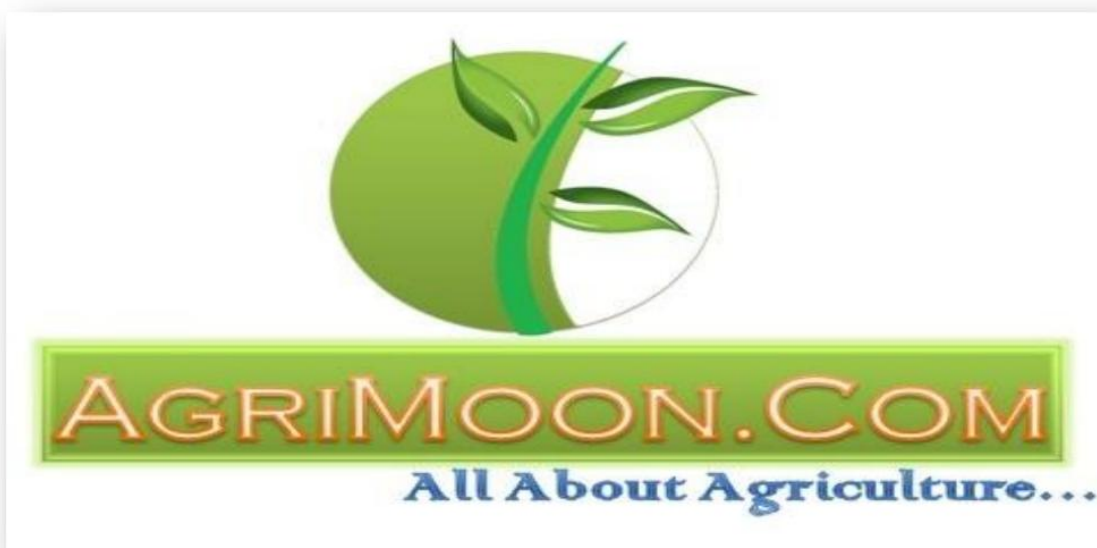
**Dr. P. Subramanian**

**Professor and Head, Agricultural Engineering Department**  
**Agricultural College and Research Institute, TNAU,**  
**Madurai**

**-:Content Reviewed by :-**

**Dr. A. Sampathrajan**

**Formerly Dean (Engg.), TNAU**



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**Module 1. Design and operational parameters****Lesson 1. Introduction of renewable energy technologies**

The depletion of conventional energy necessitates studies on new and renewable energy sources. Renewable energy sources such as wind, solar, small hydro, and biomass are receiving increased attention in developed as well as developing countries. Long term sustainable development not only in agriculture but also in all other sectors, requires implementation of renewable energy technologies that are more equitably distributed and environmental friendly. The cost of renewable energy technologies have declined significantly and further reduction of cost is also projected in the next few years.

Estimates of technical potential for renewable energy technologies

Source/System	Approximate potential
Biogas plants (no.s)	12 million
Improved cook stoves (no.s)	120 million
Biomass energy	17000 MW
Solar energy	20 MW/km <sup>2</sup>
Wind energy	45000 MW
Small hydropower	15000 MW
Ocean energy	50000 MW

Source : MNRE

The applications of various renewable energy technologies are discussed below.

**Solar Energy**

Our country is blessed with abundant supply of solar radiation. By adopting suitable gadgets solar energy can be used not only in agricultural sector but also for domestic and industrial applications.

Solar dryers, solar water heaters, solar cookers etc are some of the solar based thermal appliances. Solar water heating systems have two major applications: domestic and industrial. In the industrial sector, solar thermal energy is utilized for preheating boiler feed water and also for supplying direct process heat. These techniques are helpful in agricultural related industries like, food processing industries, agro based industries etc. According to an estimate, the potential for the deployment of solar water heaters is around 30 million square

meters of collector area, of which around 7 million square meters has already been installed.

Semiconductors based solar cells provides one of the most environmentally friendly routes for power production. Solar cells are connected together into a module as per the requirement of the appliance. Module becomes the basic building block of a PV power system and required numbers of modules are suitably interconnected in a series and parallel combination to form a PV panel or an array. About 1700 MW of power production has been achieved through solar photovoltaic systems.

Solar street lights, solar lantern, solar water pumps etc are some of the solar electrical appliances, which have been successfully developed. In agriculture, photovoltaic systems are widely used in water pumping for irrigation and in rural domestic households for lighting. These systems have higher installation cost with added advantages of environmental friendly and lesser operation and maintenance cost.

Cooking with solar energy appears to be a viable option in the domestic sector. Of the different types of solar cookers like concentrating type solar cookers, indirect heating type solar cookers and hybrid type solar cookers, the box type solar cookers have reached the commercialization stage.

### **Wind Energy**

Wind energy has a potential of 45000 MW in India. Wind mills are commercially used for power generation, which is technically and economically viable and is a suitable alternate for fossil fuel power generation. Out of the potential energy sources about 40 – 45 per cent has already been installed ie. India has about 19000 MW of wind mill installations. Apart from power generation, water pumping is one of the applications of wind mills, which helps for irrigating water from shallow deep water sources.

### **Biomass Energy**

Biomass energy resources are organic matter available on a renewable basis for energy generation. Forest thinning, agricultural crop residues, wood and wood wastes, animal wastes, aquatic plants, municipal waste etc. are all various available biomass. Biomass, as a fuel, has been in use from ancient times and is produced locally everywhere. They are generally available in sufficient quantities and have lesser economic value due to improper utilization. Some of the benefits include CO<sub>2</sub> neutrality, lesser release of pollutants like SO<sub>x</sub> and NO<sub>x</sub>, water and soil quality improvement, biodiversity, landscape, job creation, rural rehabilitation etc. emphasis the development of newer technologies for effective utilization of biomaterials.

Biomass provides the possibility of conversion in to liquid, solid or gaseous fuels through various conversion routes which provides more opportunities for its use in different applications. Biomass could become a central part of future sustainable energy supply, due to its economic and technical feasibility.

Biomass power generation potential is vast in a predominantly agricultural country like India. With an annual biomass availability of about 500 million tonnes, the power generation

potential is in the order of 17,000 MW. With the available biomass conversion technologies, the installed power generation is about 500 MW.

Varieties of technologies are available for the conversion of biomaterials to useful energy forms. The major classification is thermochemical and biochemical conversion technologies. In biochemical conversion processes, microorganisms play major role in energy generation. Where as in thermochemical conversion processes, heat will be introduced during the process.

### **Thermo Chemical Conversion**

Thermochemical conversion can be classified into three major processes based on the supply of air viz. combustion, gasification and pyrolysis.

Direct combustion in excess air (incineration) is the best understood and most widely used energy conversion process today. However, direct combustion in excess air has several problems, especially for general large-scale use. There is also a serious air pollution problem associated with direct burning in excess of air, since large quantities of particulates are produced. Combustion in a controlled atmosphere (gasification) is the conversion of solid or liquid to a gas. The capabilities of this process were shown during World War II in Europe and Japan where gasifiers were used to operate tractors, automobiles and buses because petroleum was scarce. Heating in the absence of air (pyrolysis) is the transformation of materials into another form by heating in the absence of oxygen. This approach appears to offer a number of advantages over incineration. Generally pyrolysis and gasification can be considered as very efficient means of increasing the options available for utilizing waste materials.

Gasification is the process in which restricted amount of air will be supplied. Due to lesser air supply, the raw materials will be converted into an intermediate chemical gaseous product called producer gas. Gasifiers are used for generating producer gas from biomaterials. This gas can be used for burning, drying and also running engines. This technology was used during World War II itself. Due to the dominance of petroleum products during mid 20<sup>th</sup> century, this technology got lesser importance. Now, due to the dwindling nature of coal and petroleum products, gasification technology is re-energized and popularised.

Pyrolysis is the process, through which organic materials are converted into secondary fuels and chemical products in the absence of oxygen. The products are gases, condensed vapours as liquids, tars and oils and charcoal (solid).

Among thermochemical methods, combustion and gasification are now widely in use for energy generation, and also for rural and industrial applications.

### **Biochemical Conversion**

These processes utilize microorganisms for the conversion of biomaterial into different end products such as biogas, ethanol, compost etc. In standardizing and optimization of these processes, biochemical engineering concepts such as reaction rates, kinetics, design of

reactors, transport phenomenon etc. play a major role. Based on physiological conditions of the process, biochemical conversion processes are classified into aerobic and anaerobic.

Biogas production through anaerobic fermentation of biomass offers a very prominent route for gaseous fuel generation besides fertiliser generation. Biomethanation of industrial waste, garbage, domestic waste etc. is also being perfected and implemented by many institutions/agencies. These raw materials are digested by anaerobic organisms (survive in the absence of oxygen) such as acetogenic and methanogenic bacteria and biogas will be released. In addition to biogas, the nutrient rich organic manure (digested effluent) is also released. The predominant types of bioreactors for generating biogas high rate reactors such as Upflow anaerobic sludge blanket, hybrid reactors and various biogas plants like floating drum, Janatha, Deenbandhu etc.

Fermentation of suitable biomaterials leads to the production of alcoholic products. Bioethanol can be produced from various sugar, cellulose and starch based biomaterials. Sugar materials can be easily fermented and ethanol can be generated. Whereas, starch and cellulosic based complex materials have to be subjected to different pretreatments and converted into simple sugars before fermentation. Using microorganisms, biomaterials can be converted into compost, which has higher nutritive value and supplies nutrients to soil.

### **Biodiesel**

Biodiesel is a chemical process, by which vegetable oils can be converted into biodiesel. This is the best alternative to diesel and can be used in engines and automobiles. The raw vegetable oils are subjected into chemical and thermal processes and by removing the by product (glycerol), biodiesel is segregated. The suitable crops for the production of biodiesel are oil bearing seeds producing trees such as Jatropha, Pungam etc.

Thus, various forms of energy like chemical, mechanical, electrical and thermal can be generated efficiently and effectively from biomaterials, which is otherwise unutilized or underutilized. The selection of process for various biomaterials is the key factor in efficient biomass energy conversion. These end use forms of biomass based energy can be substituted well in various industrial and domestic applications, in the place of conventional energy sources. This not only provides energy conservation but also safe, clean and greener environment to the mankind.

Our country is well endowed with renewable sources of energy. But, the exploitable potential depends upon the availability of resources, the status of technology, and the end-use patterns. The application of these technologies is dependent on the degree of R&D, development of consumer satisfied appropriate products, as well as their commercialisation. Widespread information dissemination and awareness campaigns need to be launched to apprise people of the benefits of renewable energy technologies and their advantages over other technologies.





## Lesson 2. Design and operational parameters

In the assessment of performance of any gadget, it is important to understand the basics of their design and operational aspects. For better understanding of the design and operational aspects, the parameters that play important role in the process and operation of the gadgets have to be understood very well. This lecture deals with the various design and operational parameters involved with the renewable energy based gadgets and their significance.

### 1. Temperature

Temperature is an important parameter and has major effect in almost all the processes. It is the measure of heat present in the substance. It is measured using thermometers, thermocouples etc. It can be measured either by physical contact with the substance or by noncontact such as infra red thermometers. The units of measurement are °C, F, K etc

### 2. Pressure

It is the measure of force per unit area. Normally it will be given in terms of atmospheric pressure by considering atmospheric pressure as 1 atm. The other units of measurement of pressure are psi, Pascal,  $\text{kgm s}^{-1}$  etc.

### 3. Relative humidity

The degree of saturation of air is given in terms of relative humidity. It is the ratio of actual water content of air to the moisture content of saturated air at a particular temperature.

### 4. Air velocity

This is the movement of air in meters per unit time. The unit is given as  $\text{m s}^{-1}$ .

### 5. Flow rate

**Mass flow rate :** The quantity in terms of mass of substance flowing with respect to time. The unit is given as mass per unit time ( $\text{kg min}^{-1}$ ).

**Volume flow rate :** The quantity in terms of volume of substance flowing with respect to time. The unit is given as volume per unit time ( $\text{m}^3 \text{s}^{-1}$ ).

### 6. Solar radiation

The quantity of solar radiation falling on a surface may be measured in terms of total, beam and diffused radiation. The beam radiation is the radiation falling perpendicular to the surface. The diffused radiation is the resultant of the scattered radiation falling on the plane. The sum of both the radiation provides total radiation from sun falling on a surface.

## 7. Voltage

Voltage is the electrical potential or electromagnetic force appears across a resistance of one ohm when a current of one ampere flows through that resistance.

## 8. Current

Current is the rate of flow of charge. The unit is ampere. It is the current which produces a specified force between two parallel wires, which are 1 meter apart in a vacuum.

## 9. Power

It is the measure of electrical energy consumption done by any utility. For single phase and three phase utilities, the power calculation is given as below.

$$P(\text{single phase}) = (V \times I \times PF)$$

$$P(\text{three phase}) = \sqrt{3} \times (V \times I \times PF)$$

## 10. Power factor

It is a measure of quality of power. This is due to the inductive or capacitive effect created in the magnetic load. This is the ratio between active power and apparent power.

## 11. Efficiency

The ratio between output and input is known as efficiency of any system. This gives the performance of the system in terms of effectiveness of the conversion or process performed by the system.

**Thermal Efficiency :** Thermal efficiency is used to assess the performance of a system whereas the output is in terms of thermal energy.

**Electrical efficiency :** If the system's output is measured in terms of electricity, electrical efficiency can be used to assess the performance of the system.

**Mechanical efficiency :** Mechanical efficiency is used to assess the performance of a system whereas the process of conversion of mechanical energy prevails.

## 12. Feed rate

The consumption of feed or raw material to any system with respect to time is given as feed rate. This has to be optimised for better performance of the process inside the system and maximum output.

## 13. Heating value

This is the measure of energy content of the material otherwise called as calorific value.

**Higher Heating Value (HHV) :** HHV considers all vapour produced during the combustion process is fully condensed. Hence, this value is higher than LHV.

**Lower Heating Value (LHV) :** Whereas LHV considers that the water vapour leaves with the combustion products without fully being condensed.

#### **14. Viscosity**

Viscosity is a measure of internal resistance to flow of fluids. The units for viscosity is Stokes / Centistokes, Engler, Saybolt or Redwood. The measurement of viscosity is made with an instrument called Viscometer.

#### **15. Cetane number**

The Cetane Number (abbreviated CN) refers to the combustion quality of diesel fuel. It represents the time delay between the start of injection process and the the point where the fuel ignites. This value is determined by the % volume of cetane or hexadecane ( $C_{16}H_{34}$ ) in isocetane that provides the identical ignition delay of the measured fuel sample.

#### **16. Octane number**

Octane number is a value used to indicate the resistance of a motor fuel to knock. Octane numbers are based on a scale on which isooctane is 100 (minimal knock) and heptane is 0 (bad knock).

#### **17. Flash point**

The flash point of a fuel is the lowest temperature at which the fuel can be heated so that the vapour gives off flashes momentarily when an open flame is passed over it.

#### **18. Pour point**

The pour point of a fuel is the lowest temperature at which it will pour or flow when cooled under prescribed conditions.

#### **19. Specific fuel consumption**

This is one of the major energy consumption indicators. This represents the quantity of energy consumed per unit specific to the product.

#### **20. Brake thermal efficiency**

It is the ratio of brake thermal horse power to the fuel input.

#### **21. Brake Horse Power**

This is the mechanical output of engine in terms of horse power. The measure of an engine's horsepower without the loss in power caused by the gearbox, generator, differential, water pump and other auxiliaries. The actual horsepower delivered to the driving wheels is less.

## **22. Biological Oxygen Demand**

This is the indicator of the presence of organic matter in the given sample. Biochemical oxygen demand or B.O.D is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water.

## **23. Chemical Oxygen Demand**

Chemical oxygen demand (COD) is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. It is the measure of oxygen required to oxidize compounds and measures the amount of chemicals in the water that can be oxidized by oxygen.

Chemical Oxygen Demand is a test done to indirectly determine the amount of organic compounds present in a water sample. It is vital for the assessment of the quality of effluents and waste water.

## **24. Moisture content**

The amount of moisture present in the system and can be measured by keeping the material above 100°C in an oven till reaching a standard dry weight of material.

## **25. Drying rate**

The rate at which the moisture removal from a substance has to be carried out to achieve the required quality of the produce.

## **26. Specific heat**

It is the amount of heat energy needed to raise the temperature of 1 kg of liquid by 1°C.



## ***Module 2. Performance evaluation and maintenance aspects of combustors and gasifiers***

### **Lesson 3. Characteristics determination of biomass**

Agricultural biomass which includes crop residues and weeds are a source of renewable energy with good scope or exploitation through different conversion routes. Selection of suitable energy conversion route is very essential for the efficient conversion of biomass.

In order to effectively utilize the biomass, their characteristics are to be assessed. To assess the suitability of biomass for conversion through any of the processes, characterisation of physical (moisture content, density, etc.) chemical (proximate and ultimate composition, trace elements content etc.) and thermal properties (calorific value, tar content, charcoal content etc.) of biomass is essential. Classification of commonly available species for their suitability based on their characteristics is important for their proper selection in different applications such as thermo chemical, biochemical and other conversion processes.

#### **A. Physical Characteristics**

- Density
- Moisture content

#### **B. Chemical Characteristics**

##### **(i) Proximate composition**

- Volatile content
- Ash content
- Fixed carbon

##### **(ii) Ultimate composition**

- Elemental carbon
- Elemental hydrogen
- Elemental nitrogen
- Elemental oxygen
- Elemental sulphur

(iii) Trace elements

## C. Thermal Characteristics

- Calorific value
- Condensable tar yield
- Charcoal yield
- Temperature of maximum devolatilisation

The methodologies for the characterisation of the biomass materials are given below.

## Physical Characteristics

Physical characteristics are useful to estimate the portion of biomass available for energy conversion.

### Density

The specimen whose density is to be measured has to be made into a regular geometrical shape. An electronic balance (Fx/Fy series) having provision to weigh using the built-in 'under hook' may be used. The under hook is to be fitted through the lower end of the riser beam directly below the pan support peg of the balance. A light-weight strand of thin rod will be hung through the hook. After placing the balance on a firm metal stand designed for under hook weighing, the weight of the regularly shaped specimen in air will be taken. Then the sample has to be fixed in the lower end of the hook and allowed to immerse in glycerol and the weight is to be taken. The density of the specimen will be then worked out from the formula:

$$\text{Density} = \frac{\text{wt. of the sample in air} \times \text{density of glycerol}}{\text{wt. loss of the sample in glycerol} + \text{rod wt. loss in glycerol}}$$

### Moisture Content

For the moisture content determination, known weight of sample is to be dried in an open petry dish in an electrical oven at  $103 \pm 5^\circ \text{C}$  for 1 hour and weighed. It is assumed that this oven dried weight indicated a condition of zero moisture content. The difference in weight, before and after drying indicates the moisture content of each sample. As the moisture content of biomass differs from each other, oven dry sample are taken for analysis of all the other properties. The moisture content can be determined as follows:

$$\text{Moisture content (\% (w.b))} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \times 100$$



### **Chemical Characteristics**

The chemical constituents of the biomass materials can be determined (proximate, ultimate composition and trace elements) as per the procedures given below.

#### **Proximate Composition**

Proximate analysis gives information of biomass constituents such as volatiles, fixed carbon and ash content of water free samples.

#### **Volatile Matter**

Volatile matter can be determined by keeping the dried sample in a closed crucible at 600° C for six minutes and then at 750° for another six minutes. The difference in the weights due to the loss of volatiles will be considered as the total volatile matter present in the sample.

#### **Ash Content**

The samples may be taken in a silica crucible and heated gradually in a muffle furnace to 750° C for two hours or more till recording constant weight. The weight of the residue represents the ash content.

#### **Fixed Carbon**

The fixed carbon may be found out by subtracting the sum of percentages of ash content and volatile matter from 100.

#### **Element Analysis**

This analysis has to be carried out to determine the content of carbon, hydrogen, nitrogen, potassium, sodium, calcium, magnesium and phosphorus in the sample. These amounts are expressed as percentage of the weight of the water free sample. The methods of determination for each element are described below.

#### **Instrumental Method**

The ultimate analysis of samples may be carried out using Elemental Analyser. The element C, H, N and S are determined using the instrument and the element O may be found by difference.

#### **Analytical Method**

The analytical methods for the determination of Carbon, Nitrogen, Hydrogen and other elements are described below.

#### **Carbon**

For the determination of carbon, Tyurin method can be adopted. In this method a known amount of sample (about 10 g) is placed in a 100ml conical flask. Ten ml. of 0.4 N potassium dichromate solution is added to the flask. A 4cm diameter funnel is kept on the flask, which

is heated to allow gentle boiling of these contents for 5 minutes. After boiling, the flask is allowed to cool. The funnel and the flask are then rinsed with 10 ml of distilled water. The orange yellow colour of the liquid in the flask after rinsing is an indication of complete oxidation of carbon. If the colour is found to be a greenish brown, it is an indication of incomplete oxidation and the reaction is repeated using larger amounts of potassium dichromate. The unused quantity of potassium dichromate in the content of the flask after the reaction is determined by titrating the contents against 0.1 N

Mohr's salt using phenyl anthranilic acid as indicator. For blank same amount of potassium dichromate is heated under similar conditions and titrated against 0.1 N Mohr's salt. The percentage of carbon in the sample is calculated from the following equation:

$$\text{Carbon (\%)} = \frac{V \times .0003 \times 100}{\text{Wt. of water free sample}} \times 1.17$$

Where V is the difference in volume of Mohr's salt used for blank and test runs.

### Nitrogen

Modified Kjeldahl method is used to determine the nitrogen content. One gram air dried and ground sample (-50+100 mesh ASTM) is mixed with 5 g of digestion mixture ( $\text{K}_2\text{SO}_4$  :  $\text{CuSO}_4$  : 1:10). The mixture is put in a 300 ml Kjeldahl digestion flask and 25 ml of concentrated  $\text{H}_2\text{SO}_4$  is added to the contents of the flask. The flask is heated for 3-4 hours till the digestion is completed. Appearance of light green colour in a transparent solution is an indication of complete digestion. The digested mixture is diluted with distilled water to make the volume up to 100ml. Two ml of diluted mixture is taken in Kjeldahl distillation apparatus and mixed with 5 ml of 40% NaOH. Vapours are absorbed in 4% boric acid. The solution thus obtained is titrated against 0.01 N  $\text{H}_2\text{SO}_4$  using mixed indicator (bromocresol green 0.5% and methyl red 0.1% in ethyl alcohol).

Nitrogen content is calculated by the following equation.

$$\text{Nitrogen \%} = V \times 0.7 / \text{weight of sample}$$

Where V is the volume of .01 N  $\text{H}_2\text{SO}_4$  used.

The value has to be corrected to be expressed as per cent of weight of water free sample.

### Hydrogen

It is determined by combustion method. One gram of air dried and ground sample is oxidized by heating it in oxygen atmosphere in the presence of cupric oxide. The resultant water vapours are absorbed in dehydrated calcium chloride. The amount of hydrogen may be calculated from the weight of the water vapours. Appropriate correction factor is used to take into account the initial moisture content of the sample and the hydrogen content of the sample can be expressed as per cent of the weight of the water free sample.

### Determination of Potassium, Sodium, Calcium, Magnesium and Phosphorus

For the determination of potassium, sodium, calcium, magnesium and phosphorus content, 0.5 g sample is digested with 15ml of acid mixture ( $\text{HNO}_3 : \text{HClO}_4$ , 3:1) in a 100 ml conical flask. The digested mixture is analyzed with flame photometer using appropriate filters for the determination of potassium and sodium. The values are corrected to be expressed as per cent of the water free residue sample. The digested mixture, after adequate dilution is analysed on atomic absorption spectrometer for the determination calcium and magnesium. The values are corrected to be expressed per cent of moisture free sample. For the determination of phosphorus the digested mixture is analysed on spectrophotometer.

For the determination of silica, 1 g of air dried and ground sample is treated with 40 ml of hydrochloric acid of 50% concentration in a china dish which is heated for 30 minutes on a water bath. One ml of concentrated  $\text{HNO}_3$  is then added to the contents of the dish, which is again heated on a burner/hot plate till the liquid evaporated completely leaving only dry residue. The dry residue is heated on a water bath for 30 minutes after which 10 ml HCL of 50% concentration is added to it. The mixture is stirred and 50 ml of distilled water mixed with it. The mixture is filtered through what man No.44 filter paper. The residue along with filter paper is kept in weighted silica crucible and heated in a furnace for 2 hours at  $700^\circ \text{C}$ . The crucible is cooled in a desiccators and weighed to determine the amount of silica. The silica is expressed as per cent of the weight of water free sample.

### Thermal Properties

The procedures followed for the determination of the other properties like, calorific value, condensable tar yield temperature of maximum devolatilisation and charcoal yield are given below.

#### Calorific Value

Calorific value (HHV) of most of the biomass reported is determined in bomb calorimeter. Calorific value can also be found out using either by Jenkins and Ebeling formula or by Dulong's formula:

$\text{CV} = (0.293 \text{ C} + 5.21) \text{ MJ kg}^{-1}$  jenkins and Ebeling formula

Where C is the per cent composition of element carbon.

$\text{CV} = (8080 \text{ C} + 34500 (\text{H} - (\text{O}/8)) + 2240 \text{ S}) \text{ kcal kg}^{-1}$  Dulong's formula.

Where C, H, O and S are fractional composition of element carbon, hydrogen and oxygen and sulphur respectively.

#### Condensable tar yield and temperature of maximum devolatilisation

This is a simple approximate procedure for estimating condensable tar yield and temperature of maximum devolatilisation. The experimental set up which has a covered cup with a stem, is used. A known weight of sample is taken in the cup. This set up is kept in a programmable furnace. The tar released at varying heat rate is condensed by condensers. The tar released is

collected at temperature intervals of 0-200° C, 200-400° C, 400° -600° C, 600° -800° C and 800° - 1000° C separately. Then the final weight of the sample and tar collected can be observed.

The peak temperature corresponding to maximum tar yield is taken from a plot of condensable tar yield against temperature to be the approximate maximum devolatilisation temperature.

### **Charcoal Yield**

The sample of known weight (say 50 g) is taken in the closed container. It is kept in a muffle furnace for specified time at 200°C - 350°C. Then the container is cooled and the charcoal is weighed. The percentage of charcoal yield is calculated.

Based on the characteristics of the biomass, suitable conversion technologies can be adopted for efficient energy production from the available sources.

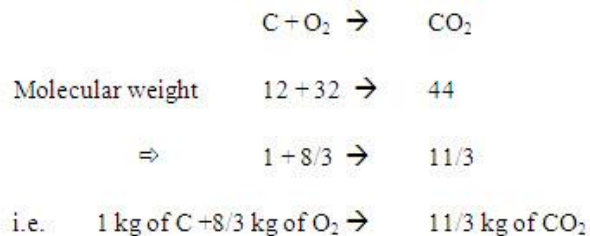


#### Lesson 4. Stoichiometric air requirement calculation

Every material requires oxygen for combustion. If a material has to be completely combusted, it requires specific amount of oxygen. The specific amount will be calculated based on the elemental composition of the material and is named as stoichiometric oxygen requirement. As air is the cheapest source of oxygen, normally air will be supplied for combustion of materials unless it is warranted. Thus stoichiometric air requirement is an important factor in achieving complete combustion of a material.

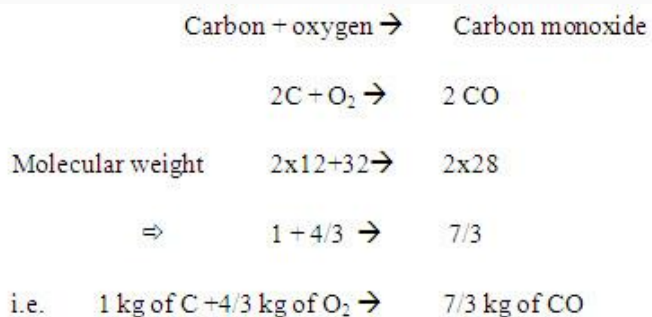
The procedure for calculating the stoichiometric air requirement of a material whose elemental composition such as carbon, hydrogen, nitrogen, oxygen and sulphur are known is given below.

##### Carbon



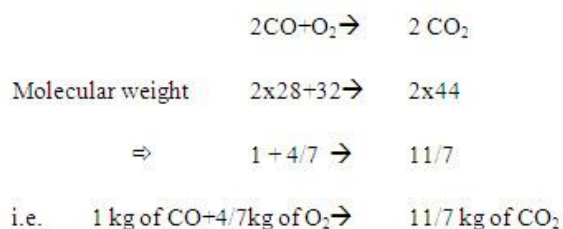
In burning 1 kg of carbon needs 8/3 kg of oxygen to produce 11/3 kg of CO<sub>2</sub>

If the oxygen supply is insufficient then the equation may be



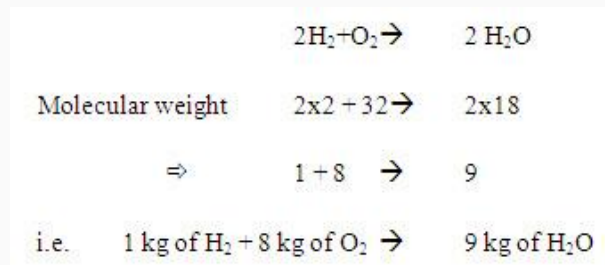
In burning 1 kg of carbon needs 4/3 kg of oxygen to produce 7/3 kg of CO

##### Carbon monoxide



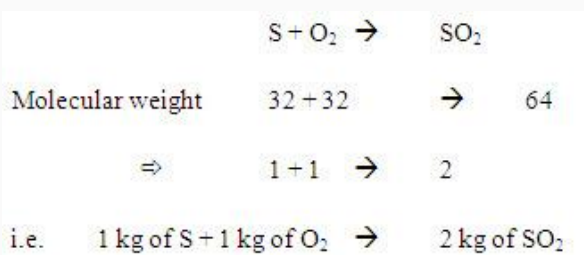
In burning 1 kg of carbon monoxide needs  $\frac{4}{7}$  kg of oxygen to produce  $\frac{11}{7}$  kg of  $\text{CO}_2$

Hydrogen



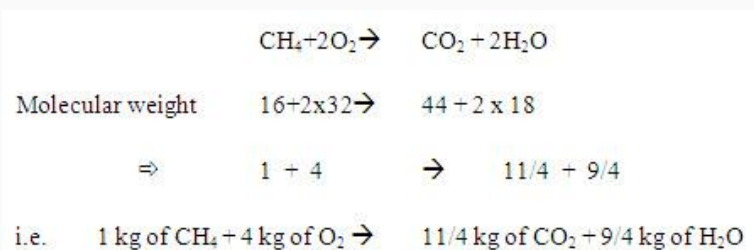
In burning 1 kg of hydrogen needs 8 kg of oxygen to produce 9 kg of  $\text{H}_2\text{O}$

Sulphur



In burning 1 kg of sulphur needs 1 kg of oxygen to produce 2 kg of  $\text{SO}_2$

Methane



In burning 1 kg of methane needs 4 kg of oxygen to produce  $\frac{11}{4}$  kg of  $\text{CO}_2$  and  $\frac{9}{4}$  kg of water vapour

For complete combustion minimum amount of oxygen requirement by elements

1 kg of carbon  $\frac{8}{3}$  kg

1 kg of hydrogen 8 kg

1 kg of sulphur 1 kg

Total oxygen requirement =  $\frac{8}{3} \text{ C} + 8 \text{ H}_2 + \text{S}$

Oxygen available in fuel =  $\text{O}_2$

Net oxygen requirement is =  $\frac{8}{3} \text{ C} + 8 \text{ H}_2 + \text{S} - \text{O}_2$



Directly supply of pure oxygen of combustion process is not economical and also not necessary. Hence naturally, abundantly and freely available oxygen source, air can be supplied for combustion of raw materials. While considering the amount of oxygen in air is 23% by weight and 21% by volume. Considering weight fraction the amount of air required for combustion of the fuel material is given by

$$\text{Air}_{st} = \frac{100}{23} \left[ \frac{8}{3} C + 8 H_2 + S - O_2 \right] \text{ kg}$$

If the theoretical air supply is supplied, some amount of fuel may be unburnt. Air supplied may not come into intimate contact with the fuel particles; there by excess air supply is required for complete combustion. This excess air depends on the quantity of material, rate of combustion, firing system etc. Generally 25 to 50 per cent excess air will be supplied. The supply of excess air produces cooling effect. But this can be avoided by preheating the air before its supply for combustion.

$$\text{Total air supplied (Air}_{tot}) = \text{Air}_{st} + \text{Air}_{ex}$$

### Products of combustion

Similarly, the quantity of products of combustion may be calculated through the above methodology. The products such as carbon dioxide from carbon, water vapour from hydrogen, sulphur dioxide from sulphur, excess oxygen and uncombusted remaining nitrogen can be calculated using the formulae given in the table.

Products of combustion	Amounts of products of combustion		Percentage by mass ( $m/\sum m \times 100$ ), %
	Formula	Mass, m, kg	
CO <sub>2</sub>	$\frac{11}{3} \times C$	$m_1$	$m_1/\sum m \times 100$
H <sub>2</sub> O	$9 H_2$	$m_2$	$m_2/\sum m \times 100$
SO <sub>2</sub>	$2 S$	$m_3$	$m_3/\sum m \times 100$
O <sub>2</sub> in excess air	$0.23 \times m_{ex}$	$m_4$	$m_4/\sum m \times 100$
N <sub>2</sub> in total air	$0.77 \times m_{0.77}$	$m_5$	$m_5/\sum m \times 100$
		$\sum m$	100%

The excess oxygen gives an idea about energy efficiency of the combustion process. More amount of oxygen in the combustion product will indicate additional supply of oxygen than requirement and inefficient combustion. In this case, not only higher energy is added for the supply of oxygen but also, the excess oxygen will carry some quantity of heat of combustion to the atmosphere and will lead to reduced heat supply to the system.

## Lesson 5. Performance evaluation of improved wood stoves

### Combustion

Combustion is the thermochemical process, in which excess than the calculated stoichiometric quantity of oxygen will be supplied to the system, to ensure complete combustion. Where as, the efficiency of the combustion systems are comparatively lesser due to heat losses. As the temperature at the combustion chamber is very high than the surrounding atmosphere, the heat transfer to the surrounding leads to heat losses. The efficiency of the conventional wood stoves are in the range of 8 – 10 per cent. Hence, efforts are taken for better air supply to the combustion zone and also to reduce the heat losses from the stoves, in the improved wood stoves. The performance of the wood stoves can be assessed using simple water boiling test. The procedure of the test is given below.

### Observations

The theoretical background in assessing the performance of the wood stoves is that the quantity of thermal energy transferred to the known quantity of water kept in the wood stoves will be found out. The proportion of the thermal energy used to heat the water to the total energy available in the known quantity of fuel wood expresses the performance of the wood stove in terms of thermal efficiency.

In this experiment, take a known quantity of water in two vessels having lids. The diameter of the vessel should be higher than the diameter of the combustion chambers. Place the vessels on the ports of stove. Fit thermometers on the lid of vessel to read the water temperature. Use 1 kg of firewood for every one hour for combustion. Note down water temperature every 15 minutes. When the temperature of water reaches 98°C open the lid and continue to observe the temperature while water is boiling. When little water is remaining in the main vessel stop the test. Collect charcoal and ash from stove and weigh after cooling.

### Observations

- (i) Initial weight of fuel wood,  $W_1$  =
- (ii) Final weight of fuel wood,  $W_2$  =
- (iii) Total weight of fuel wood used ( $W_1 - W_2$ ) ,  $W$  =
- (iv) Volume of kerosene used ,  $W_3$  =
- (v) Initial weight of water in the first vessel ,  $m_1$  =
- (vi) Final weight of water in the first vessel ,  $m_2$  =
- (vii) Initial weight of water in the second vessel ,  $m_3$  =

(viii) Final weight of water in the second vessel ,  $m_4$  =

(ix) Weight of charcoal collected ,  $W_4$  =

(x) Initial temperature of water ,  $t_1$  °C =

(xi) Final temperature of water ,  $t_2$  °C =

### Calculation

Weight of water taken ( $m_1 + m_3$ ) =  $M$  =

Loss in weight of water ( $m_1 - m_2$ ) + ( $m_3 - m_4$ ) =  $\Delta M$  =

### Heat utilization

Thermal energy used for water heating =  $H_o$

$H_o$  =  $M c_p \Delta t + L \Delta M$

$c_p$  = specific heat of water ( $1 \text{ kcal kg}^{-1} \text{ }^\circ\text{C}^{-1}$ )

$\Delta t$  =  $(t_1 - t_2) \text{ }^\circ\text{C}$

$L$  = latent heat of water ( $540 \text{ kcal kg}^{-1}$ )

### Heat input

Energy input =  $H_i$

$H_i$  =  $CV_F \times W + CV_K \times W_3 - CV_C \times W_4$

$CV_F$  = calorific value of fire wood

$CV_K$  = calorific value of kerosene

$CV_C$  = calorific value of charcoal

### Efficiency of wood stove

Thermal efficiency,  $\eta$  (%) = Thermal energy used / Energy input

=  $H_o / H_i$

### Power output rating

Power output rating,  $W$  =  $W \times CV_F \times 860 / 1000$



## Lesson 6. Performance evaluation of boilers

### Boilers

Boiler is a system which transfers the energy from the fuel to water. The boiler fuel will be combusted and the thermal energy generated will be transferred to the feed water. The water gets heated up and hot water or steam will be generated. The maximum transfer of energy from fuel to steam shows better performance of boiler.

If a boiler has good combustion system, which converted the fuel energy into thermal energy more thermal energy will be produced from the available fuel energy. If the boiler's heat transfer system is efficient, a maximum portion of generated heat will be absorbed by water during the generation of steam.

The performance of boiler can be assessed by the following procedure.

### Performance assessment

The efficiency of boiler is found out by calculating fuel energy input to the thermal energy available in the form of steam. Fuel energy can be calculated by knowing the calorific value of fuel used in the boiler. The thermal energy used for the production of steam can be calculated from the enthalpy of the steam based on the initial and final temperatures.

### Observation

The boiler will be allowed to operate for a specific period to reach stabilization to avoid the fluctuations in the energy consumption during initial period. After stabilization period, the quantity of fuel consumed will be calculated and its average calorific value has to be assessed per unit time. The energy content of the input water and the output steam can be calculated based on the inlet and out let temperature. Based on the temperature the enthalpy will be found out and the thermal energy consumed can be calculated.

Quantity of fuel consumed	-	$F, \text{ kg h}^{-1}$
Calorific value of fuel	-	$CV_F, \text{ kCal}$
Quantity of steam generated	-	$M, \text{ kg h}^{-1}$
Initial temperature of water	-	$t_1, ^\circ\text{C}$
Enthalpy of water	-	$h, \text{ kCal kg}^{-1}$
Pressure of steam	-	$p_2, \text{ ksc}$
Temperature of steam	-	$t_2, ^\circ\text{C}$

Enthalpy of steam based on the

pressure and temperature -  $H, \text{ kCal kg}^{-1}$

Boiler efficiency =  $\text{Heat in steam} / \text{Heat in Fuel}$

Heat in steam =  $M (H-h)$

Heat in fuel =  $F \times CV_F$

### Problem

A 10 TPH boiler is fed with water at temperature  $75^\circ\text{C}$  and steam is produced at 10 ksc with temperature of  $180^\circ\text{C}$ . The sugarcane bagasse is used as fuel and its fuel consumption rate is 3 TPH with calorific value of  $2800 \text{ kCal kg}^{-1}$ . Find out the efficiency of boiler for the given condition.

Fuel consumption rate,  $F$  -  $3000 \text{ kg h}^{-1}$

Calorific value of fuel,  $CV_F$  -  $2800 \text{ kCal kg}^{-1}$

Steam production rate,  $M$  -  $10\,000 \text{ kg h}^{-1}$

Inlet water temperature -  $75^\circ\text{C}$

Enthalpy of feed water,  $h$  -  $75 \text{ kCal kg}^{-1}$

Steam pressure,  $p_2$  -  $10 \text{ ksc}$

Steam temperature,  $t_2$  -  $180^\circ\text{C}$

Enthalpy of steam,  $H$  -  $665 \text{ kCal kg}^{-1}$

Heat in steam -  $M (H-h)$

-  $10\,000 \times (665-75)$

-  $59\,00\,000 \text{ kCal}$

Heat in fuel -  $F \times CV_F$

-  $3000 \times 2800$

-  $84\,00\,000$

Heat in steam

Boiler efficiency =  $\frac{\text{Heat in steam}}{\text{Heat in fuel}}$

Heat in fuel

59 00 000

= -----

84 00 000

= 70%





## Lesson 7. Gasifier parts and accessories

### 1. Gasification

Gasification is the process in which the supply of oxygen is controlled and the raw materials are converted into chemical product called producer gas. This process transfers the majority of the chemically bound energy of the solid fuel into the gas phase. The oxygen supply will be 20 to 40 per cent of the stoichiometric air requirement. In combustion process, raw materials are directly converted into heat energy, where as in gasification process, raw materials are converted into an intermediate chemical product, which constitutes mainly of carbon monoxide and hydrogen.

The calorific value of producer gas is 950-1200 kcal m<sup>-3</sup>. The main components of producer gas are carbon monoxide (18-24%), hydrogen (18-20%), carbon dioxide (9-12%), nitrogen (45-55%), methane (1-5%) and water vapour (4%).

In gasification, the solid fuel is subjected to a series of thermochemical processes like drying, pyrolysis, oxidation and reduction. The resultant product is producer gas. It has the thermochemical conversion efficiency of about 70 to 90 per cent.

### 2. Gasifier

Gasifiers are used to convert the solid fuel materials into producer gas. Based on the mode of travel of fuel and air supply, the gasifiers are broadly classified into down draft gasifiers, updraft gasifiers and cross draft gasifiers. Though there are various thypes of gasifiers are employed for gasification of various types of fuel materials, the basic components of a gasifier are same. They are reactor, air supply system, feeding system, gas outlet system, grate, ash removal system etc. In this chapter the significance of every system of gasifier is discussed.



**Figure 7.1 Pilot scale gasifier set up**

## Reactor

The configuration of reactor is an important aspect in deciding sufficiently high residence time of the biomass to provide good carbon conversion. The reactor diameter decided based on the feed rate of the fuel materials, residence time of the material, air flow rate etc. However, in general the specific gasification rate for gasifiers is considered to be  $175 - 225 \text{ kg h}^{-1} \text{ m}^{-2}$ . Based on the feed rate and feed material, the cross-sectional area of the reactor may be decided. Accordingly the height of the reactor is also calculated for the given volume of the feed material. Generally the reactor is made up of MS of suitable thickness to withstand the higher temperature attained during gasification.

**Feeding system :** Feeding is normally from the top of the gasifier for majority of the gasifier systems. Suitable feeding system has to be arranged based on the nature of materials, size of feed, bulk density of feed etc. For higher capacity gasifiers, mechanical system of feeding may be arranged.

**Air flow system :** Air flow is calculated based on the stoichiometric air requirement for specific feed materials. The equivalence ratio between 0.2 to 0.4 will be assessed for better gasification yield. Accordingly the blower type, capacity will be decided for the supply of calculated amount of air to the gasifiers. For the uniform supply of required air to the oxidation zone, suitable air distribution systems such as tuyers may be used and hence the oxygen supply can be assured for better gasification.

**Grate :** Grate is the assembly which separates the ash released during the gasification process. The grate opening should be selected in such a way that it should not allow the flow of feed materials but assure a proper ash removal. If needed, mechanical systems are employed for the proper removal of ash immediately after formation. Proper removal of air helps in proper flow of feed materials, better and uniform air supply during gasification and avoids formation of clinkers in suitable environment.

**Gas out let :** The gas outlet system should consider the direction of flow of producer gas. Feed materials with higher moisture content or tar release are used for gasification and if the producer gas passes through the materials, the quality of the gas will be affected. Hence, the gas produced after reduction zone has to be immediately taken out for further applications.

**Gas cleaning system :** The outlet producer gas consists of particulate matters, tar particles, moisture as impurities. For thermal applications the impurities may not have much problem. However, the tar can be removed easily after condensation in the outlet pipe during its transit. For engine applications, the gas should be free from all the foreign materials, otherwise it will affect the performance of the engine and further that will damage the engine.

Hence, the gas cleaning systems are employed at different stages to remove the impurities. They are:

**Cyclone** : Coarse particles are separated from the gas stream in a high efficiency cyclone separator. Entrained particles in the producer gas are collected in a separate bin at the bottom of the cyclone assembly and can be cleaned periodically.

**Impingement separator** : Intermediate size particles and most of the fines are removed from the gasifier in an impingement separator. This separator is insulated so as to avoid condensation of vapours and to allow passage of hot gas (above 150°C) to the glass fibre cloth filter.

**Glass fibre cloth filter** : To guard the engine against any solid material, the product gas is passed through a glass fibre cloth filter, which removes any solids that have slipped through the previous filter sections.

**Cooler** : The cooling section consists of a tubular heat exchanger. Condensate can be tapped from the cooler by drain vessels, equipped with safety taps. Cooler outlet temperatures vary between 30° and 50°C, depending on environmental conditions (temperature, wind) and engine load.



### Lesson 8. Performance evaluation of gasifiers

Performance evaluation of gasifier has to be carried out to assess the thermal efficiency, gas production rate, energy output etc. of the gasifier.

#### 1. Start up of the gasifier

Small amount of ignited charcoal will be placed in the bottom of the gasifier and further feed material will be added. The blower connected with the gasifier will be turned on and air is supplied into the reactor. Air supply was regulated by regulating valves and measured using rotameters before entering into the reactor. This initiates the gasification. The reactor is closed for providing conducive environment with higher temperature and proper oxygen supply. Instead of using charcoal, LPG torch system can be used to ignite the bed of feed material.

#### 2. Air requirement

The air requirement for gasification of fuel materials can be calculated by calculating the stoichiometric air requirement for complete combustion and equivalence ratio (ER) adopted. Stoichiometric air requirement is calculated from the following formula.

$$Q_c = \frac{2.7 C + 8 H_2 + S - O_2}{0.23}$$

where

$Q_c$  - Stoichiometric air supply, kg of air / kg of feed material

C, H, S and O - elemental composition of carbon, hydrogen, sulphur and oxygen, per cent

$$Q_G = ER \times Q_c$$

where

$Q_G$  - Gasification air supply, kg of air / kg of feed material

ER - Equivalence ratio

$$A_F = Q_G \times F$$

where

F - Feed rate, kg h<sup>-1</sup>

The producer gas was taken out from the reactor and passed through the cleaning systems. The tar, char, dust and carryover particles were collected and the clean gas was brought down to the burner system for thermal applications or to the engines.



**Figure 8.1 Gasifier testing setup**

### 3. Instrumentation

The methods and instrumentation used for measuring various parameters in the study are given below.

#### 3.1 Flow measurement

Airflow rate to the reactor was measured using rotameters. The flow rate of outlet producer gas was measured using a sharp-edge orifice meter, the most widely employed flow-measuring element.

$$Q_t = \frac{C_d A_{2f}}{\sqrt{1 - (A_{2f}/A_{1f})^2}} \sqrt{\frac{2(p_1 - p_2)}{\rho_g}}$$

where

- $C_d$  - Coefficient of discharge
- $A_{1f}$  - pipe cross-sectional area,  $m^2$
- $A_{2f}$  - orifice cross-sectional area,  $m^2$
- $p_1, p_2$  - static pressures, Pa
- $\rho_g$  - density of gas,  $kg\ m^{-3}$

### 3.2 Temperature measurement

Temperature readings at various zones such as drying, pyrolysis, oxidation and reduction zones are measured using K-type thermocouples, which can be connected with digital indicators or recorder with data loggers.

### 3.3 Gas composition

Composition of generated producer gas was analyzed using gas chromatograph.

## 4. Performance results

From the gasification results, parameters such as gas yield ( $\text{Nm}^3 \text{ kg}^{-1}$ ), specific gas production ( $\text{Nm}^3 \text{ m}^{-2} \text{ h}^{-1}$ ), calorific value ( $\text{kCal}/\text{Nm}^3$ ) and hot gas efficiency (%) can be calculated as per the methods given below.

### 4.1 Gas yield

The gas yield ( $G_y$ ) was found out from the flow rate of producer gas ( $Q_t$ ) and feed consumption rate ( $F_r$ ). The formula used was given below.

$$G_y, \text{Nm}^3 \text{ kg}^{-1} = \frac{Q_t}{F_r}$$

### 4.2 Specific Gasification Rate

Specific gasification rate (SGR) was calculated using the weight of dry rice husk gasified for a run, net operating period and the cross sectional area of the reactor using the following relation.

$$\text{SGR} = \frac{\text{Weight of feed material used, kg h}^{-1}}{\text{Cross sectional area of the reactor, m}^2}$$

### 4.3 Specific Gas Production Rate

Specific gas production rate is the rate of producer gas generation at STP per unit cross-sectional area of the gasifier.

$$\text{SGPR} = \frac{\text{Rate of gas production, m}^3 \text{ h}^{-1}}{\text{Cross sectional area of the reactor, m}^2}$$



Cross sectional area of the reactor, m<sup>2</sup>

#### 4.4 Calorific value of producer gas

Calorific value of producer gas (CV<sub>PG</sub>) was calculated based on the composition such as CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub> and water. The procedure followed in calculating calorific value of producer gas is:

$$CV_{PG}, \text{ kCal Nm}^{-3} = \frac{\sum X_i CV_i}{Z}$$

where

$X_i$  - mole fraction of  $i^{\text{th}}$  component of gas

$CV_i$  - calorific value of  $i^{\text{th}}$  component of gas

$$Z = \text{Compressibility factor} = \left[ 1 - \sum X_i \sqrt{1 - Z_i} \right]^2$$

#### 4.5 Hot gas efficiency

The performance of the gasifier was determined by calculating hot gas efficiency of the reactor system. Hot gas efficiency was found out as follows.

$$\eta_H, \% = \frac{Q_t \times CV_{PG}}{F_f \times CV_F} \times 100$$

where

$CV_{PG}$  - calorific value of producer gas, MJ/Nm<sup>3</sup>

$CV_F$  - fuel calorific value, MJ/Nm<sup>3</sup>



### Lesson 9. Energy analysis of gasification

Mass and energy balance of gasifier system can be carried out when gasifying the selected feedstocks studies.

#### i. Mass balance

Mass balance study can be conducted for the gasification of biomaterials. The various mass input and out put to be considered and the corresponding calculation procedure is given below.

##### Mass input

- |                                  |   |                   |  |
|----------------------------------|---|-------------------|--|
| 1. Feed rate, kg h <sup>-1</sup> | : | $F_r$             |  |
| 2. Air flow, kg h <sup>-1</sup>  | : | $F_a$             |  |
| 3. Charcoal, kg                  | : | $M_c$             |  |
| Total mass input ( $M_I$ )       | = | $F_r + F_a + M_c$ |  |

##### Mass output

- |                                    |   |                                |
|------------------------------------|---|--------------------------------|
| 1. Product gas, kg h <sup>-1</sup> | : | $Q_t \times F_r \times \rho_G$ |
| 2. Tar, kg h <sup>-1</sup>         | : | $M_t$                          |
| 3. Char/ dust, kg h <sup>-1</sup>  | : | $M_{ch}$                       |
| 4. Ash, kg                         | : | $M_A$                          |
| 5. Char coal, kg                   | : | $M_{co}$                       |

where

$Q_t$  - quantity of producer gas generated, Nm<sup>3</sup> h<sup>-1</sup>

$\rho_G$  - density of producer gas, kg Nm<sup>-3</sup>

$$\text{Total mass output } (M_O) = Q_t \times F_r \times \rho_G + M_t + M_{ch} + M_A + M_{co}$$

Mass balance is given as,

$$\text{Total mass input } (M_I) - \text{Total mass output } (M_O) = 0$$

$$F_r + F_a + M_c - (Q_t \times F_r \times \rho_G + M_t + M_{ch} + M_A + M_{co}) = 0$$

From the mass difference worked between input and out put, accuracy of the method adopted for calculation can be determined by mass closure procedure.

#### ii. Energy balance

The procedure adopted for the calculation of energy balance for fluidized bed gasification of all biomaterials are given below.

**Energy input**

1. Feed, MJ h<sup>-1</sup> :  $F_r \times CV_F$
2. Charcoal, kg :  $M_c \times CV_C$

where

$CV_F$  - calorific value of feed material, MJ kg<sup>-1</sup>

$CV_C$  - calorific value of char, MJ kg<sup>-1</sup>

3. Air (if preheated) :  $m_a \text{ } cp_a \text{ } dt_a$

where

$m_a$  - mass of air, kg

$cp_a$  - specific heat of air, MJ kg<sup>-1</sup>K<sup>-1</sup>

$dt_a$  - temperature difference in air, °K

$$\text{Total energy input (E}_I\text{)} = (F_r \times CV_F) + (M_c \times CV_C)$$

**Energy out put**

1. Gas energy output, MJ h<sup>-1</sup> (E<sub>g</sub>)

$$= (Q_t \times F_r \times \rho_G \times CV_G) + (Q_t \times F_r \times \rho_G \times cp_G \times \Delta T_g)$$

where

$\rho_G$  - density of producer gas, kg Nm<sup>-3</sup>

$cp_G$  - specific heat of producer gas, MJ kg<sup>-1</sup>

$\Delta T_g$  - temperature difference of producer gas to atmosphere, °C

2. Char energy out put MJ h<sup>-1</sup> (E<sub>c</sub>) =  $(M_{ch} \times CV_C) + (M_{ch} \times cp_{ch} \times \Delta T_c)$

where

$cp_G$  - specific heat of char, MJ kg<sup>-1</sup>

$\Delta T_c$  - temperature difference of char to atmosphere, °C

3. Energy loss, MJ h<sup>-1</sup> (E<sub>c</sub>) =  $U \times S_{re} \times hr \times \Delta T_r$

where

$U$  - overall heat loss coefficient

$S_{re}$  - Surface area of the reactor, m<sup>2</sup>

hr - heat transfer coefficient,  $\text{kCal m}^{-2} \text{ }^{\circ}\text{C}$

$\Delta T_r$  - temperature difference of reactor to atmosphere,  $^{\circ}\text{C}$

Total energy out put (Eo) :  $E_g + E_C + E_L$

Energy balance is given as,

Total energy input ( $E_I$ ) - Total energy output ( $M_o$ ) = 0

$$(F_r \times CV_F) + (M_c \times CV_C) - [(Q_t \times F_r \times CV_G) + (Q_t \times F_r \times \rho_G \times c_{pG} \times \Delta T_g) + (M_{ch} \times CV_C) + (M_{ch} \times c_{p_{ch}} \times \Delta T_c) + E_L] = 0$$

The difference in energy between input and out put of the study gives the accuracy of the method adopted for calculation of energy balance and the corresponding energy closure calculation.



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## **Lesson 10. Operational maintenance of gasifier**

Various types of gasifiers are used to convert the solid fuel materials into producer gas. Basic components of a gasifier system are reactor, air supply system, feeding system, gas outlet system, grate, ash removal system etc. In this chapter the maintenance of systems of gasifier is discussed.

### **Reactor**

Generally the reactor is made up of MS of suitable thickness to withstand the higher temperature attained during gasification. The insulation of reactor gives significant reduction of heat from the gasification zone to atmosphere. The perfectness of insulation has to be assessed periodically to avoid heat transfer. The loss of heat through improper insulation not only led to heat loss but also will lead to reduced thermal efficiency of gasifier.

The reactor is made up of mild steel in most of the cases. It is always subjected to very high temperature of around 1200°C during gasification. Hence, heat injury or damage in the reactor surface has to be inspected periodically for better performance of the gasifiers.

### **Feeding system**

Manual feeding system does not need much of maintenance. However the automated systems like mechanical feeding like screw systems, elevator or bucket systems have to be maintained. As these systems have more moving parts and also dealing with higher temperature of the reactor zone and also the dusty biomaterials. Proper greasing and lubrication of the system has to be carried out. The joints, hinges, ropes, chains, belts etc have to be checked. They not only under perform during loading but also will cause severe injury to the persons working with the gasifier.

### **Air flow system**

Air flow has significant contribution in the generation of quantity of producer gas and also the quality in term of energy content of producer gas. Hence, it has to be assessed whether the air supply is proper during gasification. Hence the performance of blower can be assessed to determine the quantity of air supply to the gasifier. The speed has major role in deciding the air flow rate of the blowers. The air flow rate of the blower has to be measured against the specified blower speeds and has to be checked with the manufacturer's specification. The pressure drop against various air flow rate of blowers has to be checked and compared with standards. If the deviation is more the inner surface of air supply system (pipes) have to be checked for blockage due to condensed tar, particulate matters etc. and may be cleaned for smoother air supply.

The damage in the air supply system or tuyers are predominant as these systems are in contact with oxidation zone of gasifier whereas the temperature will be about 1200°C. If the damage is beyond repair immediate replacement has to be made to maintain proper air

supply. The blockage of the air supply system also has to be considered as the biomaterials will release more tar during gasification process. After closing of gasification process the residual tar will be condensed in the surface of the reactor as well as the opening of the air supply system. Hence, the blockage has to be removed periodically for proper air supply to the gasification system.

### **Grate**

Grate separates the ash, producer gas and feed material. This is the part exposed always in the higher temperature at about 1500°C. Though it is made up of cast iron, they will be damaged easily due to not only the higher temperature but also the chemical constituents of the gas and ash due to the varying chemical composition of the feed materials. Hence,

### **Gas out let**

The gas outlet system should consider the direction of flow of producer gas. Feed materials with higher moisture content or tar release are used for gasification and if the producer gas passes through the materials, the quality of the gas will be affected. Hence, the gas produced after reduction zone has to be immediately taken out for further applications.

### **Gas cleaning system**

The outlet producer gas consists of particulate matters, tar particles, moisture as impurities. For thermal applications the impurities may not have much problem. However, the tar can be removed easily after condensation in the outlet pipe during its transit. For engine applications, the gas should be free from all the foreign materials, otherwise it will affect the performance of the engine and further that will damage the engine.

Hence, the gas cleaning systems are employed at different stages to remove the impurities. They are:

Coarse particles are separated from the gas stream in a high efficiency cyclone separator. Entrained particles in the producer gas are collected in a separate bin at the bottom of the cyclone assembly and can be cleaned periodically.

Intermediate size particles and most of the fines are removed from the gasifier in an impingement separator. This separator is insulated so as to avoid condensation of vapours and to allow passage of hot gas (above 150°C) to the glass fibre cloth filter.

To guard the engine against any solid material, the product gas is passed through a glass fibre cloth filter, which removes any solids that have slipped through the previous filter sections.

The cooling section consists of a tubular heat exchanger. Condensate can be tapped from the cooler by drain vessels, equipped with safety taps. Cooler outlet temperatures vary between 30° and 50°C, depending on environmental conditions (temperature, wind) and engine load.

### **Starting up of gasifier**

Initially add charcoal over the grate for about 10 cm depth. The feeding system may be filled with the fuel materials. Start the blower by adjusting the flow rate valves to allow the calculated amount of air supply in to the system. Open the ignition port of the gasifier and ignite using gas flame. After a few minutes of smoky exhaust, test the gas for consistent burning. If the gasifier is used for running the engine, the blower may be stopped and the engine can be started. This will facilitate the sucking action from the engine for required air supply in to the gasifier. If the gasifier is used for thermal applications, the burner can be ignited with continuous supply of air using blowers.

### **Operational aspects**

Refill the feeding system before it becomes completely empty. Periodically shake down the ash from the grate. Periodically drain water from the cooler.

### **Shutting down of gasifier**

For shutting down the gasifier, completely close the air control valve. The lid of the fuel supply system or gasifier has to be closed fully to avoid any further air entry.

### **Routine maintenance**

Regular checking of the welding and fitting portions for air tightness or leakages is an essential maintenance.

### **Daily maintenance**

Complete removal of ash by shaking or any other method from the gasifier for easier starting and smoother operation during the next run.

Residual unburnt fuel material has to be removed immediately after completion of the gasifier operation to avoid further combustion of the material and also wastage of fuel materials.

Drain out the tar condensate in the gas pipe line and also in the filter or cleaning units.

### **Weekly maintenance**

- Clean the reactor drum if necessary

- Clean the feeding system

- Filter system

- General cleaning

- Replace the filter materials inside the filter

- Ensure air tightness on filter pipes and filter lids

In addition to the above maintenance, the following occasional maintenance such as once in a fortnight or every 30 hours of operation may be carried out.

Checking up of all the pipe lines of the gasifier and to the accessories for air tightness

Check the connections with the producer gas appliances with burners or engines

Check for rusting or damage in the reactor and piping

Check the thermal insulation in the system



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### *Module 3. Performance evaluation and maintenance aspects of biogas plants*

#### **Lesson 11. Structural aspects of biogas plants**

Biogas technology is an appropriate technique to convert non-conventional energy into conventional energy i.e. suitable organic matters in to end use forms of energy such as heat, mechanical and electrical energy. Biogas is a neat, clean, combustibile and pollution-free gaseous fuel. The technology is simple and appropriate for both rural and urban areas as it converts the organic matter available both in rural and urban areas.

Biogas plant has multiple applications for the benefit of individual households, community level and also industrial areas. Some of the important applications of biogas plant are:

- ♣ Cooking fuel
- ♣ Fuel for lighting
- ♣ As engine fuel
- ♣ Enriched organic manure
- ♣ To trap insects at the farm

#### **Types of Biogas Plants**

There are many designs and models of biogas plants in operation with each one are having some special characteristics; however, each popular model has some basic components. The basic difference in models are the storage structure such as floating drum and fixed drum biogas plants. Other than these, based on the flow of influent slurry, the biogas plants may be classified as Janata model, horizontal plug-flow model, continuous vertical flow reactors etc. have some special components for proper functioning of these designs.

#### **Basic components**

The basic components of plants which are common to most of the models are:

1. Digester or fermentation chamber
2. Gas holder or gas storage chamber
3. Inlet (pipe or tank)
4. Outlet (pipe or tank)
5. Mixing tank
6. Gas outlet pipe

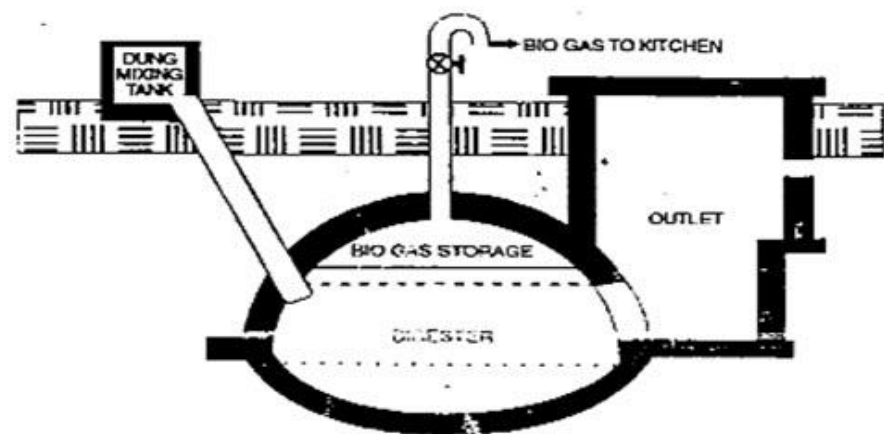
### a. Floating gasholder digester (KVIC)

The drawing consists of three main views: a top view, a side elevation, and a cross-sectional view.

- Top View:** Shows a central circular component with a crosshair pattern. It is flanked by two rectangular components. The left rectangular component has a central hole labeled  $\phi 2.5$  HOLE. Dimensions include 10, 15, 25, and 15 for the rectangular parts.
- Side Elevation:** Shows the profile of the assembly. The central circular component has a diameter of  $\phi 4.61$  HOLE. The rectangular components have a height of 15 and a width of 25. The central component has a height of 15. The overall width is 25.
- Cross-sectional View:** Shows the internal structure of the assembly. It includes labels for CC WORK, BRICK WORK, EARTH FILLING,  $\phi 10$  ASB/CEM PIPE, 25 25 FLANGE PLATES, GUIDE FRAME, and CC FOUNDATION 1:3:6. Dimensions include 75, 20, 60, 30, 15, 23, and  $\phi A$ . The overall height is labeled B, and the overall width is labeled C.

**Fig.1. Floating drum biogas plant**

Fixed dome digesters run on a semi-continuous batch mode, which digest animal and human wastes as well as plant wastes. It is usually built below ground level, hence it is easier to insulate in a colder climate. The digester can be built using several materials such as bricks, cement mortar, concrete, lime concrete and lime clay. This facilitates the introduction and use of local materials and manpower.



**Fig.2. Fixed dome (Deenbandhu) biogas plant**

## **After construction**

### **a. General**

#### **Plant**

Initial filling of the slurry should be done after 2 weeks of curing of the plant. Care should be taken to avoid the entry of sand and gravel with the slurry in to the plant.

Fill the plant with properly mixed dung slurry. (mix ratio, dung : water =1:1) Recommended quantity of slurry mixed (i.e. 25 kg. dung with 25 litres of water per cubic meter plant) should be added daily.

Do not allow scum to form in the digester, otherwise the production of gas will be reduced. Once the manure pit gets filled up with ejected slurry from biogas plant, it should be removed to the field or compost pit.

The initial gas obtained should be let out because it will contain more of Carbon dioxide.

### **i. KVIC (Floating drum) model biogas plant**

When charging fresh slurry in the bigger sized floating drum type plants, make sure that it is filled equally on both sides of the central partition wall. After the initial filling of the digester tank, drum moves upwards due to gas pressure. Regular loading of the plant should be commenced after this. Rotate the gas holder once or twice every day in order to break the scum.

### **ii. Deenbandhu biogas plant**

During the initial filling, fill the plant with slurry up to second step level of the outlet (bottom of the gas chamber). The regular loading of the plant should be commenced only after automatic ejection of the slurry through the outlet opening. Proper loading of the plant will avoid the scum formation because of the slurry movement. The entire biogas plant should be covered with soil to a minimum thickness of 15 cm.

### **Pipes**

From the gas outlet pipes, remove the condensed water at regular intervals.

### **Burner**

The right type of burner designed for bio - gas (as per ISI specification) should be used for efficient utilization of gas. Do not open the gas valve before lighting the gas appliances. Burner holes and jets should be cleaned with kerosene and small iron wire to avoid blocking of gas. Wide bottom utensils should be preferably used so that loss in heat will be minimum. Pressure cooker should be used to reduce the gas consumption.

Adjust the flame by turning the gas cock and air regulator till blue flame is obtained. Do not test the biogas flammability at the top of the biogas plant.

(Source : TNAU-Bioenergy-BDTC manual)



## **Lesson 12. Performance evaluation of biogas plants**

Biogas plants convert the organic matter into a gaseous fuel. The biogas plants will be designed and constructed based on the feed material availability or the gas production requirement. To assess the performance of any biogas plant the gas production per day has to be monitored. In addition to that the rate of conversion of organic matter into biogas can also be assessed. The energy content of the gas is also decides the energy output from the biogas plant for a given input of feed materials. The procedures to adopt in the assessment of biogas plants are given below.

### **Gas production**

Daily gas production may be measured using gas flow meters. Gas flow meters can be connected with the outlet of the biogas plant. The gas outlet can be observed daily. This can be compared with the actual capacity of the plant.

### **COD destruction**

There is a correlation between Chemical Oxygen Demand (COD) and methane generation in biogas plants. For every kg of destruction of COD, about 0.3 m<sup>3</sup> of methane can be generated. Hence, the destruction of COD and generation of biogas in the plant can be assessed by observing the COD content of the influent and effluent and the biogas production.

### **COD measurement**

The Chemical Oxygen Demand (COD) is a measure of oxygen equivalent of that portion of the organic matter in the sample that is susceptible to oxidation by strong chemical oxidant. This is an important and quickly measured parameter for pollution studies of streams and industrial wastewater.

Most of the organic matter is destroyed in boiling mixture of chromic and sulphuric acid. The purpose of running blank is to compensate for any error that may result because of presence of extraneous organic matter in the reagents.

### **Apparatus**

- a) COD reflux apparatus of 500 ml flat bottom flask with ground glass joints and condensers.
- b) Pipette, burette, measuring cylinders etc.

### **Reagents Required**

- a) **Standard 0.25 N potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>) solution**

Dissolve 12.259 gm of pure  $K_2Cr_2O_7$  in distilled water and dilute to 1 litre. Add about 120 mgs of sulphuric acid.

#### b) Sulphuric acid-Silver sulphate reagent

Add 5.5 gms of  $AgSO_4$  to 1 Kg of Conc  $H_2SO_4$ . Keep the same overnight.

#### c) Standard 0.1 N Ferrous Ammonium Sulphate Solution $Fe(NH_4)_2.(SO_4)_2.6H_2O$

Dissolve 30 gm of pure salt in distilled water. Add 20 ml of conc  $H_2SO_4$  and dilute to 1 litre.

#### d) Ferroin indicator

Dissolve 1.485 gm of 1-10 Phenanthraline monohydrate with 0.695 pure  $FeSO_4.7H_2O$  in distilled water. Dilute to 100 ml. This indicator is commercially available.

#### e) Con. $H_2SO_4$

#### Procedure

- Take 0.4 gm of  $H_2SO_4$  and 20 ml of sample in a reflux flask (if required dilute to suitable degree). Mix well.
- Add 10 ml of 0.25 N,  $K_2Cr_2O_7$ . Drop some pumice stone and slowly add 30 ml of Con  $H_2SO_4$ - $AgSO_4$  reagent.
- Mix the contents thoroughly and connect the flask to condenser. Reflux for 2 hours.
- Cool and wash down the condensers. Dilute the mixture to 150 ml by adding distilled water.
- Add 3 drops of Ferroin indicator and titrate with N/10 Ferrous Ammonium sulphate solution till the colour changes from green to wine red. Note the end point.
- Perform the same procedure with 'Blank' using distilled water instead of the sample.

#### Observation table

Sl.No	Sample volume, ml	ml of Ferrous Ammonium sulphate rundown	
		Sample $V_1$	Blank $V_2$
1	20 ml		
2	20 ml		
3	20 ml		
4	20 ml		

$$(V_1 - V_2) \times \text{Normality of Ferrous Ammonium Sulphate} \times 8000$$

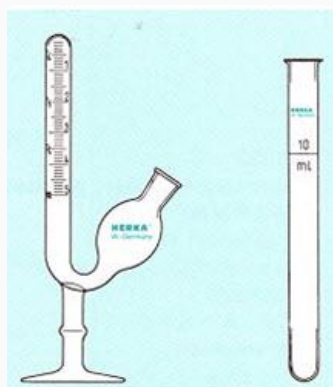
COD in mgs/litre = -----

Volume of Sample

If the sample is diluted COD in mgs/litre = COD as above  $\times$  dilution ratio

(For example if dilution is 10% (i.e. 10 to 100) i.e. 10 ml of sample and 90 ml of distilled water. Then COD in mgs/litre = COD  $\times$  10 mg l<sup>-1</sup>)

### Methane content of biogas



The saccharometer is used to measure the methane content of biogas sample. Saccharometer is filled with 10 per cent NaOH solution. 5 ml of biogas is injected into the saccharometer using syringe. The carbon dioxide present in the biogas will be dissolved in NaOH solution. The methane will be collected on the top of the saccharometer and the volume can be measured.

The constituents of biogas such as methane, carbondioxide etc. can also be measured using gas chromatography method.

### Determination of calorific value of biogas

The continuous flow gas calorimeter comprises of a gas flow meter, a gas pressure regulator, a manometer and a combustion chamber with a burner. The gas, whose calorific value has to be determined, is passed through the gas flow meter, then through the regulator and then to the burner. The pressure is measured using the manometer and the temperature is measured at the inlet of the gas meter and also of the products of combustion

The inlet and outlet temperatures of water are measured. The calorimeter is so designed that the gases from the flame pass upwards through the central portion of the calorimeter known as combustion chamber and at the top are deflected down wards and pass through the flues, finally escape into air through the outlet. The calorimeter chamber is cooled by cooling coils. The calorimeter is enclosed in an outer container. The air gap between outer cover and calorimeter acts as insulation against radiation losses. There is an outlet to collect the condensate obtained from the cooling coils as a result of burning of H<sub>2</sub> in the gas to water. The condensate is also weighed.

Volume of gas used =  $V_1$

Temperature of gas used =  $T_1$

Gas manometer reading, =  $G$

Barometric height, =  $B$

Mass of cooling water used =  $M_1$

Mass of condensate collected =  $M_2$

Cooling water temp. at inlet =  $T_{ci}$

Cooling water temp. at outlet =  $T_{co}$

Absolute pressure of gas,  $P_1$  =  $[B + (G / 13.6)]$

The volume of gas must be converted to the volume, as it would exist at 25°C and 760 mm Hg.

Let this volume be  $V_o$ . Then

$$P_1 V_1 / T_1 = P_o V_o / T_o$$

$$V_o = (P_1 / P_o) (T_o / T_1) V_1$$

Now, Energy transferred by gas = Energy gained by the cooling water

$$V_o \times \text{HCV} = M_1 \times (h_2 - h_1)$$

From steam table,

$h_2$  = Specific enthalpy of water at  $T_{co}$ , J kg<sup>-1</sup>

$h_1$  = Specific enthalpy of water at  $T_{ci}$ , J kg<sup>-1</sup>

Hence,

$$\text{HCV} = \text{kJ m}^{-3}$$

$$\text{Latent heat of vaporization} = L$$

$$\text{Therefore, LCV} = \text{HCV} - (M_2 \times L)$$





### Lesson 13. Periodical maintenance of biogas plants

All the models of biogas plants are designed in such a way that least attention is necessary for operation and maintenance. It is however necessary to follow some simple guidelines, failing which there would be problem in the working of the unit. Operation and maintenance guidelines could be categorized as:

(i) Daily routines, (ii) Weekly routines, (iii) Monthly routines and (iv) Half Yearly/Yearly routines.

#### Daily Routines/Maintenance

1. About 25 kg of cattle dung is required for generation of 1 m<sup>3</sup> gas per day (calculated at 1.4 cft/kg). For higher capacities, the dung required for daily feeding is (25 × X) kg, where X is the capacity of the plant. The required quantity of dung along with equal quantity of water is fed into the mixing tank after plugging the inlet pipe. The contents are thoroughly mixed. Materials like, straw, trash etc. should be removed. The slurry is then led into the digester by removing the plug put at the opening of the inlet.

After feeding, the inlet opening is again closed by the plug. The inlet tank is cleaned with water and the washing is drained out through the hole provided at the lowest point of the floor of the inlet tank. Inorganic materials like sand, mud, *etc.* will get washed away while cleaning the mixing tank.

2. In the case of KVIC model, the gas holder is given half rotation in clockwise and anticlockwise direction 2-3 times, immediately after feeding to break the scum on the surface of the digester slurry. This is to be repeated once more during the day, when the gas holder has submerged in the slurry.
3. As far as possible, the main gate valve is opened only when gas is required. In any case, it should be made as a practice to close the gate valve at night, when no more gas is required. Next day the valve is opened when use of gas is to start.
4. The air shutter's position is checked while starting the use of burner in the morning and is properly readjusted, if necessary.
5. In the case of KVIC model, during the first month after commissioning the plant, it is likely that the outlet pipe is choked by hard cattle dung that must have gone into the digester at the time of initial feeding. It may therefore be checked about the flow of the slurry from outlet pipe immediately after daily feeding. If there is any chocking, it may be cleared by inserting a long bamboo into the outlet pipe.
6. In winter, the rate of gas production would be low. As such it is better to use a little warm water for daily feeding so that slurry with lower temperature may not disturb

the system inside the digester when daily feeding is done. One way is to make the slurry in the mixing tank in the morning and allow to get warm by direct solar energy. This slurry may be allowed inside the digester when no more sun rays fall on the slurry.

### Weekly routines/Maintenance

1. The burners and lamps are to be cleaned. Particularly dirt, dust etc. if any at the ports and injector orifice of the burners are removed. Smooth gas flow must be ensured; Similarly the nozzle of biogas lamp and the chimney are also cleaned.
2. The water remover/water trap may be checked for any collection of water and the condensed water any be drained out, the plug is properly fitted again. If it is an automatic water remover, it may be checked for its proper functioning.
3. In the case of fixed dome plants, a long bamboo may be inserted in the digester through the outlet gate and stirring is done to prevent accumulation of scum.
4. In the case of KVIC model, the dry mat that must have been collected in the gap between the digester wall and the gas holder may be removed manually, so that smooth vertical motion of the gas holder is not disturbed.

### Monthly Routine/Maintenance

1. Gate valve and gas pipe line be tested for leakage and rectification is done if found necessary.
2. Gas taps/gas cock may need lubrication which may be done.
3. Ventury and mantles of gas lamps may be checked and replaced if necessary.
4. If the manure pit by the side of the gas plant is full, the outlet slurry may be diverted to the next pit.

### Half Yearly / yearly Routines/Maintenance

1. Gas holder, dome and pipe line are checked for leakage and corrective steps are taken where necessary. Particularly the flexible pipe connected the gas outlet and the main pipe line (KVIC biogas plant) may be checked for leakage and replaced if found brittle.
2. In the case of KVIC model, outer surface of the mild steel gas holder is prone to corrosion more than the inner surface. For protecting the gas holder from corrosion, outer surface need to be painted once in a year. Some times, it may be necessary to paint in about 6 months, if the earlier painting has not been proper and the atmosphere is humid. It is not necessary to take out the gas holder from its position. When the gas holder if full with gas, the main gate valve may be closed, entire outer surface visible above slurry level is thoroughly cleaned with water. Wire brush may be used for cleaning the rusted portion if any. Black enamel paint is applied over the entire surface. The paint may be allowed to dry for one day and then the gas should be allowed to pass in the pipe line for routine use.

3. Worn out accessories are to be repaired or replaced.
4. The manure from the pits which are full is removed for manuring purpose and the pits are kept ready for further use.

### **Do's and Dont's for maintenance of biogas plants**

#### **a. Do's:**

1. Decide the size (capacity) of biogas plant matching the availability of feed material and requirement of gas for various needs.
2. Select the site for biogas plant which is nearer to the points of use (say kitchen) and also nearer to the cattle- shed, as far as possible.
3. Install biogas plant in an open space where Sun rays are freely falling during day time.
4. Install biogas plant strictly as per the approved drawings and specifications with trained persons.
5. Install the biogas plant below ground level as shown in the drawings (except a small projection in case of KVIC model).
6. Do back filling by filling up the gap between the outer surface of the digester and the portion of the earth cutting, firmly compacting with sand/soil and also putting some water as per installation guidelines.
7. Initial feeding to biogas plant should be done after curing as prescribed.
8. Feed biogas plant with cattle dung and water in 1:1 proportion, making it a homogeneous mixture after thorough mixing.
9. Remove, straw pieces of sticks, *etc.* from the slurry (mixture of dung and water) before feeding.
10. Maintain proper slope in the pipeline and fix water remover (water tap) at the lowest point.
11. Break the scum formed on the surface of the slurry in the digester by rotating the gas holder daily after feeding in case of KVIC model and by inserting a long bamboo throughout and stirring the slurry.
12. Use ISI marked burners and lamps to get maximum efficiency.
13. Close the main gas cock in the night after the use of gas is over.
14. Test the burning of the gas at the burner.
15. Use soap solution for testing leakage of gas in the dome/gas holder.
16. Put the burners on a raised platform in the kitchen.

17. Adjust the air shutter to get blue flame to get maximum heat.
18. Use lighter or light the match before opening the gas tap.
19. Cover the inlet and outlet tank openings of fixed dome models with wooden plank, stone or reinforced cement concrete slab.
20. Keep the kitchen ventilated.
21. Paint the outer surface of the gas holder of KVIC model generally once in a year or when rusting is noticed.

**b. Don'ts**

1. Don't recommend much higher capacity simply because there is enough dung, when the use of gas is less. Don't suggest a smaller plant because there is less feed material when gas required is much higher.
2. Don't select a site far-away from cattle shed and also kitchen to avoid operational inconveniences.
3. Don't install biogas plant under a tree or under any other shade.
4. Don't introduce any change in the design and/or specification of biogas plant at field level suggestions if any regarding modifications should be referred to MNRE.
5. Don't install biogas plant above ground level.
6. Don't do back filling loosely (or after completion of digester construction in case of KVIC model).
7. Don't start initial feeding without proper curing.
8. Don't add either more water or less water to make a homogeneous mixture with cattle dung for feeding.
9. Don't allow soil or sand particles to enter the digester along with the slurry.
10. Don't lay the pipeline in such a way that condensed water gets accumulated in any portion of the pipeline which disturbs the smooth flow of gas.
11. Don't allow accumulation of scum on the surface of the slurry in the digester.
12. Don't use burners and lamps which are not approved by ISI since they may not give maximum efficiency.
13. Don't leave the gas taps near the burner open after use.
14. Don't test burning of gas at the main gate valve on the dome/gas holder.
15. Don't use fire for testing the leakage in the gas holder.

16. Don't put burners on the ground in the kitchen as in the case of conventional Chula.
17. Don't make the air shutter tight or too loose. In both the cases, there would be incomplete combustion and thus wastage of gas.
18. Don't open gas tap and start searching for lighter and match box.
19. Don't keep the outlet tank open since cattle, children may accidentally fall.
20. Don't inhale biogas since it may be hazardous.
21. Don't allow the gas holder to rust which brings down its life.

(Source : TNAU-Bioenergy-BDTC manual)



## Lesson 14. Problem identification and rectification of biogas plants

### Common defects of biogas plants and the trouble shooting

S. No.	Defect	Reason	Remedy
1.	Crack in the digester wall which normally occurs in floating drum (KVIC) and fixed dome Janata models.	(a) Improper soil settlement (b) Defect in the foundation-concrete mixture (c) defect in the construction of digester wall, e.g., improper laying of bricks, mortar proportion and application (d) Use of inferior quality materials (e) sliding of earth (f) improper back filling.	By adding water 2 to 3 times a day, the leakage gets stopped in 2 to 3 days. If there is no improvement after 3 days or so, it indicates that the crack is wide. In case of suspected wide crack(s) the entire slurry in the digester is required to be pumped out and after cleaning the inside of the wall the cracked portion(s) are first marked. From all around the crack about 12" of plaster must be chipped out carefully from top to bottom and the gap of the crack should be filled up with cement mortar of 1: 4 proportion. Then fix the chicken mesh to cover the entire area chipped around the crack and plaster with 1:4 cement mortar or rebuilding of the digester wall will be necessary.
2.	Gas leakage in floating drum of KVIC model or fixed dome of Deenbandhu model	(a) In a floating drum of KVIC model gas leakage would be due to the hole in the gas holder. This hole would be generally at the welded joints of sheets if the gas holder is new and in any part of the M.S. gas holder due to rusting or corrosion if the gas holder is old Leakage in FRP gas holder can occur due to small holes or cracks. (b) In the fixed dome the leakage could be due to improper construction, improper mortar, improper curing etc.	(a) In case of floating drum, M.S. drum would be welding, sonic durable adhesive can also be applied for quick rectification. If the problem is with FRP gasholder rectification is done by putting fibre glass mat at the points of leakage and then applying resin. (b) In case of fixed dome, If the leakage is only in one or two points, the plaster on the outer surface of the dome at those points of leakage should be removed with care. A thin paste of a mixture of sodium silicate and cattle dung in equal proportion should be prepared by adding water. This paste should first be applied on the points of leakage and then a plaster of cement mortar of 1: 3 is provided. If the leakage is in several points, the entire plaster on the outer surface of the dome should be done with a fresh 1:3

			cement mortar.
3.	Large gap between the digester wall and gas holder (KVIC Model)	(a) Defective construction without checking the diameter after completing the layer of each course of brick construction. (b) The gas holder was made smaller than the required size.	(a) If the gap is not very wide (less than 3') no correction need to be attempted. However, if the gap is very wide, then a cement concrete ring may be inserted as a collar around the gasholder leaving enough space for the gasholder to move up and down. (b) Wherever a strong ledge has been constructed the gap can be corrected by building additional brick line over the ledge to cover the gap. This must be done after removing the plaster and making sure that the additional brick line is jointed to the digester wall properly. The gasholder of wider diameter can be exchanged for the smaller one.
4.	No gas is formed after first filling	If it is floating drum model inflation of gasholder indicates the collection of gas. In fixed dome rise in slurry level in the pressure chamber indicates collection of gas. If there is no such indication as stated above, it means that either the gas is not generated or the gas is leaking.	1.If the weather is cold, (winter season) it takes more time for generation of gas. 2. If the gas is leaking, check the gas holder/dome with soap water, then Stop the leakage. 3. If there is leakage in the pipe joints, tighten the joints. 4. It is possible that the gas tap/ cock are kept open and hence gas escapes. Close the tap/cock and check.
5.	First collection of gas does not burn	More of air or more of CO <sub>2</sub> in the first collection	First collection of gas generally does not burn. Second collection also may or may not burn well. Allow the gas to escape till there are clear indications of burning. Third collection would burn normally.
6.	Gas exhausts very quickly after opening of main gas valve	Gas tap fitted to burner/lamp is open. 2. There may be a considerable leakage in pipe line. 3. Higher capacity burner is used. 4. Gas pressure is high	1. Close the gas tap. 2. Mainly check T-joints in the pipeline including the one provided for removal of condensed water. Stop the leakage by putting plug or by whatever other method that would be appropriate. 3. Replace with suitable burner. 4. Adjust the burner cock suitably.
7.	Generation of gas is very slow	1. Low temperature and pH 2. Quantity of animal waste daily feeding is less	1. In winter, particularly when the ambient temperature is very low, the gas production will slow down since

		<p>3. More water is added 4. Formation of scum 5. Gas leakage</p>	<p>methanogens are very sensitive to temperature and pH. The remedies are, (a) create green house effect by covering the biogas plant by solar canopy (b) use warm water for daily feeding, preferably by putting the slurry in the mixing tank and allowing it to warm by sun rays. (Direct solar heating) (c) adjust pH by adding lime water, 2. Add correct quantity, 3. Don't use more water than specified either in daily feeding or otherwise, 4. In case of floating drum model gas holder is to be removed and scum is taken out and gas holder fixed again. In case of fixed drum model some stirring by any method may be of some help. If the problem is severe, the entire slurry may have to be taken out and recharged, 5. Locate the points and stop.</p>
8.	Gas generation has stopped after the unit has worked for some months/years.	<p>1. The slurry has become acidic (i.e. lowering of pH). This would be due to overfeeding of digester. 2. Toxic materials like soap, detergent, pesticide etc. might have entered the digester</p>	<p>1. Below pH 6.2 biogas generation stops practically. Addition of water from inlet will help in bringing down the solid content and slight increase in pH level. Since there is buffering effect of cattle dung, this simple process may make the unit to become normal. If there is no improvement, then add in small dose mild alkali (CaOH, NaOH) through the inlet and some stirring is done. At regular intervals measure pH, till it goes slightly above 6.2 and then leave the system to get normalized with time. 2. If little quantity of toxic material has entered, the digester continues daily feeding as usual and wait for normalisation in generation of gas. If the quantity of toxic material that has entered the digester is high, gas production stops completely. Best remedy in such a case would be to empty the digester and recharge. Care should be therefore taken not to allow toxic substances to enter the biogas digester.</p>



9.	Gas does not burn	1. If it is in the initial stage of charging, it is due to presence of more air and/or CO <sub>2</sub> , 2. There could be obstacle in the pipe line at any point upto the burner nozzles. The gas is, therefore, not reaching the burner ports, Too much of primary air getting mixed with gas	1. Allow the gas to escape. Try next collection, 2. Start checking and cleaning from the burner. Clean the nozzle and injector. Then check pipe line. One common obstacle for flow of gas is condensed water. Drain it out through the water trap. Even after this, if the gas does not flow, pipe line has to be checked for any solid material obstructing the flow of gas, 3. Adjust the air shutter.
10.	Flames are long and yellow	1. If it is floating drum model, insufficient primary air is mixed with gas. 2. If it is fixed dome model, there is high pressure.	1. Adjust the air shutter, 2. Operate the gas valve to reduce the height of the flame and adjust the air shutter.
11.	Flames are not steady	Generally due to condensed water in the pipe line.	Remove the condensed water in the pipeline.
12.	Poor illumination of lamp	1. Low gas pressure 2. Obstruction between gas regulator and ventury or the pin is not operating properly.	1. If it is floating drum model put additional weight on gas holder. If it is fixed dome model wait for pressure build up. 2. Clean the passage and make the pin operate properly
13.	Slurry not passing through inlet pipe	Chocking in inlet pipe.	Insert a bamboo inside the inlet it pipe and move it up and down. Take care not to damage the pipe.
14.	Slurry in the digester of floating drum model overflows from the top.	1. Chocking of outlet, 2. Outlet is above the level of digester.	1. Remove the blockage using bamboo, 2. Lower the outlet level.
15.	Slurry water comes through the gas outlet pipe.	Either slurry level inside the digester is high or gas pipe inserted inside the digester or too much frothing is there	Main remedy will be to reduce the slurry level inside the digester by adjusting the slurry outlet passage, This kind of problem is encountered in case of fixed dome models and not with KVIC model

(Source : TNAU-Bioenergy-BDTC manual)

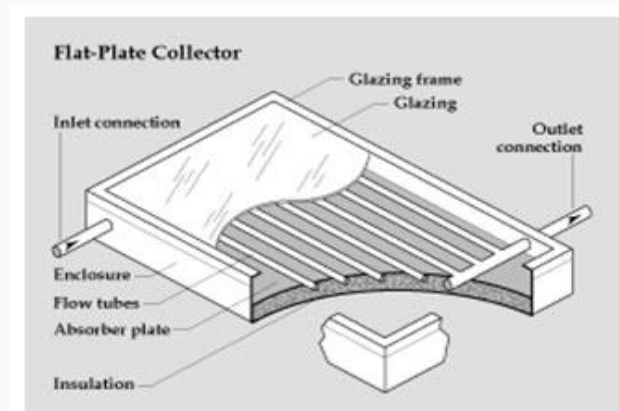
#### ***Module 4. Performance evaluation and maintenance aspects of solar passive heating devices***

##### **Lesson 15. Constructional details of solar passive heating devices**

##### **Parameters affecting performance of solar passive heating devices**

The principle of solar thermal energy system includes transmission of solar radiation through transparent cover and allowing the radiation to fall on an absorber surface, which will convert the solar radiation into heat. Flat plate collectors are the most common type of collectors which consist of

- i. black coated absorber plate
- ii. transparent cover
- iii. heat transfer fluid (air or water)
- iv. heat insulating enclosure



##### **Applications of solar thermal energy**

Using various combinations of solar radiation to heat conversion devices and heat storage devices, several application of solar thermal energy are possible. These are listed below:

- Cooking
- Water heating
- Distillation
- Drying
- Refrigeration
- Power generation



**Solar air drier**

### **Parameters affecting solar thermal devices performance**

The performance of a solar still is affected by parameters such as environmental conditions, design parameters and operating parameters. The environmental conditions such as solar insolation, atmospheric temperature, wind speed, cloudiness etc. The design parameters consist of nature of absorber plate and coating, inclination of the collector, thermo-physical properties of materials used, number of glass cover(s), insulation material etc. The operating parameters consist of flow rate of fluid, quality of water, initial fluid temperature etc. These parameters have significant effect on the performance of the solar passive heating systems.

#### **Solar insolation**

The solar thermal system output is mainly dependent on the amount of solar radiation falling on the dryer in a given location. Higher the solar insolation, higher will be the heat energy available in the solar radiation. Hence, the heat energy transferred to the fluid will be more and the performance of the thermal system will be better.

#### **Atmospheric temperature**

At higher atmospheric temperature, the energy transmitted into the solar thermal system will be higher. As well as, the higher temperature reduces the transfer of heat from the thermal system to the atmosphere and hence, the heat loss will be minimized.

#### **Wind speed**

Wind has direct effect on heat loss from the thermal systems. Higher wind speed reduced the available heat energy falling on the transparent cover and reduces temperature on the glass cover. Hence, the performance of the thermal system will be affected at higher wind velocity.

### **Inclination of collector**

Optimum inclination of collector will be resulted to higher transmission of solar radiation and in turn provides higher thermal energy for further application. Normally, the inclination should be 10 to 15° addition to the latitude of the location. The transparent cover should possess better transmissivity to allow maximum possible solar radiation in to the solar thermal system. The slope should provide easy runoff of rain water during rainy season.

### **Absorber plate**

Absorber material and coating has greater effect on absorption of solar radiation transmitted through transparent cover and should provide maximum conversion into thermal energy. Also, it has to transfer the available heat energy to the air / water for further applications. Selective coatings are available for better thermal conversion of absorber plates. The absorptivity of the absorber plate has to be higher for better performance of the gadget.

### **Number of glass cover(s)**

The number of transparent covers should be optimized so as to transmit maximum solar radiation and minimize the transmission of long wave heat energy generated in side the solar collector to the atmosphere.

### **Insulation**

The insulation materials have influence on over all heat loss coefficient. Better the insulation of material, lesser will be the heat loss from the thermal collector to atmosphere.

### **Fluid flow rate**

The working fluids such as air in dryers and water in water heaters, transfer heat from the collector to further application. If the flow rate is optimum, maximum heat transfer can be effected. Lesser the flow rate, lesser will be the heat transfer and there may be unused heat energy left in the collectors. If the flow rate is higher, the heat transfer will be faster and the energy intensity of the fluid may be lesser and in turn which will affect the performance of the solar collector.



### Lesson 16. Performance evaluation of solar water heater

Solar water heater converts solar energy into thermal energy and is transferred to water to generate hot water. The performance such as hot water generation, temperature of hot water, efficiency of hot water system etc. can be assessed by the following procedures. The assessment can be carried out for a specific period say 8 hours in a day. The seasonal variation can also be studied by parametric assessment in specified seasons.

#### Parameters to be measured

Solar insolation during the study period,  $S$  :  $\text{W m}^{-2}$

Capacity of hot water system,  $Q$  :  $\text{lpd}$

Length of the collector,  $l$  :  $\text{m}$

Width of the collector,  $w$  :  $\text{m}$

Number of collectors,  $n$  :

Atmospheric temperature,  $T_a$  :  $^{\circ}\text{C}$

Diameter of hot water pipe,  $D_m$  :  $\text{m}$

Length of hot water pipe,  $D_l$  :  $\text{m}$

Heat transfer coefficient,  $h$  :  $\text{W m}^{-2}\text{^{\circ}C}$

Temperature of hot water,  $T_h$  :  $^{\circ}\text{C}$

Transmissivity of glass cover,  $t$  :

Absorptivity of black coated surface,  $a$  :

#### Instrumentation required are

Pyranometer for solar radiation measurement

Thermometers

Useful solar heat energy available

Total area of the collector area,  $A_c$ ,  $\text{m}^2$  =  $n \times \text{length} \times \text{width of each collector}$

=  $n \times l \times w$

$1 \text{ J/s} = 1 \text{ W}$  \  $1 \text{ kWh} = 3600 \text{ kJ}$

$$\text{Daily available solar radiation, } S_D, \text{ kJ d}^{-1} = \frac{S \times A_c \times 8 \times 3600}{1000}$$

Heat energy required to heat the water

$$\text{Specific heat of water, } C_p = 4.18 \text{ kJ/kg } ^\circ\text{C}$$

$$\text{Rise in temperature of hot water, } \Delta T = T_h - T_a, ^\circ\text{C}$$

$$\text{Daily heat energy required to heat the water, } Q_u = Q \times C_p \times \Delta T, \text{ kJ d}^{-1}$$

### System performance

Energy transmission through the system

$$\text{Solar energy transmitted through the glass, } S_t = S \times t$$

$$\text{Energy absorbed by the absorber plate, } S_{ta} = S_t \times a$$

$$\text{Surface area of heat transfer, } A_s = \pi D_m \times D_l$$

$$\text{Heat energy transferred to water, } S_H, \text{ kJ d}^{-1} = \frac{S_{ta} \times Q \times h \times A_s \times 3600 \times \Delta T \times 8}{1000}$$

Output

$$\text{Thermal efficiency of solar water heater, \%} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{Q_u}{S_D} \times 100$$

### Economics of solar water heater

It is considered that the economics of solar water heater is compared with the electrical heaters. The cost required for solar hot water system and electrical systems are calculated and the pay back period is calculated.

$$\text{Cost of solar water heater} = \text{Investment, Rs.}$$

$$\text{Daily thermal energy requirement, } Q_E, \text{ kWh} = \frac{Q_U}{0.95 \times 3600}$$

(Considering the efficiency of the electrical water heating system as 0.95)

$$\text{Cost of electricity per day, } P_E, \text{ Rs.} = Q_E \times \text{Unit Price}$$

Assuming 300 days of annual utilization of solar hot water system,

$$\text{Annual saving, Rs.} = P_E \times 300$$

$$\text{Simple payback period} = \frac{\text{Investment, Rs.}}{\text{Annual savings, Rs.}}$$

### Problem

Daily hot water requirement of a hostel in a college is 5000 litres. Solar radiation available on the location is  $600 \text{ W m}^{-2}$ . Temperature of feed water is  $30^\circ\text{C}$  and the final hot water temperature should be  $60^\circ\text{C}$ . The area of the solar collector is  $50 \text{ m}^2$ . Assess the performance of the collector and also calculate the pay back period of the water heater. Assume the required data for hot water generation.

Solar insolation during the study period,  $S$  :  $600 \text{ W m}^{-2}$

Capacity of hot water system,  $Q$  :  $5000 \text{ lpd}$

Atmospheric temperature,  $T_a$  :  $30^\circ\text{C}$

Temperature of hot water,  $T_h$  :  $60^\circ\text{C}$

Area of the collector area,  $A_c, \text{ m}^2$  =  $50 \text{ m}^2$

Useful solar heat energy available

$$\text{Daily available solar radiation, } S_D, \text{ kJ d}^{-1} = \frac{S \times A_c \times 8 \times 3600}{1000}$$

Assuming 8 hours of daily operation.

$$600 \times 75 \times 8 \times 3600$$

$$= \frac{\quad}{1000}$$

$$= 1296000 \text{ kJ d}^{-1}$$

Heat energy required to heat the water

$$\text{Specific heat of water, } C_p = 4.18 \text{ kJ/kg } ^\circ\text{C}$$

$$\text{Rise in temperature of hot water, } \Delta T = T_h - T_a, ^\circ\text{C}$$

$$= 60 - 30$$

$$\text{Daily heat energy required to heat the water, } Q_u = Q \times C_p \times \Delta T, \text{ kJ d}^{-1}$$

$$= 5000 \times 4.18 \times 30$$

$$= 627000 \text{ kJ d}^{-1}$$

### System performance

$$\text{Thermal efficiency of solar water heater, \%} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{Q_u}{S_D} \times 100$$

$$= \frac{627000}{1296000} \times 100$$

$$= 48.38\%$$

### Economics of solar water heater

$$\text{Cost of solar water heater} = \text{Investment, Rs.}$$



$$\begin{aligned}
 &= \text{Rs. } 6,00,000 \\
 \text{Annual maintenance} &= \text{Rs. } 10,000 \\
 &Q_U \\
 \text{Daily thermal energy requirement, } Q_E, \text{ kWh} &= \frac{\text{-----}}{0.95 \times 3600} \\
 &627000 \\
 \text{Daily thermal energy requirement, } Q_E, \text{ kWh} &= \frac{\text{-----}}{0.95 \times 3600} \\
 \text{Cost of electricity per day, } P_E, \text{ Rs.} &= Q_E \times \text{Unit Price} \\
 \text{Cost of electricity per day, } P_E, \text{ Rs.} &= 193 \times 5 = \text{Rs. } 915 \\
 \text{Assuming 300 days of annual utilization of solar hot water system,} \\
 \text{Annual saving, Rs.} &= P_E \times 300 \\
 &= 915 \times 300 = \text{Rs. } 2,74,500 \\
 &\text{Investment + Maintenance, Rs.} \\
 \text{Simple payback period} &= \frac{\text{-----}}{\text{Annual savings, Rs.}} \\
 &610000 \\
 &= \frac{\text{-----}}{274500} \\
 &= 2.22 \text{ years (2 years and } 2\frac{1}{2} \text{ months)}
 \end{aligned}$$

### Lesson 17. Performance evaluation of solar hot air generators

Solar hot air generators are used to generate hot air and subsequently that can be used for various applications viz. space heating, drying of various commodities such as grains, vegetables, fruits etc. The performance such as quantity of hot air generation, hot air temperature, system efficiency etc. can be assessed. The assessment can be carried out for a specific period say 8 hours in a day. The seasonal variation can also be studied by performing the evaluation test during specified seasons.

#### Parameters to be measured

Solar insolation during the study period,  $S$  :  $\text{W m}^{-2}$

Mass of material to be dried,  $W_1$  : kg

Initial moisture content of produce,  $m_1$  : %

Final moisture content of produce,  $m_2$  : %

Effective hours of drying,  $P$  : h

Length of the collector,  $l$  : m

Width of the collector,  $w$  : m

Number of collector,  $n$  :

Atmospheric temperature,  $T_a$  :  $^{\circ}\text{C}$

Temperature of hot air,  $T_h$  :  $^{\circ}\text{C}$

Transmissivity of glass cover,  $t$  :

Absorptivity of black coated surface,  $a$  :

#### Instrumentation required are

Pyranometer for solar radiation measurement

Thermometers

Flow meter for measuring mass flow rate of air inlet and outlet

#### Useful solar heat energy available

Area of the collector area,  $A_c$ ,  $\text{m}^2$  =  $n \times \text{length} \times \text{width of each collector}$

$$= n \times l \times w$$

$$1 \text{ J/s} = 1 \text{ W} \quad \therefore 1 \text{ kWh} = 3600 \text{ kJ}$$

$$\text{Solar energy transmitted through the glass, } S_{\tau} = S \times \tau$$

$$\text{Energy absorbed by the absorber plate, } S_{\alpha} = S_{\tau} \times \alpha$$

$$\text{Hourly available solar radiation, } S_D, \text{ kJ h}^{-1} = \frac{S \times A_c \times 3600}{1000}$$

Heat energy required to generate hot air

$$\text{Heat energy required for drying, kJ} = \text{Specific heat} + \text{Latent heat}$$

$$\text{Hourly heat energy required for drying, } Q_u = \frac{[(m \times C_p \times \Delta T) + (l \times W_m)]}{p} \text{ kJ h}^{-1}$$

$$\text{Specific heat of drying material, } C_p = \text{kJ/kg } ^\circ\text{C}$$

$$\text{Rise in temperature of air, } \Delta T = T_h - T_a, ^\circ\text{C}$$

$$\text{Quantity of chilly to be dried, } W_1 = \text{kg}$$

$$\text{Final quantity of dried chilly, } W_2 \text{ kg} \quad \therefore W_1 (1-m_1) = W_2 (1-m_2)$$

$$W_2, \text{ kg} = W_1 (1-m_1) / (1-m_2)$$

$$\text{Moisture to be evaporated, } W_m = W_1 - W_2, \text{ kg}$$

$$\text{Heat energy required to evaporate } W_m \text{ kg} = l \times W_m, \text{ kJ}$$

$$\text{Thermal efficiency of solar air heating system, \%} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{Q_u}{S_D} \times 100$$

### Economics of solar hot air system

It is considered that the economics of solar air heating system is compared with the electrical based hot air generators. The cost required for solar hot air generator system and electrical systems are calculated and the pay back period is calculated.

Cost of solar air heaters, Rs. = Investment

Daily thermal energy requirement,  $Q_E$ , kWh =  $\frac{Q_U}{0.95 \times 3600}$

(Considering the efficiency of the electrical heating system as 0.95)

Cost of electricity,  $P_E$ , Rs. =  $Q_E \times \text{Unit Price}$

Assuming 8 hours pre day operation and 300 days of annual utilization of solar hot air system,

Annual saving, Rs. =  $P_E \times 8 \times 300$

Simple payback period =  $\frac{\text{Investment, Rs.}}{\text{Annual savings, Rs.}}$

### Problem

A farmer is drying 100 kg of chillies in a solar dryer having dimension of 2m length and 1 m width. If the effective drying time taken was 16 hours with initial moisture content of 75% (wb) to 10 % (wb) final moisture content. The average solar insolation during the study period was observed as  $600 \text{ W m}^{-2}$ . Give a report on the performance evaluation of the solar dryer for chilly drying. Assume relevant data based on the given details.

Solar insolation during the study period, $S$	:	$600 \text{ W m}^{-2}$
Initial moisture content of chilly, % (wb)	:	75%
Final moisture content of chilly, % (wb)	:	10%
Length of the collector, $l$	:	2 m
Width of the collector, $w$	:	1 m
Number of collector, $n$	:	5
Atmospheric temperature, $T_a$	:	$30^\circ\text{C}$ (Assume)
Temperature of hot air, $T_h$	:	$50^\circ\text{C}$ (Assume)

Instrumentation required are

Pyranometer for solar radiation measurement

Thermometers

Flow meter for measuring mass flow rate of air inlet and outlet

Useful solar heat energy available

$$\begin{aligned}
 \text{Area of the collector area, } A_c, \text{ m}^2 &= n \times \text{length} \times \text{width of each collector} \\
 &= n \times l \times w \\
 &= 5 \times 2 \times 1 = 10 \text{ m}^2
 \end{aligned}$$

$$1 \text{ J/s} = 1 \text{ W} \quad \therefore 1 \text{ kWh} = 3600 \text{ kJ}$$

$$\text{Hourly available solar radiation, } S_D, \text{ kJ h}^{-1} = \frac{S \times A_c \times 3600}{1000}$$

$$\text{Hourly available solar radiation, } S_D, \text{ kJ h}^{-1} = \frac{600 \times 10 \times 3600}{1000}$$

$$= 21600 \text{ kJ h}^{-1}$$

Heat energy required to dry the produce

$$\text{Hourly heat energy required for drying, } Q_u = \frac{[(m \times C_p \times \Delta T) + (l \times W_m)]}{P} \text{ kJ h}^{-1}$$

$$\text{Specific heat of drying material, } C_p = \text{kJ/kg } ^\circ\text{C}$$

$$\text{Rise in temperature of air, } \Delta T = T_h - T_a \text{ } ^\circ\text{K}$$

$$= 323 - 300 = 23^\circ\text{K}$$

$$\text{Quantity of chilly to be dried, } W_1 \text{ kg} = 100$$

$$\text{Initial water content in chilly, kg} = 100 \times 0.7 = 70 \text{ kg}$$

$$\begin{aligned}
 \text{Final quantity of dried chilly, } W_2 \text{ kg} &: W_1 (1 - m_1) = W_2 (1 - m_2) \\
 &: 100 (1 - 0.7) = W_2 (1 - 0.1) \\
 &= W_2 = 33.33 \text{ kg}
 \end{aligned}$$

$$\text{Moisture to be evaporated, } W_m \text{ kg} = 100 - 33.33 = 66.67 \text{ kg}$$

$$(l - \text{latent heat of vaporization of water, kJ/kg}) = 2260 \text{ kJ/kg}$$

$$\text{Hourly heat energy required for drying, } Q_u = \frac{[(100 \times 2 \times 23) + (2260 \times 66.67)]}{16} \text{ kJ h}^{-1}$$

$$= 9704.64 \text{ kJ h}^{-1}$$

$$\text{Thermal efficiency of solar air heating system, \%} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{Q_u}{S_D} \times 100$$

$$= \frac{9704.64}{21600} \times 100$$

$$= 44.93\%$$

**Economics of solar hot air system**

It is considered that the economics of solar air heating system is compared with the electrical based hot air generators. The cost required for solar hot air generator system and electrical systems are calculated and the pay back period is calculated.

$$\text{Cost of solar air heaters, Rs.} = \text{Investment}$$

$$\begin{aligned} \text{Hourly thermal energy requirement, } Q_E, \text{ kWh} &= \frac{Q_U}{0.95 \times 3600} \\ &= \frac{9704.64}{0.95 \times 3600} \\ &= 2.84 \text{ kWh} \end{aligned}$$

(Considering the efficiency of the electrical heating system as 0.95)

$$\begin{aligned} \text{Cost of electricity, } P_E, \text{ Rs.} &= Q_E \times \text{Unit Price} \\ &= 2.84 \times 5 = \text{Rs. } 14.20 \end{aligned}$$

Assuming 8 hours pre day operation and 200 days of annual utilization of solar hot air system,

$$\begin{aligned} \text{Annual saving, Rs.} &= P_E \times 8 \times 200 \\ &= 14.20 \times 8 \times 200 \\ &= \text{Rs. } 22720 \end{aligned}$$

$$\text{Simple payback period} = \frac{\text{Investment, Rs.}}{\text{Annual savings, Rs.}}$$

$$\begin{aligned} \text{Simple payback period} &= \frac{100000}{22720} \\ &= 4.4 \text{ years (4 years 5 months)} \end{aligned}$$





## Lesson 18. Performance evaluation of solar cooking

### Solar Cookers

Solar cookers are used to cook food using solar radiation as input energy. Solar radiation is being collected as direct radiation and/or reflected radiation/concentrated radiation. Using absorbers these radiations are converted into thermal energy. This heat energy is used to cook food which is kept in the vessels inside the solar cooker.

### Energy required for cooking

The energy required for cooking a specified food varies with the properties of ingredients such as water, vegetables etc. The method cooking such as the temperature required for cooking, minimum temperature to be maintained during cooking, duration of temperature maintenance etc. are to be considered at the time of cooking.

Thermal energy required for reaching the cooking temperature can be calculated from the following formula.

$$Q = m \, c_p \, dt, \text{ kJ}$$

Where,

$Q$  = Thermal energy requirement for cooking, kJ

$m$  = mass of material taken for cooking, kg

$c_p$  = specific energy for the selected material,  $\text{kJ kg}^{-1} \text{ } ^\circ\text{C}^{-1}$

$dt$  = difference between initial and final temperature,  $^\circ\text{C}$

The specific heat energy of various materials are given below.

Name of the materials	Specific heat (heat capacity) $\text{kJ/kg-}^\circ\text{C}$
Water	4.18
Milk	3.93
Rice	1.11
Potatoes	3.43
Onion	3.77
Chicken	3.35
Coconut	2.85
Vegetable oil	1.67
Copper	0.39
Aluminium	0.90
Eggs	3.2

**Example**

Calculation of energy requirement for cooking 1 kg of rice. Consider cooking of rice in Aluminium vessel weighing about 0.5 kg. Water used for cooking rice is 2 kg. The required heat energy is the sum of thermal energy required for heating rice, water and also the vessel material. The initial ambient temperature is 30°C and the required cooking temperature is 100°C.

Total thermal energy required for cooking rice =  $(m_1c_{p1} + m_2c_{p2} + mc_{p3}) \times dt$

Where suffix 1 for rice, 2 for water and 3 for vessel material

Hence the total energy is calculated as

$$\begin{aligned} &= \{(1 \times 3.8) + (2 \times 4.18) + (0.5 \times 0.9)\} \times \\ (100-30) & \\ &= 882.7 \text{ kJ} \end{aligned}$$

To maintain the same temperature for through cooking, let us assume 30% of energy is required through out the period of cooking.

$$\begin{aligned} \text{Total heat energy requirement} &= 882.7 \times 1.3 \\ &= 1147.51 \text{ kJ} \end{aligned}$$

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**Performance evaluation of solar cooker**

Available solar radiation	=	700 W m <sup>-2</sup>
Cooking area in solar cooker	=	0.75 x 0.75
	=	0.56 m <sup>2</sup>
Considering same area of reflector, the total area of solar radiation collection	=	0.56 x 2
	=	1.12 m <sup>2</sup>
Total solar energy collected	=	700 x 1.12
	=	784 W
Time taken for cooking	=	1.5 h
Total energy input, kJ	=	$\frac{784 \times 3600 \times 1.5}{1000}$
	=	4233.6 kJ
Efficiency of solar cooker	=	$\frac{\text{Energy spent for cooking}}{\text{Input solar energy}}$
Efficiency of solar cooker	=	$\frac{1147.51}{4233.6} \times 100$
	=	27.1%

**Simple payback period**

Consider the cooking capacity of solar cooker is for three persons at a time. Consider three meal per person and cooking energy requirement for one person as 620 kCal per day. The energy.

$$\text{Energy required for cooking} = 3 \times 620 = 1860 \text{ kCal/day}$$

Assume about 50% of cooking can be met with solar cookers and hence the energy requirement for cooking

$$= 1860 \times 0.5 = 930 \text{ kCal/day}$$

Annual cooking of about 300 days may be considered.

$$\begin{aligned}
 \text{Annual cooking energy required} &= 930 \times 300 = 279000 \text{ kCal} \\
 \text{Energy content of one cylinder with 60\% useful energy utilization (40\% loss)} &= 60000 \times 0.6 \\
 &= 36000 \text{ kJ} \\
 \text{The cost one LPG cylinder} &= ₹ 400 \\
 \text{The cost of kJ of LPG} &= \frac{400}{36000} \\
 &= ₹ 0.011 / \text{kJ} \\
 \text{Annual savings due to solar cooker} &= ₹ 0.011 \times 279000 \\
 &= ₹ 3100 \\
 \text{Cost of solar cooker} &= ₹ 4000 \\
 \text{Pay back period} &= \frac{\text{Cost of solar cooker}}{\text{Annual savings}} \\
 \text{Pay back period} &= \frac{4000}{3100} \\
 &= 1.29 \text{ years (1 year 4 months)}
 \end{aligned}$$



## **Lesson 19. Maintenance of Solar Passive Heating Devices**

A proper maintenance is required to have better performance of the solar heating devices in terms of maximum efficiency, higher output temperature etc. The following maintenance of the devices are required.

### **1. Cleaning of transmitting glass**

The transparent glass or cove of the solar heating devices should be clear from dust. So periodical cleaning of glasses are required so as to get maximum transmittance from the glass. Monthly cleaning may be done. The frequency of cleaning is based on the environment. If the surrounding is dusty environment the cleaning frequency has to be increased. Water washing gives better results. Occasional soap water washing increases the overall performance of the gadget.

### **2. Checking up of leakages in fluid passages**

The fluid passages such as pipes, pipe joints, bends, ducts, inlet and outlet joints etc. has to be checked periodically for leakages. If any leakage is found immediately has to be rectified, otherwise the thermal energy loss will be very high and also, the output energy will be reduced. This will lead to lowering of the performance of the solar thermal device.

### **3. Scaling removal**

If the water used in the solar water heater is of salty in nature, the salt deposition has to be removed periodically using suitable acids. The salt deposition will reduce the heat transfer coefficient of the pipe metal and there by decrease the heat transfer from the collector to circulating water.

### **4. Glass damage**

The damaged and broken glasses have to be removed for better transmittance of the transparent surfaces.

### **5. Insulation**

The insulation of the solar heating device has to be checked periodically. Damages in the insulation will cause more heat loss from the collector area.

### **6. Absorber coating**

The paint coating of the absorber plate has significant role in the performance of the collector. Selective coatings have higher absorptance and needs lesser maintenance. However, the absorbers have to be painted every 1-3 years to maintain the absorptance coefficient.

## 7. Pump performance

If solar water heaters are used, the flow rate plays major role in deciding the performance of the solar water heater. The flow rate will be maintained by the either natural circulation or using pumps. If pumping systems are used, the performance of the pump in terms of out put (mass flow rate) has to be assessed to maintain the required flow of fluid in the solar collectors.

## 8. Blower performance

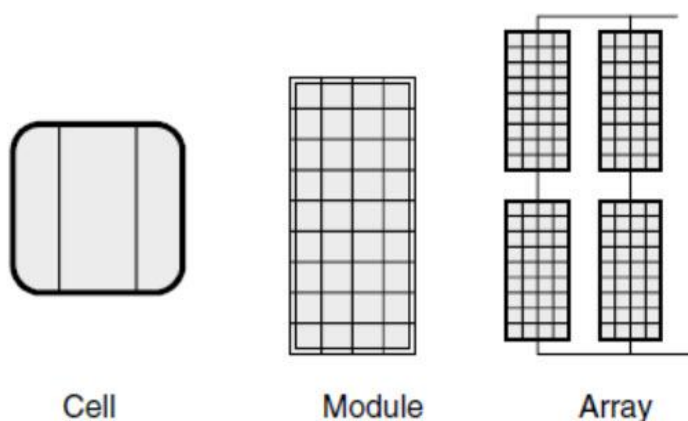
In solar hot air driers, the generated hot air quantity, heat content, temperature etc. are decided based on the flow of air through the solar collectors. This can be optimized to harness maximum quantity of thermal energy from solar radiation. For better performance of the hot air system, the blower has to be maintained properly so as to supply the required quantity of air to the solar collectors.



**Module 5. Performance evaluation and maintenance aspects of photovoltaic cells and arrays**

**Lesson 20. Components of Solar Photovoltaic systems**

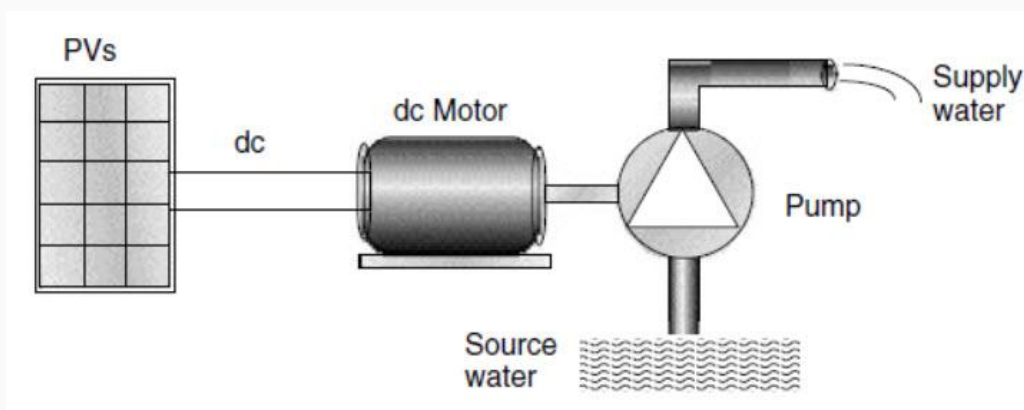
Electricity can be generated through solar photovoltaic systems – a promising option to generate electricity directly from solar radiation. Individual solar cells are connected to form modules of photovoltaic system and more modules form system of array.



**Applications of solar photovoltaic systems**

**Water pumping**

Water can be pumped from bore wells for irrigation, residential uses etc. using solar photovoltaic systems.



**Lighting**

Solar photovoltaic systems are commonly used for lighting in residences, highway signs, street lights, recreational vehicles, remote villages and schools and marine navigational buoys.

## Communications

Power generation through SPV can be applied in communications systems like relay stations, emergency radios, mobile phone applications, satellites etc.

## Refrigeration

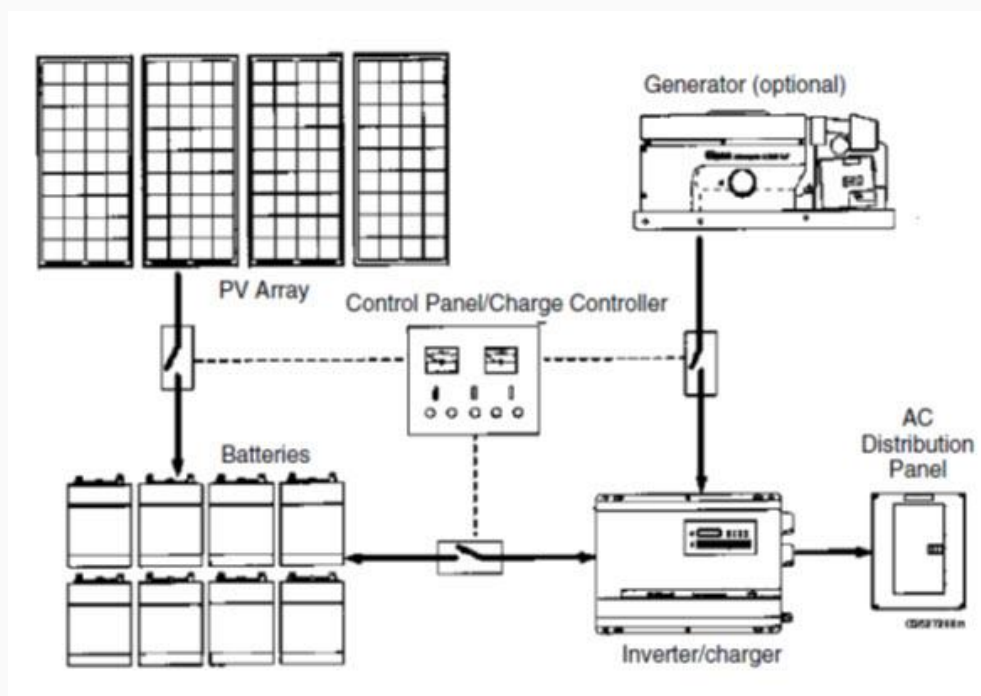
Solar based refrigeration systems are adopted in medicine storage, recreational uses, storage of commercial products in remote areas etc.

## Utility grids

Power production in the capacity of kW or MW scale is being started in various locations using solar PV systems.

## Household applications

Solar PV cells are used in lighting and fans of houses, lanterns, ventilation fans, televisions, stereos and other applications.



## Advantages of PV system

The major advantages of solar photovoltaic systems are

1. Reliability : Solar photovoltaic systems are not having any moving parts, effects little maintenance when compared to other systems of power generation.
2. Modularity : The capacity addition in photovoltaic systems is easy for meeting out any higher power requirements.

3. Environment : The SPV mode of power production do not release any pollution and hence protect the environment.
4. Hybridization : Combining PV systems with any type of power production systems such as wind, hydro, diesel etc. is easier to charge batteries and provide additional power on demand.
5. Cost : In situations where the transmission cost of power is higher to remote locations, using conventional power production system, a PV system may be a better option with most cost-effective power supply system.

### Sizing of PV systems

In sizing of solar photovoltaic system, the first step is to assess the daily energy consumption based on daily loads. Determination of total energy consumption may be carried out as follows.

1. Multiply the capacity (watt) of the appliance by the number of hours of operation in a day.
2. If the wattage of the appliance is not provided in the appliance spec plate, the wattage has to be calculated by multiplying the specified current and voltage of the appliance.
3. Sum the total daily energy consumption in watt-hours.
4. As the SPV systems are rated by peak watt (power production at 1000 watts per square meter of solar radiation).
5. Divide the total watt hr requirement by PV rating (Wh).
6. Divide with 0.8 to consider the battery efficiency.
7. Multiply with 1.2 for overlooked loads.
8. Divide by module wattage (say 37 watt)

**Example :** Calculate the daily total energy consumption and find out the number and wattage of the PV systems if all the energy requirement will be met with solar PV systems.

The loads are 2 lamps of 15 wattages for 2 hours of daily usage, 25 wattage radio for daily 2 hours, 30 wattage of VCR for daily 0.5 hours.

### Components in SPV systems

In addition to PV modules, Balance -of-system (BOS) has to be attached. This BOS includes, battery charge controllers, batteries, inverters (for loads requiring alternating current), wires, conduit, a grounding circuit, fuses, safely disconnects, outlets, metal structures for supporting the modules and any additional components that are the part of the PV systems.

### Direct current system equipment

**Charge controller :** The controller keeps the battery fully charged without overcharging. When the load is drawing power, the controller allows charge to flow from the modules into the battery, the load, or both. Many controllers will also sense when loads have taken too much electricity from batteries and will stop the flow until sufficient charge is restored to the batteries.

**Battery :** Usually lead-acid, are designed to gradually discharge and recharge 80% of their capacity hundreds of times. Automotive batteries are shallow-cycle batteries and should not be used in PV systems because they are designed to discharge only about 20% of their capacity. If drawn much below 20% capacity more than a few dozen times, the battery will be damaged and will no longer be able to take a charge.

### Alternating - Current system equipment

**Inverter :** AC systems require an inverter, which changes the DC electricity produced by PV modules and stored in batteries into AC electricity.





### Lesson 21. Performance evaluation of solar street light systems

Nowadays, installation of solar street lights becomes common in remote as well as urban areas. The evaluation of performance of the solar pumping system can be carried out based on the solar insolation as input and power consumption of street lights as output.

The required data are

- Average solar insolation,  $\text{W m}^{-2}$
- Average sun shine hours in the test day, h
- Area of one SPV module,  $\text{m}^2$
- Number of SPV modules
- Wattage of street light system, W
- Operating factor = 0.7 (considering the peak rated power of PV panel)

#### Input

Total power availability for the SPV modules

= solar insolation x area of one module x no of modules

Power available from the module

= Open circuit voltage x Circuit current x operating factor

Panel efficiency = 
$$\frac{\text{power available from the module}}{\text{Total power availability}}$$

#### Output

Wattage of the lighting system in W

Efficiency of the SPV pump = 
$$\frac{\text{Lighting wattage}}{\text{power available from the module}}$$

Total system efficiency = panel efficiency x pump efficiency

#### Problem

A solar street light has two SPV panels of 37 Wp capacity. Considering the peak rated power of the panel the operational factor of the panel is decided as 0.65 (including mismatch factor). The average solar radiation in the experimental area is observed as  $580 \text{ Wm}^{-2}$  and the average sun shine period is 8 h. The area of one module is  $65.5 \times 61 \text{ cm}$ . A 12 V battery of 75 Ah with C/10 discharge rate is used for storage purpose. The light is fitted with 11 W CFL. Assess the efficiency of the system.

The available solar radiation	-	$580 \text{ W m}^{-2}$
Total radiation available to the panels	-	$580 \times 0.655 \times 0.61 \times 2 \times 8$
	-	$3707.84 \text{ W}$
Power available from the panels	-	$37 \times 2 \times 0.65 \times 8$
	-	$384.8 \text{ W}$
Panel efficiency	-	$\frac{384.8}{3707.84} \times 100$
	-	$10.37\%$
Street light capacity	-	$11 \text{ W}$
Power consumed by the street light for one day -	-	$11 \times 8$
	-	$88 \text{ W}$
	-	$88$
Pump efficiency	-	$\frac{88}{384.8} \times 100$
	-	$22.87\%$
Overall system efficiency	-	$10.37 \times 22.87 / 100$
	-	$2.37\%$

## Lesson 22. Performance evaluation of solar water pumping systems

One of the agricultural based applications of solar photovoltaic system is water pumping for irrigation. Though quantity and timing of irrigation may not match with the solar insolation, the pumped water can be stored and irrigated during required periods. The performance evaluation of the solar pumping system can be carried out based on the solar insolation as input and pumped water as out put.

The required data are

- Average solar insolation,  $\text{W m}^{-2}$
- Average sun shine hours in the test day, h
- Area of one SPV module,  $\text{m}^2$
- Number of SPV modules
- Open circuit voltage, Volts
- Circuit current, Amps
- Amount of pumper water, litre or  $\text{m}^3/\text{day}$
- Total head to be pumped, m
- Water density,  $\delta = 1000 \text{ kg m}^{-3}$
- Acceleration due to gravity,  $g = 9.8 \text{ m/s}^2$
- Operating factor = 0.7 (considering the peak rated power of PV panel)

### Input

Total power availability for the SPV modules

$$= \text{solar insolation} \times \text{area of one module} \times \text{no of modules}$$

Power available from the module

$$= \text{Open circuit voltage} \times \text{Circuit current} \times \text{operating factor}$$

$$\text{Panel efficiency} = \frac{\text{power available from the module}}{\text{Total power availability}}$$

### Output

$$\text{Hydraulic power} = Q (\text{m}^3/\text{s}) \times \text{total head (m)} \times 1000 \times 9.81$$

$$\text{Efficiency of the SPV pump} = \frac{\text{Hydraulic power}}{\text{power available from the module}}$$

$$\text{Total system efficiency} = \text{panel efficiency} \times \text{pump efficiency}$$

**Problem**

A solar photovoltaic system has the 10 SPV panels of 75 Wp capacity. Considering the peak rated power of the panel the operational factor of the panel is decided as 0.65 (including mismatch factor). The average solar radiation in the experimental area is observed as  $600 \text{ W m}^{-2}$ . The area of one module is  $92.5 \times 65 \text{ cm}$ . The pump is used to draw water of  $25000 \text{ l day}^{-1}$  and the total head to be pumped is  $15 \text{ m}$ . Study the performance of the SPV system.

The available solar radiation	-	$600 \text{ W m}^{-2}$
Total radiation available to the panels	-	$600 \times 0.925 \times 0.65 \times 10$
	-	$3607.5 \text{ W}$
Power available from the panels	-	$75 \times 10 \times 0.65$
	-	$487.5 \text{ W}$
Panel efficiency	-	$\frac{487.5}{3607.5}$
	-	$13.5\%$
Hydraulic power	-	$25 \times 15 \times 1000 \times 9.81 / 3600 / 8$
	-	$127.73 \text{ W}$
Pump efficiency	-	$\frac{127.73}{487.5}$
	-	$26.2\%$
System efficiency	-	$13.5 \times 26.2$
	-	$3.5\%$



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## **Lesson 23. Maintenance aspects of photovoltaic systems**

### **Operational and maintenance procedure of Solar Street light**

#### **General operational and maintenance aspects**

1. Use the solar solar photovoltaic systems regularly.
2. Clean the dust on SPV module once in a month for better transmittance of the solar rays into the photovoltaic cells
3. Avoid impact on the module
4. Do not attempt to dismantle the module
5. Do not focus any other light source on the module for want of enhanced power output.
6. Do not stretch the cable (wire) of the module
7. Check the working of the system once in a week for its output. For ex. glowing of CFL (dawn to dusk operation), power output from the system in case of power generation in terms of voltage, current etc.
8. Do not work with the system while connected with the SPV or with working condition
9. The performance of the accessories such as pumps, batteries, motors, lighting systems etc. are to tested periodically for better output.
10. Ensure working of charge controllers to maintain the battery charging and discharging cycle For battery based systems
11. Maintain battery terminals free from corrosion.
12. Check specific gravity and temperature in each cell in battery once in a week
13. Check charging voltage in battery terminals once in a week.
14. Maintain distilled water level in battery once in a month
15. Apply petroleum jelly / vaseline / grease to the battery terminal once in a month
16. Keep the battery box neat and clean
17. Never draw power from the battery for other purposes

**The following parameters may be recorded in a possible periodical interval to assess the performance of the photovoltaic system**

1. Energy generation (continuous, daily, monthly or annual cumulated)
2. Ambient conditions such as temperature, relative humidity and wind velocity
3. Solar radiation (beam and diffused)
4. Sun shine hours
5. Solar system temperature
6. Voltage and current of AC and DC systems
7. AC Power factor
8. AC harmonic distraction in current and voltage
9. System efficiency in terms of inverter, battery and solar photovoltaic system in total
10. Performance of tracking system if installed

### **Trouble Shooting Chart**

The expected troubles and possible reasons and remedies are consolidated in this section.

1. Lesser output from the PV panel

This may be due to accumulation of dust over the PV modules. Periodical cleaning will solve the problem. If the system is with tracking facility, the tracking may be checked for effective solar insolation collection.

2. Charging of battery is low

First check the output from the PV panel and if any problem is identified that may be corrected.

Still the problem persists; the batter may be checked for its condition. The proper maintenance of battery may be done with periodical checking of battery cells.

The performance of charge controller may be analysed for proper function which may cause the nil or reduced charging of battery.

The fuse may be burnt in the controller and may be rectified.

3. Improper functioning of end use systems such as street light or pumps

Check the condition of the system.

For Ex. Solar street lights,

The fuse in the lighting system may be checked

The condition of CFL may be analysed

Fixing of the CFL fitting with the light may be checked

Connection of charging connector with the light may be checked



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## **Module 6. Performance evaluation and maintenance aspects of briquetting machines and balers**

### **Lesson 24. Briquetting Systems**

Briquetting technologies used in the briquetting of the agro residues are divided into three categories. They are (i) high pressure or high compaction technology, (ii) Medium pressure technology and (iii) low pressure technology. In high pressure briquetting machines, the pressure reaches the value of 100 MPa. This type is suitable for the residues of high lignin content. At this high pressure the temperature rises to about 200 - 250° C, which is sufficient to fuse the lignin content of the residue, which acts as a binder and so, no need of any additional binding material. In medium pressure type of machines, the pressure developed will be in the range of 5 MPa and 100MPa which results in lower heat generation. This type of machines requires additional heating to melt the lignin content of the agro residues which eliminates the use of an additional binder material. The third type of machine called the low pressure machines works at a pressure less than 5 MPa and room temperature. This type of machines requires addition of binding materials. This type of machines is applicable for the carbonized materials due to the lack of the lignin material.

#### **1. High Compaction Briquetting technologies**

The two major types of binder less or high compaction technologies used for briquetting of agro residues are: (i) piston press (ram and die) technology and (ii) screw press technology. In the piston press type, the biomass is extruded through a die by a reciprocating ram at a very high pressure. In the screw press type, the biomass is extruded continuously by a screw through a heated taper die.

##### **1.1. Piston press technology**

Most of the briquetting machines installed in India are piston press type. In these machines the agro residues are punched into a die by a reciprocating ram with a very high pressure. The capacity of these machines ranges between 500 kg/hr to 1200 kg/hr.



**Piston press briquetting machine**



## 1.2. Screw press technology

This technology was invented and developed in Japan in 1945. As of April 1969 there were 638 plants in Japan engaged in manufacturing saw dust briquettes known as “ogalite” amounting to a production of 0.81 million tonnes per year. Recently a number of plants in Europe and South East Asia have been constructed. In a screw extruder, the rotating screw takes the material from the feed port, through the barrel and compact it against a die which assists the build-up of a pressure gradient along the screw. During this process the biomass is forced into intimate and substantially sliding contact with the barrel walls. This also causes frictional effects due to shearing and working of biomass. The combined effects of the friction caused at the barrel wall, the heat due to internal friction in the material and high rotational speed of the screw cause an increase in temperature in closed system which helps in heating the biomass. Then it is forced through the extrusion die where the briquette of required shape is formed.

## 2. Comparison between piston press and screw press

In a piston press the wear of the ram and die is less compared to the wear of the screw and die in a screw extruder press. The power consumption in the former is less than that of the latter. But in terms of briquette quality and production procedure screw press is definitely superior to the piston press technology. The central hole incorporated into the briquettes produced by a screw extruder helps to achieve uniform and efficient combustion and, also, these briquettes can be carbonised.

**Comparison of piston press and screw extruder**

Parameters	Piston press	Screw press
Optimum moisture content of raw material	10-15 %	8-9 %
Wear of contact parts	Low in case of ram and die	High in case of screw
Output from the machine	In strokes	Continuous
Power consumption	50 kWh/ton	60 kWh/ton
Density of briquette	1 – 1.2 g/cm <sup>3</sup>	1 – 1.4 g/cm <sup>3</sup>
Maintenance	High	Low
Combustion performance of briquettes	Good	Very good

*Source: FAO of the United Nations, Bangkok, April 1996*

## 3. Briquetting Process

The series of steps involved in the briquetting process are (i) collection of raw materials (ii) preparation of raw materials (iii) compaction and (iv) Cooling and Storage.

### **3.1. Collection of raw materials**

In general, any material that will burn but is not in a convenient shape, size or form to be readily usable as fuel is a good candidate for briquetting.

### **3.2. Preparation of raw materials**

The preparation of raw materials includes size reduction, drying, mixing of raw materials in correct proportion, mixing of raw materials with binder etc.

#### **3.2.1. Size reduction**

The raw material is first reduced in size by chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc. until it reaches a suitably small and uniform size (1 to 10 mm). For some materials which are available in the size range of 1 to 10mm need not be size reduced. Since the size reduction process consumes a good deal of energy, this should be as short as possible.

#### **3.2.2. Drying**

The raw materials are available in higher moisture contents than what required for briquetting. Drying can be done in open air (sun), with a heater or with hot air. Drying can be done either before or after drying.

#### **3.2.3. Raw material mixing**

It is desirable to make briquettes of more than one raw material. Mixing will be done in proper proportion in such a way that the product should have good compaction and high calorific value.

#### **3.2.4. Mixing of raw materials with binders**

Mixing of raw materials with binders in correct proportion is important for the production of briquettes of good compaction. This is best accomplished by a trial and error method of making several briquettes with different mixtures of binding material and testing each for mechanical strength and burning characteristics. The cost of binding material can be critical to the economic success of the project. Natural or synthetic resins, tar, animal manure, molasses, ligno-sulphonates, sewage mud, fish waste, algae, starch, slime, clay, mud and cement are some of the binders used in briquetting process.

### **3.3. Compaction**

Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted.

### **3.4. Cooling and Storage of briquettes**

Briquettes extruding out of the machines are hot with temperatures exceeding 200°C. They have to be cooled and stored.

## Lesson 25. Performance evaluation of briquetting machines

Briquetting machine has various sub systems such as drying system, shredding system, dust removing system and briquetting system.

### Drying system

Mainly drying of the briquetting feed crop materials will be carried out. The excess moisture will be dried out in the drying system. Generally solar based systems will be adopted as drying involves higher cost and will increase the price of briquettes.

In general, the performance of the drying system will be assessed in terms of efficiency of the system, capacity and quality of the final product. The efficiency will give the better utilization of incoming solar radiation for drying of the crop residues. The capacity will give the ability of the dryer to dry the residues to the required moisture content in a given time. The quality of the product deals mainly with the moisture content of the dried crop residues which will be used for briquetting..

### Shredding system

This is used to shred the dried mass. In this system, the dried materials will be size reduced before using in briquetting machines. The size of the dried mass will be reduced to about 1 to 10 mm. The out put will be higher with higher size of the material as the work done on the material will be less. Lesser the size of the material, better will be the briquetting of crop residues. The efficiency of the shredding system may be improved by having better sharp edged cutting blades, properly maintained rotating parts and well dried crop residues.

### Typical specification of a shredding machine

Power requirement	: 10 HP
Production Capacity	: 250 kg/h
Finished product size	: 1 to 10 mm
Raw materials	: Agro residues

The performance of the shredding machine during the size reduction of cotton stalks, pigeon pea stalks, and soybean stalks are given below.

Sl.no	Particulars	Cotton	Red gram	Soy bean
1.	Sieve size	$\frac{1}{16}$ "	$\frac{1}{16}$ "	$\frac{1}{16}$ "
2.	Weight of raw materials before shredding	100 kg	100 kg	100 kg

3.	Weight of raw materials after shredding	86 kg	84 kg	88 kg
4.	Loss of weight during shredding	14 kg	16 kg	12 kg
5.	Percentage of losses	14 %	16 %	12 %
6.	Total time	2.0 hrs	1.30 hrs	2.0 hrs
7.	Power consumption	0.8 kw/hr	0.6 kw/hr	0.8 kw/hr

### Briquetting system

The performance evaluation of the briquetting system may be assessed in terms of efficiency of the system, output capacity etc. The efficiency deals with the input power supplied to the system to the energy spent for the production of briquettes in a specified time. The quantity of briquette produced in unit time reveals the performance of the briquetting system. With proper care and maintenance, the specified quantity of the briquette can be produced.

### Economic analysis of briquetting system

The economic evaluation of briquetting plant of 500 kg/h for production from briquettes from saw dust is given below.

#### Machine Cost

Cost of Briquetting machine (500kg/h) = Rs. 9, 00,000

#### Production Cost

Raw material Cost = Rs. 1850 / tone

Power Cost = Rs. 200 / tone

Labour charges = Rs. 150 / tone

Cost of loading in gunny bags = Rs. 50 / tone

Cost of maintenance of Machine parts = Rs. 110 / tone

Administrative Cost (Cost for supervision) = Rs. 250 / tone

Cost of production of Briquette /tone = Rs. 2610 / tone

Transport charges of product = Rs. 400 / tone

Net Cost of production = Rs. 3010 / tone

Sale price of briquettes = Rs. 3600 / tone

Profit / tone of briquette produced = Rs. 590 / tone

Rated Capacity of briquetting machine	=	500 kg/h
Production Capacity	=	400 kg/h
Number of Working hours/ day	=	10 hours
Therefore, Machine outturn/ day	=	4000 kg
	=	4 tones
Profit/ day	=	4 x Rs. 590
	=	Rs. 2360
Number of working days per annum	=	300
Profit/ year	=	300 x Rs. 2360
	=	Rs. 7, 08,000
Simple Pay Back Period	=	9, 00,000 / 7, 08,000
	=	1.27 years

**(Source : ICAR - NAIP - TNAU - Briquetting Scheme)**

From the economic evaluation, it was concluded that the pay back period for the briquetting machine of 500 kg/h producing 60 mm diameter briquettes, working for 300 day per annum is approximately 2 years.



## Lesson 26. Characteristic measurement of briquettes

The briquettes can be produced through densification process. After the preparation of briquettes, the quality of the product has to be assessed through characteristic measurement. The following methodologies are used to study the characteristics of briquettes.

### Combustion properties determination

The combustion properties include percentage of volatile matter, fixed carbon, ash content and heating value. The percentage of volatile matter, fixed carbon and ash contents of four representative samples can be determined based on ASTM Standard E711-87 (2004). For percentage of volatile matter, 1g of the briquette is placed in a crucible of known weight and oven dried to constant weight after which it is heated in the furnace at temperature of 600°C for 10 minutes. The percentage of volatile matter is expressed as the percentage of loss in weight to the oven dried weight of the original sample. The percentage of ash content was measured by keeping the sample in the furnace for 3 hours in about 900°C. The ash content obtained after cooling in a dessicator is then expressed as percentage of the original sample.

### Proximate Composition of fresh briquettes

S. No	Briquette type	Fixed carbon (%)	Volatile matter (%)	Moisture content (%)	Ash Content (%)
1					
2					
3					

### Bulk density

Bulk density of biomass briquettes is found by observing the weight of known volume of briquette.

### Calorific values

Using bomb calorimeter, calorific value of briquettes can be measured.

Briquette types	Powdered biomass (kCal/kg)	Briquettes (kCal/kg)

### Characteristics of stored briquettes

#### Diameter study

The change in shape of briquette may be assessed by studying the diameter of the briquette before and after storage.

#### Measurement of strength and durability

The effectiveness of the briquettes produced during the densification process can be measured in terms of strength and durability. Procedures for measuring the compressive resistance, abrasive resistance, impact resistance and water resistance of the densified products are given below.

#### Water resistance

Short-term exposure to rain or high humidity conditions during transportation and storage could adversely affect the quality of the densified products. Each briquette is immersed in water at 27°C for one min. The swelling of briquette can be observed. Lower the swelling, better the quality.

#### Impact resistance

Impact resistance (or drop resistance or shattering resistance) test may simulate the forces encountered during emptying of densified products from trucks onto ground, or from chutes into bins. Briquettes may be dropped from about 1.5 m height onto a metal plate for 4-5 times. The weight retained as the percentage of the initial weight was taken as the briquette durability.

#### Shatter resistance

Briquettes are dropped onto a concrete surface from 1 m height for about 10 times. The percent loss indicates the shatter resistance of the briquettes. Lesser the loss better will be the resistance.



**Hardness test**

### Water stability test

The sample piece of briquettes is dipped into the water. The time required for the briquette to become pieces may be measured. If the briquettes are stable for more than 15 min, the briquette is considered as good quality.



### Thermogravimetric analysis

The thermogravimetric analysis of briquettes reveals the changes in physical and chemical properties as a function of increasing temperature or as a function of time.



**Thermogravimetric analysis**



## **Lesson 27. Operation and safe working of balers**

A baler is machinery used to compress the cut and raked hay or straw or silage into bales. The advantages of bales are due to its compactness; easy to handle, transport and store. There are three types of balers are used in common. They are square balers, large square balers and round balers.

Square balers are used to compress straw or hay into square compressed bales. The square shape is easy to handle and safe compare to round balers. These are used in small scale operations.

Large square balers basic operation is same as that of square operations other than handling of larger quantity. Hence, it has higher compression capacity and safe wrapping and tying option. Normally the capacity is 20 to 40 times higher than the small scale square balers.

Round bales are effective for large scale operations with minimal cost.

The balers involve typical hazards and risks during operation. Hence suitable precautions have to be made while operating large balers in fields. The following points are to be considered for safe operation of the balers.

1. The basic modes of operation of balers are : loading, compression and ejection
2. Operate the balers after thorough understanding of the operation and safety measures
3. Only trained persons should operate the system
4. Always follow the safety instructions
5. Keep away from the path of ejection of bales from the balers
6. Ensure safe bale ejection by following proper instructions of the supplier
7. Beware of moving components of the balers while working
8. Always keep the safety guards in place
9. Required fire preventive measures are to be carried out
10. Use proper hydraulic pressures as suggested by the manufacturer
11. Use the baler for specified materials only as directed by the manufacturer
12. Don't over load the baler than the specified capacity
13. Using safety glasses and hand gloves are to be followed during the operation of balers.

14. Check the baling wires for damage and do not use damaged wires
15. Mismatching of baler capacity and quantity of hay/straw or windrow may lead to blockage or improper operation of balers. Hence, care should be taken to select a suitable baler in the selected field.
16. Baling material should be of specified moisture content. Higher the moisture in the materials will cause series problems during baling such as poor core formation, blockage etc.
17. Baling lighter materials during windy condition may be avoided to prevent poor core formation and blockage.
18. Informative manual with relevant information on clearing blockages, rethreading, dealing with poor core forming etc. to facilitate the operation at difficult conditions
19. During ejection of bales specifically round bales the landing area may be selected as flat and without any slope.
20. Do not stop a rolling bale as it weighs about 500 kg and rolling gives momentum to the bales. This may lead to accidents to the machinery or person.
21. Inspect all belts or chains for of wear or breakage to avoid blockages and heat build up
22. While checking or repairing the balers stop the baler by putting down the power or disengage with the PTO of tractor. Make sure that there is no moving part is in operation before performing the baler repair.
23. Operate the baler at a safer speed
24. Do not attempt to feed the material into the baler manually either by hand or feet
25. Remove excessive grease or accumulated crop parts on moving parts



## **Module 7. Biodiesel utilization in CI engines**

### **Lesson 28. Production of Bio-Diesel**

Liquid biofuels are derived from the renewable biomass sources. Biomass resources comprise those which are obtained from agriculture, forestry and agro and wood industries. Though these biomass can provide heat, mechanical energy and power, their conversion into liquid biofuels has the advantage of immediate substitution to liquid fossil fuels in an environmentally friendly way. In addition to the existing biomass sources, the biomass energy production in degraded lands may also be of interest in some areas.

Liquid biofuel production uses both old (fermentation) and new (transesterification) technologies. Based on production technologies, biofuels can be classified as first generation biofuels and second generation biofuels. Conventional “first generation” ethanol is made by fermenting sugars from plants with high starch or sugar content into alcohol, using the same basic methods that brewers have relied on for centuries. The purest form of biodiesel is straight vegetable oil, but a more refined form uses a fairly simple process called transesterification to produce biodiesel. “Second-generation” biofuel technologies employ more sophisticated processes to convert biomass into fuel. These include enzymatic and other processes to convert cellulose from grasses and waste wood into ethanol and other fuels, and to process animal waste and fat, algae, and urban wastes into biodiesel. Many developed countries have active bio-diesel programmes. Currently bio-diesel is produced mainly from vegetable oils such as rapeseed, sunflower, soybean, palm oil etc. where as in India and African countries bio-diesel production is mainly from Tree Borne oils seeds such as *jatropha* oil, *pungam* etc.

#### **Triglycerides (vegetable oils) as diesel fuels**

Triglycerides of vegetable oils or fatty substances and their derivatives are considered as viable alternatives for diesel fuels. Whereas, direct substitution of triglycerides for diesel fuels will lead to the problems such as higher viscosities, low volatilities etc. The following processes help in making these vegetable oils and fatty substances compatible to petrodiesel fuels for various applications.

- pyrolysis
- microemulsification
- dilution and
- transesterification

## **Pyrolysis**

Pyrolysis refers to the process of thermochemical conversion of selected fuel materials in the absence of air or nitrogen. The liquid fractions of the thermally decomposed vegetable oil are likely to approach diesel fuels. The pyrolyzate had lower viscosity, flash point, and pour point than diesel fuel and equivalent calorific values.

## **Micro-emulsification**

Micro-emulsions are defined as transparent, thermodynamically stable colloidal dispersions with droplet diameters from 100 to 1000 Å. A micro-emulsion can be made of vegetable oils with an ester and dispersant (co-solvent), or of vegetable oils, an alcohol and a surfactant and a cetane improver, with or without diesel fuels.

## **Dilution**

Dilution of vegetable oils can be accomplished with such materials as diesel fuels, solvent or ethanol.

## **Transesterification reaction**

In the transesterification of vegetable oils, a triglyceride molecule of oil reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acids alkyl esters and glycerol. The fatty acid alkyl esters from the transesterification reaction are called as biodiesel. The stoichiometric transesterification reaction requires one mole of a triglyceride and three moles of the alcohol. Excess of the alcohol is used to increase the yields of the alkyl esters and to allow its phase separation from the glycerol formed.

## **Lab scale transesterification unit**

Laboratory scale biodiesel setup of one litre capacity can be formed with a three-neck flask, water cooled condenser, thermometer, mechanical stirrer and water bath. The condenser was used to condense methanol vapour released from the reactor and return the condensed methanol to reactor. Thermometer was used to measure the reactants mixture temperature during the experiment and vigorous mixing of reactants was done by mechanical stirrer.

## **Figure Lab scale transesterification unit**

Studies can be conducted in lab scale biodiesel reactor to determine the optimum quantity of methanol, catalyst (NaOH), reaction temperature and reaction time required for the transesterification of selected vegetable oil by varying the concentration of methanol, NaOH concentration, reaction temperature and reaction time. After optimizing the concentration of methanol and NaOH, reaction time and reaction temperature in alkali-catalysed transesterification of *Jatropha curcus* oil, experimental studies on large-scale production of biodiesel can be carried out.

## **Biodiesel pilot plant**

After optimizing the concentration of methanol, NaOH, reaction time and reaction temperature in alkali-catalysed transesterification of *Jatropha curcus* oil in the laboratory set up, experiments can be carried out in biodiesel pilot plants of higher capacity.

### **Figure Biodiesel pilot plant**

#### **Components of biodiesel pilot plant**

The biodiesel unit consists of a biodiesel reactor, mechanical stirrer, oil lifting pumps, chemical mixing tank, steam generator and settling tanks. The biodiesel reactor is made of stainless steel and insulated to arrest heat loss so as to maintain the reaction temperature during the process. The function of mechanical stirrer is to make vigorous stirring of reactant mixtures in the reactor. Steam generator is used to supply heat to the reactor in order to maintain reaction temperature for transesterification reaction. Oil lifting pumps are used to pump the raw oil to the reactor and also to pump the reactant mixtures to glycerol settling tank for separation of biodiesel and glycerol. The chemical mixing tank having a stirrer is used to dissolve the catalyst in methanol. The chemical mixing tank is connected to biodiesel reactor.

The amount of raw material, catalyst and methanol are measured before the biodiesel production process and the end products namely glycerol and biodiesel can be measured after the reaction to assess the performance of the reactor and reaction effectiveness.

#### **Process variables**

The most important variables that influence transesterification reaction and conversion are :

- reaction temperature
- alcohol addition
- catalyst type and concentration

#### **Reaction temperature**

The rate of biodiesel production is influenced by the reaction temperature. The reaction temperature will be maintained just above the boiling point of type of alcohol added (60 to 70°C).

#### **Ratio of alcohol to oil**

Another important variable affecting the yield of ester is the molar ratio of alcohol to vegetable oil. A molar ratio of 6:1 is normally used to obtain methyl ester yields higher than 98% by weight. Higher molar ratio of alcohol to vegetable oil interferes in the separation of glycerol.

### Catalyst type and concentration

Transesterification process occurs faster in the presence of an alkaline catalyst. Potassium hydroxide and sodium hydroxide are the most common catalyst used in transesterification process. The optimized dosage of alkaline catalyst concentration is in the range of 0.5 to 1% by weight and will result 94 to 99% conversion of vegetable oil into esters. Further, increase in catalyst concentration does not increase the conversion and it adds to extra costs because it is necessary to remove it from the reaction medium at the end.



### **Lesson 29. Performance evaluation of biodiesel transesterification system**

To assess the effect of important variables that influence transesterification reaction and conversion, the performance evaluation of selected biodiesel plant has to be carried out. The parameters which affect the performance of the reactor are

- reaction temperature
- agitator speed
- alcohol addition
- catalyst type and concentration

As per the capacity of the reactor, the quantity of vegetable oil to be added can be measured. Various factors considered for the variables can be listed below.

**Reaction temperature :** The reaction temperature of the transesterification process will be decided based on the temperature of vapourization of selected alcohol. If methanol is selected for the process, the temperature considered for the transesterification may be from 50 to 70°C.

**Agitator speed :** The rate of mixing of the chemicals and vegetable oil has a significant effect on the production of biodiesel. This can be decided based on the viscosity of the oil, capacity of the reactor etc. The mixing speed has to be optimized to assure proper mixing of the oil and chemical, lesser the agitation speed will lead to improper mixing of reactants and higher rpm may cause the disturbance of the reactants which may hinder the reaction.

**Alcohol addition :** Theoretically the addition of alcohol is in 3:1 molar ratio. Where as for proper completion of reaction, this will be increased upto 6:1 molar ratio. This will be about 15 – 20 per cent of weight of oil used in the reaction. Lesser addition of alcohol will lead to incomplete reaction. Whereas, higher addition of alcohol is unnecessarily increase the cost of operation and also make segregation of ester and glycerol more difficult.

**Catalyst :** Potassium hydroxide and sodium hydroxide are the most common catalyst used in transesterification process. The optimized dosage of alkaline catalyst concentration is in the range of 0.5 to 1% by weight. The effect and suitability of catalyst and dosage of catalyst are to be assessed for maximum biodiesel production.

Performance evaluation studies can be taken up by varying the above parameters to optimize them for maximum biodiesel recovery.

The calculated amount of oil is pumped into the reactor. The measured quantity of alcohol and catalyst is fed into the chemical tank and is mixed thoroughly. After proper mixing, the chemical is fed into the reactor and is agitated in the predetermined rpm. After allowing the reaction for about 1 ½ to 2 h, the products will be pumped into the sedimentation tank. It

will be sedimented for 4 to 6 h. The sedimented glycerol will be collected initially and the esters, biodiesel will be collected in separate tank. The quantity of biodiesel produced will be measured. The following calculations can be made for the reactor.

### Observation table

Sl. No.	Input			Output	
	Oil (kg)	Alcohol (kg)	Catalyst (kg)	Biodiesel (kg)	Glycerol (kg)

Similarly, by varying the type of alcohol, quantity of alcohol, type of catalyst, quantity of catalyst etc., the experiments can be repeated and the biodiesel production may be observed.

$$\text{Biodiesel recovery} = \frac{\text{Biodiesel production, kg}}{\text{Oil used, kg}}$$

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## **Lesson 30. Storage and Handling of Biodiesel**

### **30.1. Storage of Biodiesel**

During storage, all the fuels are subject to degradation over time due to various reasons such as microbial action, water intrusion, air oxidation, etc. Hence, it is recommended to store bio-diesel in clean, dry and appropriate tanks. During storage, the parameters of biodiesel such as acid number, water and sediment, viscosity etc. will be changed. Though the flash point of bio-diesel is high, still storage precautions somewhat like that in storing the diesel fuel need to be taken.

Underground storage is preferred in cold climates with proper precautions and equipment. The 20:80 (B 20) blend fuel can be stored in above ground tanks depending on the pour point and cloud points of the blend.

Biodiesel will be readily oxidized while storage. Hence, long storage will lead to the deterioration of quality. The presence of moisture in biodiesel will react with the esters to make free fatty acids and can support microbial growth in storage tanks. This biological growth can be mitigated by using biocides in small concentration.

The storage considerations are given as follows.

#### **Exposure temperature**

The temperature at which the biodiesel is being stored has significant effect on the quality of biodiesel. Generally the diesel fuels have the tendency of gelling at low temperatures. Similarly, biodiesel also has the problem of gelling during storing at low temperatures. Temperature required to gelling is more for biodiesel than diesel. To avoid formation of gel in biodiesel at low temperatures, additives can be used. In general, biodiesel has to be stored at temperatures 15°F higher than pour point of fuel.

#### **Oxidative stability**

This is the ability of the biodiesel to be stored for extended periods without degradation. This particular degradation is due to reaction of the fuel with oxygen and catalysts. The instability of fuel is correlation with number of C = C bonds in the fuel. It is assessed that the instability is 50% for two C=C when compared to one C=C bond. The instability may be estimated by iodine number and which is evident by high acid number, higher viscosity and formation of gums and sediments. It is recommended that a safe storage period of 6 months and with suitable anti-oxidant additives may be stored for longer periods.

#### **Fuel solvency**

The solvent properties of biodiesel plays major role in the selection of storage tanks and storage period. Biodiesel has higher enzyme hydrolysis properties than diesel fuel. If

biodiesel is stored in old tanks, biodiesel dissolve the sediments due to the mild solvent nature. Hence, the blend of biodiesel and diesel is stored in tanks, residual sediments in diesel storage tanks or vehicle fuel tanks can be solvated by biodiesel. The 20:80 (B 20) blend fuel can serve the purpose.

### **Material compatibility**

The material compatibility deals with the interaction of the biodiesel with materials of construction for storage tanks, seals, and gaskets during storage. It is recommended to use stainless steel or aluminum equipment in the processing of biodiesel. Normally during storage of blends of diesel and biodiesel, oxidation and sediment production in either biodiesel or diesel can be initiated by contact with brass, bronze, copper, lead, tin and zinc. Hence, generally the acceptable materials for biodiesel storage are aluminum, steel, Teflon, fluorinated polyethylene or polypropylene etc.

### **30.2. Handling of Bio-Diesel**

Generally, biodiesel blends are considered as petrodiesel for handling. Though biodiesel contains no hazardous materials, it should be handled in well ventilated areas. Care should be taken during handling of biodiesel, there should not be heat, spark, or flames sources in the nearer sources. If biodiesel is stored in drums, proper drum handling procedures such as free from drum puncturing, no dragging or sliding should be followed.

Biodiesel does not contain volatile organic compounds which will cause the release of poisonous or noxious fumes. Biodiesel do not contain aromatic hydrocarbon (benzene, toluene, zylene) or chlorinated hydrocarbons also. There is no lead or sulfur to react and release any harmful or corrosive gases from biodiesel.

While handling, safety glasses or face shields should be used to avoid mist or splash on face and eyes. Fire fighting measures to be followed as per its fire hazard classification. It is recommended that PVC-coated gloves as well as safety glasses or goggles should be used when handling biodiesel.



## **Lesson 31. Engine testing for biodiesel blends**

### **31.1. Engine testing**

The different blend levels adopted for the Engine testing study are Diesel 100% (D100), Biodiesel 20% and diesel 80% (B20), Biodiesel 40% and diesel 60% (B40), Biodiesel 60% and diesel 40% (B60), Biodiesel 80% and diesel 20% (B80) and Biodiesel 100% (B100).

### **31.2. Performance evaluation of biodiesel blends in Power tiller engine under laboratory condition**

An engine test rig was developed specifically for the purpose of testing Power tiller engine. The test rig used an electrical dynamometer consisting of an AC generator and load created by a panel of incandescent bulbs. The torque input into the dynamometer was measured by a transmission torque sensor. The rated speed of the engine is 2200 rpm and that for the dynamometer is 1500 rpm. A 'V' belt speed reduction device was provided between engine output shaft and the dynamometer input shaft. The engine was modified by mounting three grove V belt pulley of 110 mm pitch circle diameter at the center of the fly wheel in place of the original pulley. The engine, V belt drive, torque transducer and alternator were mounted on a frame structure.

The drive from the engine pulley was transmitted to a speed reduction pulley on the dynamometer shaft. The larger pulley had a pitch circle diameter of 160 mm, so as to provide a speed reduction of 1:1.45. The driven pulley was mounted on a 40 mm diameter shaft which was supported on a two pedestal bearings. The bearings in turn were mounted to support brackets welded on the main frame. The torque transducer used for measuring the line torque was mounted on separate pedestal in line with the dynamometer shaft. The pulley shaft torque transducer and alternator were coupled through suitable flange couplings. The overall view of the experimental setup is shown in Fig. 7.

The Power tiller engine performance was evaluated using IS test code 9935-1981, the test was carried out at two different conditions of the engines.

1. Torque - Speed test at varying throttle setting
2. Varying load test

#### **31.2.1 Torque-Speed test at varying throttle setting**

During this test, the power, torque and fuel consumption were measured as a function of speed by gradually loading after stabilized working condition of the engine. Stable operation conditions were maintained for a minimum period of 5 minute at each load setting before beginning the test measurement. The no-load engine speed before and after every test was

recorded to verify that there is no change in throttle setting.

The Torque - Speed curve of power tiller engine was recorded with three high idle speeds of 2200, 2000 and 1800 rpm under different load levels for all the selected biodiesel blends.

After the test, the following characteristics curves of the engine were drawn

1. Power as a function of engine speed
2. Torque as a function of engine speed
3. SFC as a function of engine speed
4. Fuel consumption as function of engine speed

### (i) Torque Vs Speed

The maximum torque at 2200 rpm is 34.15 for D100 but it gradually reduced with increased proportion of biodiesel in the blend and decreases to around 32 Nm. The different blend shows the reduction of 2-5 per cent torque as compare to diesel. Similarly reduction in maximum torque values was observed at 2000 and 1800 rpm. The maximum torque at rated Power tiller engine speed of 2200 rpm decreased.

### (ii) Power Vs Torque

The maximum power obtained at any throttle setting is gradually reduced as the blend become richer in biodiesel. The power at 2200 rpm is differenced by 8.1 per cent for D100 and B100 while the corresponding changes at 2000 and 1800 rpm where 3.8 and 8.1 per cent respectively.

### (iii) SFC Vs Speed

The important observation from the engine testing is the increase in SFC with increase in blend ratio. The minimum SFC for D100 is 0.232 kg/ kWh while it increased to 0.248, 0.25, 0.24, 0.266 and 0.277 as the blend ratio was increased from D100 to B100. The primary reason for the increased in SFC may be the lower calorific value of the fuel as the blend ratio is increased.

The behavior of the engine when operating with different blends was presented in Table 5 and Fig 8 to 13.

**Table 5 Torque, Power, SFC and FC Vs Speed of power tiller engine for variable throttle tests**

Throttle speed, rpm	Torque Vs Speed			Power Vs Speed		SFC Vs Speed		FC Vs Speed	
	Max. T, Nm (1)	Max T-S, rpm (2)	T/100 rpm (3)	Max P, kW (4)	Max P-S, rpm (5)	Min. SFC, kg/kWh (6)	Min. SFC-S, kg/kWh (7)	Max. FC, l/h (8)	Max. FC-S, rpm (9)

D100 fuel									
2200	34.15	1933	25.60	6.91	1933	0.232	2042	2.11	1864
2000	33.25	1735	17.71	6.04	1735	0.227	1814	1.82	1753
1800	30.10	1604	21.05	5.06	1604	0.230	1604	1.44	1604
B20 blend									
2200	33.31	1853	21.44	6.65	1979	0.248	2040	2.04	2041
2000	33.78	1667	17.12	6.1	1763	0.23	1829	1.78	1667
1800	31.11	1533	23.11	5.24	1638	0.227	1661	1.50	1638
B40 blend									
2200	32.46	1764	25.77	6.39	1824	0.250	1824	2.0	1978
2000	32.19	1621	23.13	5.89	1752	0.251	1859	1.78	1752
1800	28.45	1558	17.62	4.76	1652	0.249	1647	1.14	1532
B60 blend									
2200	32.28	1758	18.15	6.79	2017	0.240	1758	2.04	2017
2000	31.04	1742	12.52	5.66	1742	0.259	1899	1.74	1742
1800	29.35	1608	16.89	4.95	1608	0.177	1614	1.56	1608
B80 blend									
2200	33.30	1835	16.30	6.51	1961	0.266	1998	2.04	1961
2000	32.72	1728	22.23	6.01	1804	0.254	1804	1.78	1805
1800	30.36	1519	1704	4.96	1625	0.266	1550	1.48	1625
B100 blend									
2200	32.48	1868	23.67	6.35	1868	0.277	1789	2.04	1969
2000	32.19	1722	17.12	5.81	1722	0.272	1815	1.83	1722
1800	29.21	1518	18.60	4.65	1518	0.273	1630	1.59	1513

1- Maximum Torque, Nm

2- Speed Corresponding value of Maximum Torque, rpm

3- Torque/100 rpm

4- Maximum power, kWh

5- Speed Corresponding value of Maximum Power, rpm

6- Minimum value of Specific fuel consumption, kg/kWh

7- Speed Corresponding value of Minimum Specific fuel consumption, rpm

8- Maximum Fuel consumption, l/h

9- Speed Corresponding value of Maximum Fuel consumption, rpm

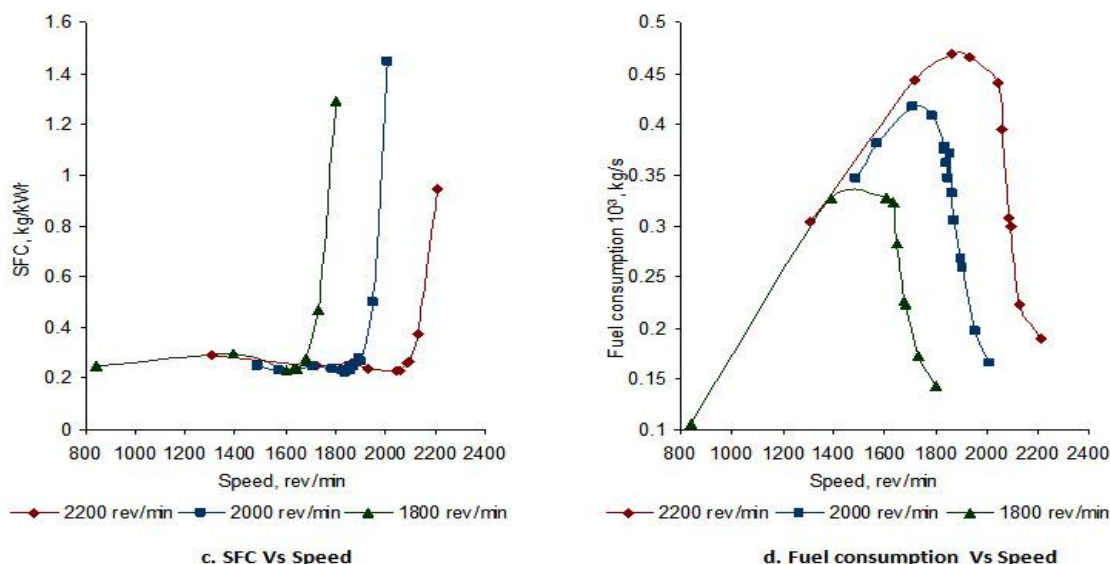


Fig. 13. Characteristic performance curves for D100

### 31.2.2 Varying load test

The variable load test was conducted as per IS test cod 9935-1981. During this test, speed torque and hourly fuel consumption were measured as a function of power. The test was conducted in following sequence of loading and each load state was maintained for 20 minute duration.

1. 85 per cent of the load corresponding to the load at maximum power
2. Minimum load
3. 50 per cent of the load defined at (a)
4. Load corresponding to the load at maximum power
5. 25 per cent of the load at maximum power (a), and
6. 75 per cent of the load defined at (a)

The variable load test was conducted at engine rated speed of 2200 rpm for all blend levels throughout the experiment as per SAE J708c- "Agriculture tractor test code" of Society of Automotive engineers and IS 9935-1981-Test code for Power tiller. The power, torque and fuel consumption were measured as a function of power by gradually loading after stabilized working condition of the engine are reached. The performances of the engine under varying load test with different blends are tabulated from Table 6 to Table 11 and shown in Fig.14.

**Table 6 Engine performance during variable load test for D100 at 2200 rpm idle speed**

Applied load in terms of maximum torque	Engine speed, rpm	Torque, Nm	Fuel consumption, l/h	Power, kWh	SFC, kg/kWh
85 per cent of the load corresponding to the load at maximum power	1992.29	28.90	1.76471	6.029	0.241
Minimum load	2200.98	2.82	0.83721	0.650	1.061
50 per cent of the load defined at (a)	2060.18	14.54	1.13924	3.138	0.299
Load corresponding to the load at maximum power	1898.67	34.03	1.85567	6.766	0.242
25 per cent of the load at maximum power (a)	2129.81	7.33	0.86957	1.635	0.483
75 per cent of the load defined at (a)	2047.15	21.43	1.39535	4.594	0.233
Average	1716.15	18.17	1.31	3.80	0.42

**Table 7 Engine performance during variable load test for B20 biodiesel blend at 2200 rpm idle speed**

Applied load in terms of maximum torque	Engine speed, rpm	Torque, Nm	Fuel consumption, l/h	Power, kWh	SFC, kg/kWh
85 per cent of the load corresponding to the load at maximum power	1994.91	29.13	1.978	6.08	0.271
Minimum load	2202.60	2.70	0.829	0.73	1.111
50 per cent of the load defined at (a)	2110.08	14.77	1.111	3.26	0.284
Load corresponding to the load at maximum power	1875.99	34.29	2.118	6.74	0.262
25 per cent of the load at maximum power (a)	2168.32	7.24	0.887	1.64	0.450
75 per cent of the load defined at (a)	2059.87	21.48	1.538	4.63	0.277
Average	2068.62	18.27	1.41	3.84	0.442

**Table 8 Engine performance during variable load test for B40 biodiesel blend at 200 rpm idle speed**

Applied load in terms of maximum torque	Engine speed, rpm	Torque, Nm	Fuel consumption, l/h	Power, kWh	SFC, kg/kWh
85 per cent of the load corresponding to the load at maximum power	1998.55	28.60	1.836	5.985	0.259
Minimum load	2198.21	2.84	0.849	0.653	1.096
50 per cent of the load defined at (a)	2130.56	15.77	1.304	3.518	0.312
Load corresponding to the load at maximum power	1894.87	33.21	1.914	6.589	0.245
25 per cent of the load at maximum power (a)	2141.4	6.88	1.011	1.542	0.553
75 per cent of the load defined at (a)	2052.58	22.66	1.651	4.870	0.286
Average	2069.36	18.33	1.420	3.86	0.459

**Table 9 Engine performance during variable load test for B60 biodiesel blend at 2200 rpm idle speed**



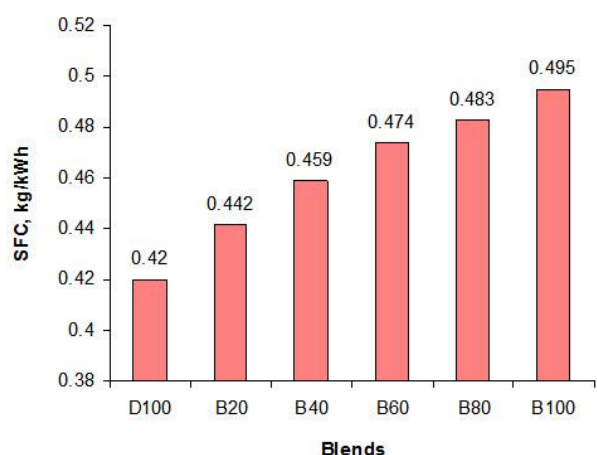
Applied load in terms of maximum torque	Engine speed, rpm	Torque, Nm	Fuel consumption, l/h	Power, kWh	SFC, kg/kWh
85 per cent of the load corresponding to the load at maximum power	2057.36	27.2	1.894	5.859	0.275
Minimum load	2200.3	3.4	0.932	0.781	1.014
50 per cent of the load defined at (a)	2123.2	13.6	1.417	3.023	0.399
Load corresponding to the load at maximum power	1884.9	31.5	1.651	6.217	0.226
25 per cent of the load at maximum power (a)	2171.73	6.8	1.077	1.546	0.594
75 per cent of the load defined at (a)	2087.1	20.4	1.764	4.458	0.337
Average	2087.43	17.2	1.45	3.640	0.474

**Table 10 Engine performance during variable load test for B80 biodiesel blend at 2200 rpm idle speed**

Applied load in terms of maximum torque	Engine speed, rpm	Torque, Nm	Fuel consumption, l/h	Power, kWh	SFC, kg/kWh
85 per cent of the load corresponding to the load at maximum power	2016.4	26.86	1.935	5.67151	0.295
Minimum load	2207	3.29	0.878	0.76013	0.999
50 per cent of the load defined at (a)	2123.42	13.43	1.295	2.98626	0.375
Load corresponding to the load at maximum power	1815.4	31.61	2.118	6.00859	0.305
25 per cent of the load at maximum power (a)	2155.12	6.71	0.984	1.51429	0.562
75 per cent of the load defined at (a)	2066.6	20.14	1.818	4.35845	0.361
Average	2063.99	17.00	1.50	3.54	0.483

**Table 11 Engine performance during variable load test of B100 at 2200rpm idle speed**

Applied load in terms of maximum torque	Engine speed, rpm	Torque, Nm	Fuel consumption, l/h	Power, kWh	SFC, kg/kWh
85 per cent of the load corresponding to the load at maximum power	1995.39	26.7	2.069	5.579	0.324
Minimum load	2201.82	3.5	0.918	0.807	0.993
50 per cent of the load defined at (a)	2123.57	13.85	1.385	3.080	0.392
Load corresponding to the load at maximum power	1992.57	31.8	2.222	6.635	0.292
25 per cent of the load at maximum power (a)	2155.12	6.92	1.104	1.562	0.617
75 per cent of the load defined at (a)	2082.36	20.77	1.818	4.529	0.350
Average	2091.80	17.26	1.58	3.69	0.495

**Fig. 14 SFC for diesel and selected biodiesel blends during variable load test**

### 31.2.3. Performance of biodiesel run power tiller under field condition

To measure the average fuel consumption rate of the power tiller engine during field operation, the field test of the power tiller was conducted. Fuel consumption for rotavator operation under dry soil condition was measured. The field trials were conducted at Eastern block of Tamil Nadu Agricultural University campus.

The power tiller engine was run in the field by marking a known distance and operated at three different Low speed gears viz., L- I, II & III. In each gear, the power tiller was operated for 45 minutes. The area covered, forward travel speed and time taken for tillage in each forward speed was recorded. The field test was run with B40 biodiesel blend and diesel fuel. The performance of the power tiller is tabulated in Table 11.13. The field view of the power tiller under test is given in Fig.15.

It was observed that the fuel consumption rate slightly decreased when the forward speed was increased from 1.5 to 2.13 km/h. However when forward speed was increased to 4.04 km/h (gear III) the fuel consumption was rapidly increased. The comparison of fuel consumption between D100 and B40 shows that the consumption of B40 fuel l/h was 17.2 per cent more than D100 at 1.5 km/h (I gear), While this value decreased to 15.74 per cent at 2.13 km/h (II gear) and 6.02 per cent at 4.40 km/h (III gear).

It is seen that as the speed is increased the fuel consumption per hectare is reduced from 7.68 at I gear to 4.1 l/ha at III gear for diesel fuel. The fuel consumption per hectare for B40 is 8.55 l/ha at I gear but reduced to 4.94 l/ha at III gear. This clearly shows that the fuel consumption per ha is 20 per cent more for B40 than diesel. The fuel consumption per hectare reduces rapidly when the forward speed is increased and confirming the “Gear-up throttle-down” strategy for enhancing fuel performance for power tillers.

**Table 12 Fuel performance of power tiller engine in rotary tillage operation with D100 and B40 biodiesel blend**

Gear selection	D100				B40			
	Forward speed, km/h	Area covered, ha/h	Fuel consumption		Forward speed, km/h	Area covered, ha/h	Fuel consumption	
			l/h	l/ha			l/h	l/ha
L-I	1.5	0.151	1.16	7.68	1.58	0.159	1.36	8.55
L- II	2.13	0.213	1.08	5.07	2.1	0.207	1.25	6.03
L- III	4.04	0.405	1.66	4.1	3.56	0.356	1.76	4.94

#### 31.2.4. Engine emission while operation with biodiesel blend

The Multi gas analyzer and Diesel Smoke tester were procured from M/s. Nevco Engineers, Chennai, Tamil Nadu. The specifications of the equipments are given below.

i) Flue Gas Analyser Model: KM 9106 (Quintox) – O<sub>2</sub> (0-25%), CO 0-10%, CO<sub>2</sub> (0-20%), CO/CO<sub>2</sub> (Calculated) Make: M/s. Kane International Ltd., U.K. Optional: NO (0 - 5000 ppm), NO<sub>2</sub> (0 - 1000 ppm), SO<sub>2</sub> (0 - 5000ppm).

ii) Smoke meter – Diesel smoke tester Model: DS-2000; Make: Koen Co., Ltd, Korea. Range: 0.0 to 100%

In the present investigation the power tiller engine emissions were measured during the variable load test. The data recorded during each set of trail for different blends is given in Table 13 and is shown in Fig 16 to 19. The recording flue gas analyzer model KM 9106 of Quintox was used to measure the exhaust emissions. The particulate emission was measured using Koen DC-2000 model of Diesel smoke tester (smoke density meter).

#### (i) Carbon dioxide (CO<sub>2</sub>) emission

It is observed that D100 and B20 exhibit gradual increase of CO<sub>2</sub> concentration in the 3 - 7 kW range. However B80 and B100 show a steep increase in the 3-4.5 kW range then drops by around 1%. It is interesting to note that the CO<sub>2</sub>% of all blends almost converges to a value of 7-8% at a load of 7 kW. From these patterns it can be concluded that up to about 50% of the rated load there is no significant difference between the blends in terms of CO<sub>2</sub> concentration. Fuels with lesser biodiesel per cent show lesser CO<sub>2</sub> emission at loads of 6-7 kW. The CO<sub>2</sub> emission converges towards 7-8%.

#### (ii) Carbon monoxide (CO) emission

It is observed that there is no significant difference between D100 and B20 in terms of CO emission over the entire operating range. The B40, B60, B80 and B100 showed higher values of CO emission than D100 above 4 kW load. Higher concentration of CO in jatropha oil blended with diesel as compared to D100.

#### (iii) Oxygen emission

The residual O<sub>2</sub> in the exhaust gas is linearly decreased from around 16% at 1kW to around 8% at 7 kW. The highest concentration of O<sub>2</sub> is observed in blends with lesser biodiesel at a given power output. The air requirement for diesel fuel is lesser than biodiesel blends. The differences tend to reduce as the load reaches the peak value. At part load operation, better performance can be obtained by ensuring higher air flow in biodiesel run engines.

#### (iv) Oxides of Nitrogen emission

The NO<sub>x</sub> emission of D100 and B20 are almost identical and that of B40 and B60 are identical. The NO<sub>x</sub> values gradually increase from around 100 ppm at 1 kW to 300 ppm at around 7 kW. Except for B100 all other blends show all most linear increase in NO<sub>x</sub> in the 1 to 7 kW range.

**Table 13 Exhaust gas emission of variable load test for diesel and biodiesel blends**

Blends	Loads	O <sub>2</sub> , %	CO <sub>2</sub> , %	CO, %	NO <sub>2</sub> , ppm	NO, ppm	NO <sub>x</sub> , ppm	SO <sub>2</sub> ppm
D100	a	10.5	8.2	0.141	5	334	339	64

	b	16.7	3.1	0.019	7	85	92	0
	c	15.0	5.7	0.017	6	197	203	5
	d	8.8	8.0	0.197	4	319	323	70
	e	15.7	5.4	0.015	7	132	139	1
	f	12.6	7.0	0.020	6	261	267	16
B20	a	10.2	8.8	0.143	5	353	358	47
	b	16.2	3.5	0.024	7	90	97	0
	c	14.0	5.9	0.022	6	215	221	5
	d	8.9	8.5	0.200	4	336	348	52
	e	15.7	5.5	0.023	7	126	133	1
	f	12.0	7.2	0.024	5	269	274	16
B40	a	10.3	8.6	0.137	1	390	391	28
	b	16.5	3.3	0.023	5	93	98	0
	c	13.8	5.9	0.024	1	186	187	1
	d	8.7	7.8	0.188	1	378	379	30
	e	15.1	5.6	0.022	3	134	137	0
	f	12.3	7.9	0.027	2	217	219	7
B60	a	9.8	7.7	0.139	1	392	393	23
	b	16.3	3.5	0.022	3	76	79	0
	c	12.5	6.1	0.023	2	189	191	1
	d	8.7	7.5	0.185	1	384	385	23
	e	14.3	5.7	0.022	4	136	140	1
	f	11.8	8.3	0.25	2	220	222	4
B80	a	9.7	7.5	0.145	2	379	381	19
	b	16.5	3.3	0.025	4	67	71	0
	c	11.7	5.8	0.024	2	245	247	2

	d	8.5	7.6	0.217	2	351	353	19
	e	13.7	5.9	0.023	3	179	182	1
	f	10.1	8.6	0.033	2	316	318	2
B100	a	10.1	7.8	0.147	3	360	363	9
	b	16.2	3.4	0.027	4	45	49	0
	c	12.0	6.2	0.025	3	295	298	0
	d	8.8	7.8	0.223	3	348	351	13
	e	14.0	5.7	0.024	4	109	113	0
	f	10.6	8.5	0.037	3	352	355	1

a, 85 percent of the load corresponding to the load at maximum

b, Minimum load

c, 50 percent of the load defined at (a)

d, Load corresponding to the load at maximum power

e, 25 percent of the load at maximum power(a), and

f, 75 percent of the load defined at (a)

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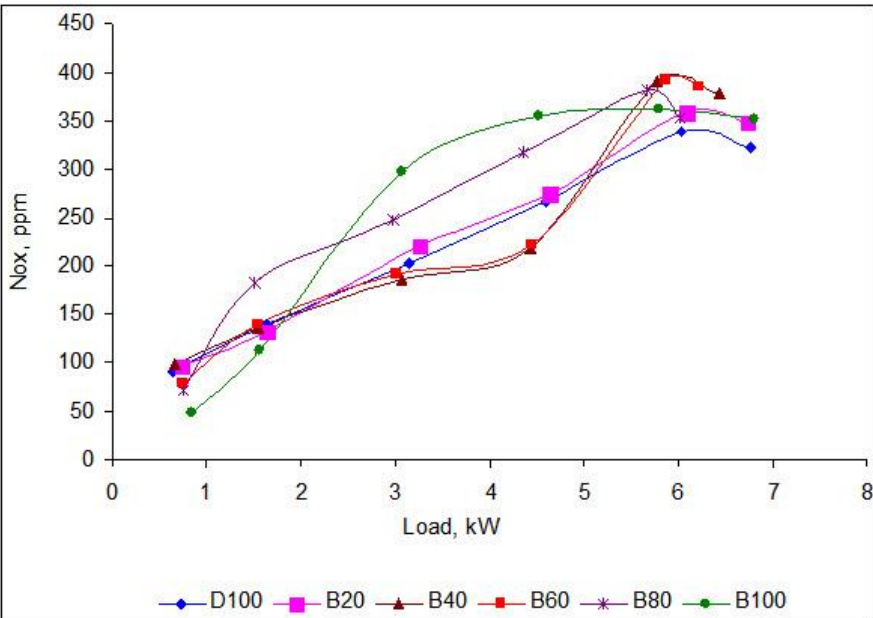


Fig. 19 Oxides of Nitrogen (NO<sub>x</sub>) emission for diesel and selected biodiesel blends

(v) Smoke density emission of exhaust gas

The smoke density of exhaust gas for diesel and selected biodiesel for the blends are plotted as a function of engine power in Fig.20.

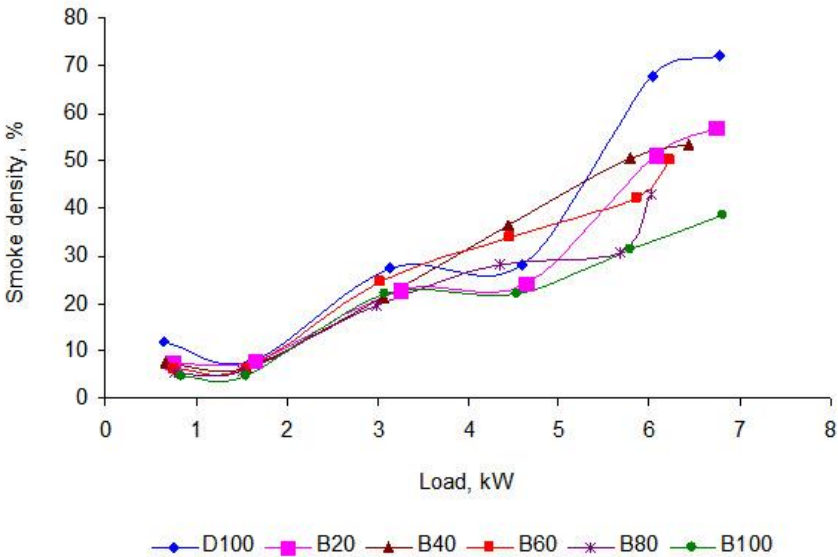


Fig.20 Smoke density (%) of exhaust gas for diesel and biodiesel blends

Table 14 Smoke density of diesel and biodiesel blends at various loads

Load / Blends	D100	B20	B40	B60	B80	B100
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85 per cent of the load corresponding to the load at maximum	67.8 (Bad)	51.3 (Bad)	50.3 (Bad)	42.3 (Good)	30.7 (Good)	31.4 (Good)
Minimum load	12.0 (Good)	7.5 (Good)	7.5 (Good)	6.1 (Good)	5.3 (Good)	4.7 (Good)
50 per cent of the load defined at (a)	27.3 (Good)	22.8 (Good)	21.1 (Good)	24.5 (Good)	19.5 (Good)	21.9 (Good)
Load corresponding to the load at maximum power	72.1 (Bad)	56.9 (Bad)	53.4 (Bad)	50.1 (Bad)	43.0 (Good)	38.6 (Good)
25 per cent of the load at maximum power (a)	7.9 (Good)	8.0 (Good)	6.51 (Good)	6.2 (Good)	5.7 (Good)	4.8 (Good)
75 per cent of the load defined at (a)	28.1 (Good)	24.0 (Good)	36.3 (Good)	34.0 (Good)	28.2 (Good)	21.9 (Good)

The smoke density was found to increase with increase in load in almost linear pattern from 1 to 4.5 kW. In 4.5 to 7 kW, D100 showed rapid increase in smoke density while B100 showed minimum increase in smoke density. The correlation between low black smoke emission and high NO<sub>x</sub> concentration was also observed.

### 31.3. Performance evaluation of biodiesel blends in a variable compression test rig

#### 31.3.1 Methodologies adopted

Variable Compression Ratio Multifuel Engine Test Rig procured from Legion Brothers, Bangalore (Fig. 6) was used for testing the engine performance and emission studies. The Engine specifications are given below in table 6.

**Table 6. Specification of variable compression multifuel engine**

BHP	3 HP
Speed	1500 to 2000 RPM variable speed for SI operation, Governed speed for 1500 RPM for CI operation.
Compression Ratio	5:1 to 20:1
Bore; Stroke	80 mm; 110 mm
Type of Ignition	Spark ignition (time adjustable 0 to 70 deg ATDC, 0 to 70 deg BTDC) or Compression ignition
Method of Loading	Eddy Current Dynamometer
Method of Cooling	Water



To study engine performance, the compression ratios for diesel, biodiesel and their blends were selected as 14:1, 16:1, 18:1 and 20:1 and the load ranges were selected as no load, 2 kg, 4 kg, 6 kg and 8 kg as the engine used for this study having load range from no load to 8 kg load.

### 31.3.2 Performance evaluation results

The effect of different compression ratios, loads and blends on the engine performance and emission characteristics were studied in the form of Brake Power (BP), Specific Fuel Consumption (SFC), Brake Thermal Efficiency (BTE) and Heat Balance Chart (HBC). It was found out that BSFC was higher for Jatropha biodiesel ( $0.425 \text{ kg kWh}^{-1}$ ) compare to diesel ( $0.350 \text{ kg kWh}^{-1}$ ) but for B20 it was lower ( $0.340 \text{ kg kWh}^{-1}$ ) than both biodiesel and diesel. The optimum compression ratio for Jatriopha biodiesel, B20 and diesel was found at 20:1, 18:1 and 16:1, respectively. The higher BTE was obtained for B20 and B40 (27.07 and 26.45 %) than other blends at compression ratio 18:1. The temperature of exhaust gas and heat input was increased with increase in percentage of Jatropha biodiesel and the maximum values were  $559^{\circ}\text{C}$  and  $43987.5 \text{ kJ h}^{-1}$ , respectively which were higher than diesel ( $519^{\circ}\text{C}$  and  $29222.4 \text{ kJ h}^{-1}$ , respectively).

The  $\text{CO}_2$  emission was found to be higher for Jatropha biodiesel (9.2 %) than diesel (8.1 %). The reduced percentage of CO and  $\text{SO}_2$  was observed for all blends as compared to diesel at different loads. The  $\text{SO}_2$  emission of Jatropha biodiesel was found to be nil due to zero sulphur content and was higher for diesel (61 ppm). Due to the presence of higher oxygen molecule in Jatropha biodiesel,  $\text{NO}_x$  emission was increased with increase in blend proportion of Jatropha biodiesel and was maximum for B100 (428 ppm) compared to diesel (413 ppm).

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## **Lesson 32. Properties of biodiesel**

A general understanding of the various properties of bio-diesel is essential to study their implications in engine use, storage, handling and safety.

### **1. Density**

Density is the measure of ratio between mass and volume. Specific gravity is the ratio of the density of a substance to the density (mass of the same unit volume) of a reference substance. Bio-diesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel).

### **2. Cetane Number:**

Cetane number (CN) is a dimensionless descriptor of the ignition quality of a diesel fuel (DF). It is a prime indicator of DF quality. It is a measure of the quality of a diesel fuel expressed as the percentage of cetane in a mixture of cetane and 1-methylnaphthalene of the same quality as the given fuel. This relates to the readiness of the fuel to self ignite when exposed to the high temperature and pressure in combustion chamber. Regular diesel fuel has a cetane number of 42-45, where as that of biodiesel varies with feed stock.

### **3. Viscosity**

Viscosity is a measure of resistance to flow of a liquid created due to the internal friction of one part of a fluid moving over another. This affects the atomization of a fuel upon injection into the combustion chamber.

### **4. Flash point**

Flash point of a fuel is defined as the temperature at which it will ignite when exposed to a flame or spark. The flashpoint of bio-diesel is higher than the petroleum based diesel fuel. Flashpoint of bio-diesel blends is dependent on the flashpoint of the base diesel fuel used, and increase with percentage of bio-diesel in the blend. The flashpoint of bio-diesel is around 160°C.

### **5. Cold Filter Plugging Point (CFPP)**

At low operating temperature fuel may thicken and not flow properly affecting the performance of fuel lines, fuel pumps and injectors. Cold filter plugging point of biodiesel reflects its cold weather performance. This can be referred as the lowest temp at which 20 ml oil safely passes through the filter within 60 s.

### **6. Pour Point**

The pour point of a liquid is the lowest temperature at which it becomes semi solid and loses its flow characteristics. This is the temperature at which crystal agglomeration is extensively

enough to prevent free pouring of fluid. To assess the pour point, thermal analytical method – sub ambient differential scanning calorimetry (DSC) can be used.

### **7. Cloud Point**

During cooling temperatures, solid wax crystal nuclei may be formed in biodiesel at submicron and invisible range. If there is any further temperature reduction, the crystals to grow. The temperature at which crystals become visible ( $d \geq 0.5 \mu\text{m}$ ) is called as cloud point. At this point, crystals form cloudy or hazy suspension. Biodiesel generally has higher cloud point than diesel fuel.

### **8. Oxidative stability**

Biodiesel is susceptible to oxidation upon exposure to air. The oxidation process ultimately affects fuel quality. Rancimat apparatus is used to test the oxidative stability of biodiesel.

### **9. Iodine Number**

Iodine number refers to the amount of iodine required to convert unsaturated oil into saturated oil. It refers to the presence of unsaturated fatty acids in the fuel.

### **10. Free and Total glycerol**

The degree of conversion completeness of the vegetable oil is indicated by the amount of free and total glycerol present in the bio-diesel. If the actual number is higher than the specified values, engine fouling, filter-clogging etc can occur.

### **11. Sulfur content**

Biodiesel generally contain less than 15ppm sulfur. ASTM D 5453 test is a suitable test for such low level of sulfur.

### **12. Lubricity**

The lubrication of the pump is provided by lubricity property of the fuel also. Due to lack of lubricity several parts of the pump can wear out even with sufficient viscosity. The lubricity of the fuel depends on the oil source, transesterification process, type of additives used etc. BOCLE ( Ball on Cylinder Lubricity Evaluator ) and HFFR(High Frequency Reciprocating Rig) are commonly used for evaluating the lubricity of the fuel.

### **13. Sulfated Ash**

Sulfated ash is controlled to ensure that all the catalysts used in the transesterification process are removed. Presence of ash can cause filter plugging and or injector deposits.

### **14. Acid number/Neutralization number**

Acid number reflects the presence of free fatty acids or acids used in manufacture of biodiesel. It also reflects the degradation of biodiesel due to thermal effects.

## 15. Water Content

The water content in biodiesel and its blends plays a major role in growing microbes when water is present in the fuel. The solvency properties of the biodiesel can cause microbial slime to detach and clog fuel filters.

## 16. Methanol/ethanol content

High levels of free alcohol in biodiesel damage to natural rubber seals and gaskets present in fuel pumps and injectors.

Biodiesel standards

There are more Biofuel standards by various organizations. They are

- ASTM D6751 (United States): Standard Specification for Biodiesel (B100) Blend Stock for Distillate Fuels
- EN 14213 (Europe): Heating Fuels: Fatty Acid Methyl Esters (FAME).
- EN 14214 (Europe): Automotive Fuels: FAME for Diesel Engines.
- Provisional Australian biodiesel standard.
- Provisional Brazilian biodiesel standard ANP 255
- Provisional South African biodiesel standard.

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