SURESH GYAN VIHAR UNIVERSITY
Accredited by NAAC with 'A+' Grade

Bachelor of Science

(B.Sc.)

ENERGY PHYSICS

Semester-iv

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COURSE TITLE : ENERGY PHYSICS

COURSE OBJECTIVES

While studying the **ENERGY PHYSICS**, the Learner shall be able to:

CO 1: Discuss the Introduction to Energy Sources and their merits and demerits.

CO 2: Describe Solar Thermal Energy and their application

CO 3: Introduce the Photovoltaic Systems and its types

CO 4: Explain the basics of Biomass Energy and their classification

CO 5: Interpret the Wind Energy and Other Energy Sources

COURSE SYLLABUS

BLOCK I: Introduction to Energy Sources

World's reserve of Commercial energy sources and their availability- India's production and reserves. Conventional and non-conventional sources of energy, comparison – Coal- Oil and natural gas. Conventional and non-conventional energy applications - merits and demerits.

BLOCK II: Solar Thermal Energy

Solar constant -Solar spectrum-Solar radiations outside earth's atmosphere –at the earth surface- on tilted surfaces – Solar Radiation geometry-Basic Principles of Liquid flat plate collector –Materials for flat plate collector – Construction and working- Solar distillation– Solar disinfection - Solar drying. Construction and working of Solar cooker(box type)- Solar water heating systems – Swimming pool heating.

BLOCK III: Photovoltaic Systems

Introduction-Photovoltaic principle-Basic Silicon Solar cell- Power output and conversion efficiency. Limitation to photovoltaic efficiency-Basic photovoltaic system for power generation-Advantages and disadvantages- Types of solar cells- Application of solar photovoltaic systems - PV Powered fan – PV powered area - lighting system – A Hybrid System.

BLOCK IV: Biomass Energy

Introduction-Biomass classification- Biomass conversion technologies. Bio-gas generation-Factors affecting bio-digestion -Working of biogas plant- floating and fixed dome type plant -advantages and disadvantage of Bio-gas from plant wastes. -Methods for obtaining energy from biomass- Thermal gasification of biomass-Working of downdraft gasifier- Advantages and disadvantages of biological conversion of solar energy.

BLOCK V: Wind Energy and Other Energy Sources

Wind Energy Conversion-Classification and description of wind machines, wind energy collectors-Energy storage. Energy from Oceans and Chemical energy resources-Ocean thermal energy conversion-tidal power, advantages and limitations of tidal power generation- Energy and power from waves- wave energy conversion devices- Fuel cells- and application of fuel cells- batteries- advantages of battery for bulk energy storage- Hydrogen as alternative fuel for motor vehicles.

Books for study:

1. Renewable energy sources and emerging Technologies,Kothari D.P., K.C. Singal and Rakesh Ranjan, Prentice Hall of India, 2008.
2. Solar Energy-principles of thermal collection and storage-S.P.SUKHAME-tata-McGraw-Hill publishing company ltd.

Books for References:

1. Solar Photvoltaics Fundamentals, Technologies and Applications,Chetan Singh Solanki, 2ndEdition, PHI Learning Private Limited, 2011.
2. Non conventional Energy sources, Rai G. D, 4th Edition, Khanna Publishers, 2010.
3. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.
4. Solar Energy Engineering: Processes and Systems Kalogirou S.A., , 2nd Edition, Academic Press, 2013.
5. Handbook of Renewable Energy Technology,Zobaa A.F.and Ramesh Bansal, World Scientific, 2011.

Web Resources

1. Sources of Energy — Vikaspedia
2. Introduction to Energy Sources - YouTube
3. Solar thermal energy - Appropedia
4. Solar Thermal Energy - YouTube
5. Lecture - 15 Solar Thermal Energy Conversion - YouTube
6. Fundamentals of Solar Photovoltaic Systems - YouTube
7. Solar Photovoltaic (PV) Systems, Scope, NEC 2020 - [690.1], (39min:21sec) - YouTube
8. Biomass crops are energy efficient and climate friendly | ERC (europa.eu)
9. Biomass Energy Basics | NREL
10. Wind Energy Basics | NREL
11. Sources of Energy — Vikaspedia
12. Wind energy facts, advantages, and disadvantages | Caltech Science Exchange
13. Fuel Cell - Definition, Working, Types, and Applications of fuel cell. (byjus.com)
14. Energy 101: Fuel Cells - YouTube

COURSE LEARNING OUTCOMES

After completion of the **ENERGY PHYSICS**, the Learner will be able to:

CLO 1: Distinguish between the Conventional and non-conventional sources of Energy and their applications

CLO 2: Demonstrate the Construction and working of cooker(box type) and Solar water heating systems

CLO 3: Design and develop photovoltaic system for power generation and discuss their Advantage and disadvantage.

CLO 4: Discuss Biomass conversion technologies and develop biogas plant from waste

CLO 5: Describe Wind Energy Conversion, Oceans and Chemical energy resources and design develop Fuel cells for energy storge

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CONTENT

BLOCK I INTRODUCTION TO ENERGY SOURCES

Unit 1: Primary and Secondary Energy Sources

Unit 2: Conventional and Non-conventional Sources of Energy

UNIT 1

PRIMARY AND SECONDARY ENERGY SOURCES

Structure

OVERVIEW

In this unit, we will learn about primary and secondary sources of energy, world's reserve of commercial energy sources and india's production and its reserves.

OBJECTIVES

After studying this unit, you will be able to

- Understand the primary and secondary energy sources
- Know the world reserves of energy sources
- know the India's reserves and production

1.1 INTRODUCTION

Classical description of energy is the ability of a system to perform work, but as energy exists in so many forms, it is hard to find one comprehensive definition. It is the property of an object that can be transferred from one object to another or converted to different forms but cannot be created or destroyed. There are numerous sources of energy. In the next few sections, let us discuss the about different sources of energy in detail. Any physical activity in this world, whether carried out by human beings or by nature, is cause due to flow of energy in one form or the other. The word 'energy' itself is derived from the Greek word 'en-ergon', which means 'in-work' or 'work content'. The work output depends on the energy input. Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them. Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy
- Conventional and Non-conventional energy

1.2 PRIMARY AND SECONDARY ENERGY SOURCES

Primary energy is the energy that's harvested directly from natural resources. Sources of primary energy fall into two basic categories. fuels and flows. The fuels in primary energy are all primary fuels. a country's different source of primary energy are aggregated into a quantity called total primary energy supply (TPES). all of human energy must come from one of these primary energy sources, there are no energy alternatives. primary energy is contrasted with end use energy. primary energy almost alwys needs to be converted through an energy conversion technology to make this primary energy source into an energy currency or a secondary fuel before it can be used.

For example

- Coal is usually put into a coal-fired power plany to generate electricity.
- Wind must be harnessed by a wind turbine before it can generate electricity.

secondary energy sources are derived from primary sources in a form of either final fuel or energy supply. involvement of technological processes in this transformation in between causes drop in primary energy on the way to consumers. secondary energy sources are also reffered to as energy carriers, because they move energy in a usable form from one place to another. the two most well-known energy carriers are Electricity and Hydrogen.

For example

- Crude oil refined and converted in products like petrol, diesel and kerosene.

1.3 WORLD'S RESERVE OF COMMERCIAL ENERGY SOURCES

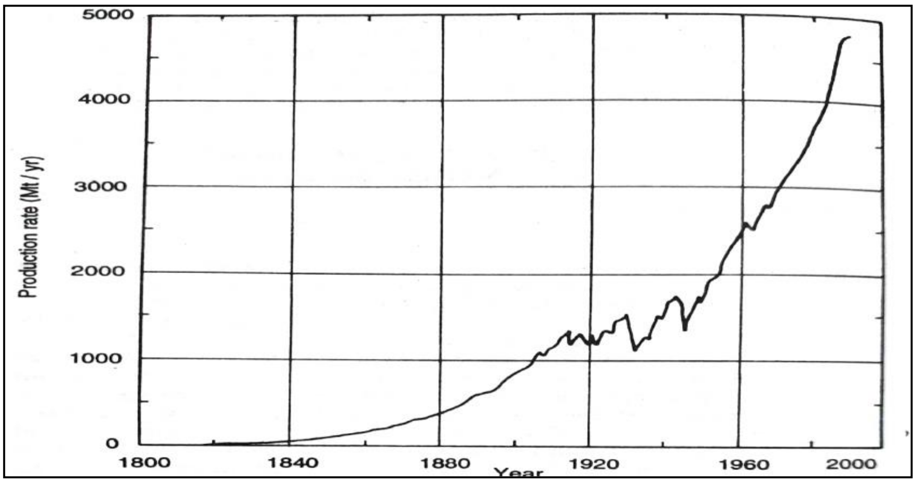
Man has needed and used energy at an increasing rate for his sustenance and well-being ever since he came on the earth a few 'million years ago. Primitive man required energy primarily in the form of food. He derived this by eating plants or animals which he hunted. Subsequently he discovered fire and his energy needs increased as he started to make use of wood and other biomass to supply the energy needs for cooking as well as for keeping himself warm. With the passage of time, man started to cultivate land for agriculture. He added a new dimension to the use of energy by domesticating and training animals to work for him. With further demand for energy, man began to use the wind for sailing ships and for driving windmills, and the force of falling water to turn water wheels. Till this time, it would not be wrong to say that the sun was supplying all the energy needs of man either directly or indirectly and that man was using only renewable sources of energy.

The Industrial Revolution which began with the discovery of the steam engine (AD 1700) brought about a great many changes. For the first time, man began to use a new source of energy, viz. coal, in large quantities. A little later, the internal combustion engine was invented (AD 1870) and the other fossil fuels, oil and natural gas began to be used extensively. The fossil fuel era of using nonrenewable sources had begun and energy was now available in a concentrated form. The invention of heat engines and the use of fossil fuels made energy portable and introduced the much needed flexibility in man's movement. For the first time, man could get the power of a machine where he required it and was not restricted to a specific site like a fast-running stream for running a water wheel or a windy hill for operating a windmill. This flexibility was enhanced with the discovery of electricity and the development of central power generating stations using either fossil fuels or water power.

Fossil Fuels

Coal

Coal is the end product of a natural process of decomposition of vegetable matter buried in swamps and out of contact with oxygen for thousands of years. The word 'coal' denotes a wide variety of solid fuels. The varieties in approximate order of their formation are peat, lignite, bituminous coal and anthracite.



The world's rate of production of coal from the time it has been used in significant amounts is shown in Figure. It is seen that from about 1860, there was a steady increase of about 4.6 per cent per year in the production rate up to the beginning of the First World War in 1914. Thereafter, for a period of 31 years till the end of the Second World War, the changes in the production rate were erratic. It decreased in some years and increased in others, the average increase over the whole time span being only 0.25 per cent per year. After 1945, the production rate has again increased (more or less steadily) at the rate of about 3 to 4 per cent per year. The production in 1980 was 3736 Mt, in 1985, 4336 Mt, and in 1990, 4783 Mt. The total amount of coal produced up to 1990 (obtained by finding the area under the curve in Fig) is approximately 200 000 Mt.

Many estimates have been made regarding the amount of coal still available in the earth. Before giving these, it will be useful to distinguish between the terms `resources' and 'reserves'. The term `resources' implies an estimate of the total quantity available that may eventually be successfully exploited and used by man. The term `reserves' generally refers to that portion of the resources which has been proved and can be economically recovered with available techniques. Estimates of the world's coal resources range from 6.9 x 10^6 to 11.8 x 10^6 Mt, while the proved reserves have been estimated to range from 0.65 x 10^6 to 1.16 x 10^6 Mt. Nearly 70 per cent of the reserves lie in the USA, Russia and China. It is of interest to estimate approximately the time for which coal would be available. Assuming a continuous growth rate in production

1.4 INDIA'S PRODUCTION AND RESERVES

Coal dominates the energy mix in India, contributing to 55% of the total primary energy production. Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10% in 1994 to 13% in 1999. There has been a decline in the share of oil in primary energy production from 20% to 17% during the same period.

Energy Supply

Coal Supply

India has huge coal reserves, at least 84,396 million tones of proven recoverable reserves (at the end of 2003). These amounts to almost 8.6% of the world reserves and it may last for about 230 years at the current Reserve to Production (R/P) ratio. In contrast, the world's proven coal reserves are expected to last only for 192 years at the current R/P ratio.

Reserves/Production (R/P) ratio- If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that the remaining reserves would last if production were to continue at that level.

India is the fourth largest producer of coal and lignite in the world. Coal production is concentrated in these states (Andhra Pradesh, Uttar Pradesh, Bihar, Madhya Pradesh,Maharashtra, Orissa, Jharkhand, and West Bengal).

Oil Supply

Oil accounts for about 36 % of India's total energy consumption. India today is one of the top ten oil-guzzling nations in the world and will soon overtake Korea as the third largest consumer of oil in Asia after China and Japan. The country's annual crude oil production is peaked at about 32 million tonne as against the current oil consumption by end of 2007 is expected to reach 136 million tonne(MT), of which domestic production will be only 34 MT. India will have to pay an oil bill of roughly $50 billion, assuming a weighted average price of $50 per barrel of crude. In 2003-04, against total export of $64 billion, oil imports accounted for $21 billion. India imports 70% of its crude needs mainly from gulf nations. The majority of India's roughly 5.4 billion barrels in oil reserves are located in the Bombay High, upper Assam, Cambay, Krishna-Godavari. In terms of sector wise petroleum product consumption, transport accounts for 42% followed by domestic and industry with 24% and 24% respectively. India spent more than Rs.1,10,000 crore on oil imports at the end of 2004.

Natural Gas Supply

Natural gas accounts for about 8.9 per cent of energy consumption in the country. The current demand for natural gas is about 96 million cubic metres per day (mcmd) as against availability of 67 mcmd. By 2007, the demand is expected to be around 200 mcmd. Natural gas reserves are estimated at 660 billion cubic meters.

Electrical Energy Supply

The all India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004, consisting of 28,860 MW- hydro, 77,931 MW- thermal and 2,720 MW- nuclear and 1,869 MW- wind (Ministry of Power).

Nuclear Power Supply

Nuclear Power contributes to about 2.4 per cent of electricity generated in India. India has ten nuclear power reactors at five nuclear power stations producing electricity. More nuclear reactors have also been approved for construction.

Hydro Power Supply

India is endowed with a vast and viable hydro potential for power generation of which only 15% has been harnessed so far. The share of hydropower in the country's total generated units has steadily decreased and it presently stands at 25% as on 31st May 2004. It is assessed that exploitable potential at 60% load factor is 84,000 MW.

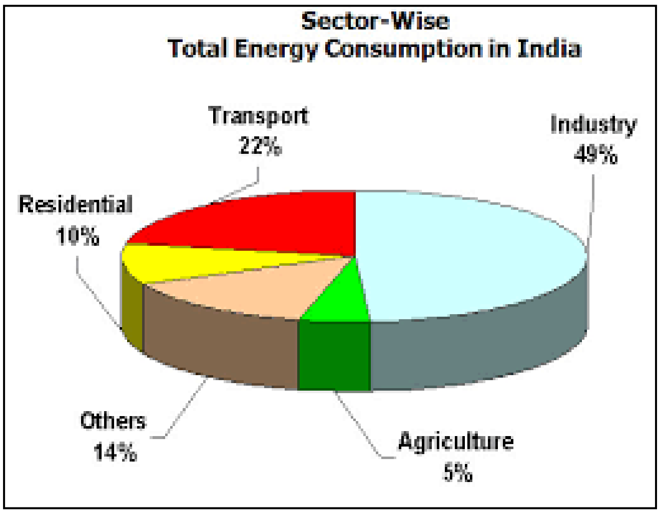
Final Energy Consumption

Final energy consumption is the actual energy demand at the user end. This is the difference between primary energy consumption and the losses that takes place in transport, transmission & distribution and refinement. The actual final energy consumption (past and projected) is given in

DEMAND FOR COMMERCIAL ENERGY FOR FINAL CONSUMPTION (BAU SCENARIO)					
Source	**Units**	**1994-95**	**2001-02**	**2006-07**	**2011-12**
Electricity	Billion Units	289.36	480.08	712.67	1067.88
Coal	Million Tonnes	76.67	109.01	134.99	173.47
Lignite	Million Tonnes	4.85	11.69	16.02	19.70
Natural Gas	Million Cubic	9880	15730	18291	20853
Oil	Million Tonnes	63.55	99.89	139.95	196.47
Source: Planning Commission *BAU:_Business As Usual*					

Sector Wise Energy Consumption in India

The major commercial energy consuming sectors in the country are classified as shown in the Figure. As seen from the figure, industry remains the biggest consumer of commercial energy and its share in the overall consumption is 49%. (Reference year: 1999/2000).



CHECK YOUR PROGRESS

1. What is mean by energy?
2. What are the types of energy resources?
3. What is secondary energy give an example.

LET US SUM UP

In this unit, we have learnt about

- primary and secondary energy sources
- world's commercial energy reserves
- India's reserves and production

ANSWERS TO CHECK YOUR PROGRESS

1. Energy is the ability of a system to perform work, but as energy exists in so many forms. It is the property of an object that can be transferred from one object to another or converted to different forms but cannot be created or destroyed.
2. There are two types of energy sources
    - Primary energy source and
    - Secondary energy source
3. secondary energy sources are derived from primary sources in a form of either final fuel or energy supply. involvement of technological processes in this transformation in between causes drop in primary energy on the way to consumers. secondary energy sources are also reffered to as energy carriers, because they move energy in a usable form from one place to another. the two most well-known energy carriers are Electricity and Hydrogen.

UNIT END EXERCISE

1. Explain primary and secondary energy resources with suitable example.
2. Explain briefly India's production and reserves in energy sources.

SUGGESTED READINGS

1. Renewable energy sources and emerging Technologies,Kothari D.P., K.C. Singal and Rakesh Ranjan, Prentice Hall of India, 2008.
2. Non conventional Energy sources, Rai G. D, 4th Edition, Khanna Publishers, 2010.

WEB RESOURCES

1. Sources of Energy — Vikaspedia

2. Introduction to Energy Sources - YouTube

UNIT 2

CONVENTIONAL AND NON-CONVENTIONAL SOURCES OF ENERGY

Structure

OVERVIEW

In this unit, we will learn about conventional and non-conventional energy sources, their application and merits and demerits.

OBJECTIVES

After studying this unit, you will be able to

- Understand the conventional and non-conventional energy sources
- Know their application
- Know the merits and demerits

2.1 INTRODUCTION

Energy is the ability of a physical system to perform work. We use energy in our daily lives from various sources for doing work. We use muscular energy for carrying out physical work, electrical energy for running multiple appliances, chemical energy for cooking food, etc. For this, we need to know the different energy sources to obtain energy in its usable form. This article will familiarize you with two important sources of energy: conventional energy and non-conventional energy

2.2 CONVENTIONAL SOURCES OF ENERGY

Conventional Sources of Energy are also known as non-renewable source of energy and are available in limited quantity apart from hydro-electric power. Further, it is classified under commercial and non-commercial energy.

Commercial Energy Sources

Coal, electricity and petroleum are known as commercial energy since the consumer needs to pay its price to buy them.

Coal

Coal is the most important source of energy. There are more than 148790 coal deposits in India, and between 2005-2006, the annual production went up to 343 million tons. India is the fourth-largest coal-producing country, and the deposits are primarily found in Bihar, Orissa, Madhya Pradesh, Jharkhand and Bengal.

Oil and Natural Gas

Oil is considered liquid gold and one of the crucial energy sources in India and the world. Oil is primarily used in planes, automobiles, trains and ships. The total oil production in India was 0.3 million tons in 1950-51, which increased up to 32.4 million tons in 2000-01. It is mainly found in Assam, Gujarat and Mumbai.**Electricity**

Electricity is a common form of energy used for domestic and commercial purposes, and it is mainly utilized in electrical appliances like fridges, T.V, washing machines and air conditioning.

The major sources of power generation are:

- Nuclear Power
- Thermal Power
- Hydro-electric power

Thermal Power : Thermal power is generated at various power stations utilizing oil and coal. It is a vital source of electric current, and its share in the nation’s total capacity in 2004-05 was 70 percent.

Hydroelectric Power : Hydroelectric power is produced by constructing dams above flowing rivers like Damodar Valley Project and Bhakra Nangal Project. The installed capacity of hydroelectric power was 587.4 mW in 1950-51 and went up to 19600 mW in 2004-05.

Nuclear Power : The fuel used in nuclear power plants is Uranium, which costs less than coal. Nuclear power plants can be found in Kaiga (Karnataka), Kota (Rajasthan), Naroura (UP) and Kalapakam (Chennai).

Non-commercial Energy Sources

Generally, the freely available energy sources are considered non-commercial energy sources. Examples of non-commercial energy sources include straw, dried dung, firewood.

2.3 NON-CONVENTIONAL ENERGY SOURCES

Non-conventional sources are also known as renewable source of energy. Examples of non-conventional sources of energy include solar energy, bioenergy, tidal energy and wind energy.

Solar Energy

Solar Energy is produced by sunlight. The photovoltaic cells are exposed to sunlight based on the form of electricity that needs to be produced. The energy is utilized for cooking and distillation of water.

Wind Energy

Wind energy is generated by harnessing the power of wind and mostly used in operating water pumps for irrigation purposes. India stands as the second-largest country in the generation of wind power.

Tidal Energy

Tidal energy is generated by exploiting the tidal waves of the sea. This source is yet to be tapped due to the lack of cost-effective technology.

2.4 MERITS AND DEMERITS OF NON-CONVENTIONAL ENERGY SOURCES

MERITS

- Non-conventional sources of energy are environmentally friendly as they cause less pollution.
- It provides employment too as it deals with extracting and transporting parts of non-renewable sources.
- Huge profits can be generated through mining coal and exporting

oil.

- Cost saving option in the long run.
- It is low-cost maintenance

DEMERITS

- The major disadvantage is that it is time-consuming and inefficient as well as unreliable in nature.
- For the workers, it is more of a health risk as they work day and night inside the coal mines also results in injuries and deaths.
- Non-conventional sources are gradually vanishing from the earth as they take billions of years to form.
- It requires a huge amount of fuel in reserve to keep the power station working.
- Energy is needed to be stored.

CHECK YOUR PROGRESS

1. What are conventional energy sources?
2. What are non-conventional energy sources?
3. State any two merits of non-conventional energy sources?

LET US SUM UP

In this unit, we have learnt about

- ➢ Conventional and non-conventional energy sources
- ➢ Application
- ➢ Advantages and disadvantages

ANSWERS TO CHECK YOUR PROGRESS

1. Coal, oil and natural gas
2. Solar, Wind and Tidel energy
3. Non-conventional sources of energy are environmentally friendly as they cause less pollution.
4. It provides employment too as it deals with extracting and transporting parts of non-renewable sources

UNIT END EXERCISE

1. Explain non-conventional energy sources, give its merits and demerits.

2. State and explain commercial energy sources.

SUGGESTED READINGS

1. Renewable energy sources and emerging Technologies,Kothari D.P., K.C. Singal and Rakesh Ranjan, Prentice Hall of India, 2008.
2. Handbook of Renewable Energy Technology,Zobaa A.F.and Ramesh Bansal, World Scientific, 2011.

WEB RESOURCES

1. Sources of Energy — Vikaspedia
2. Introduction to Energy Sources - YouTube

BLOCK II - SOLAR THERMAL ENERGY

UNIT 3

SOLAR ENERGY

Structure

OVERVIEW

In this unit, we will learn about solar constant, solar spectrum and solar radiations on earth atmosphere.

OBJECTIVES

After studying this unit, you will be able to

- Understand the concept of solar energy
- Find the solar constant
- Know the solar spectrum

3.1 INTRODUCTION

Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors. The first installation of solar thermal energy equipment occurred in the Sahara Desert approximately in 1910 when a steam engine was run on steam produced by sunlight. Because liquid fuel engines were developed and found more convenient, the Sahara project was abandoned, only to be revisited several decades late.

Solar energy is an important, clean, cheap and abundantly available renewable energy. It is received on Earth in cyclic, intermittent and dilute form with very low power density 0 to 1 kW/m^2.Solar energy received on the ground level is affected by atmospheric clarity, degree of latitude, etc. For design purpose, the variation of available solar power, the optimum tilt angle of solar flat plate collectors, the location and orientation of the heliostats should be calculated.

Units of solar power and solar energy:

In SI units, energy is expressed in Joule. Other units are angley and Calorie where

1 angley = 1 Cal/cm^2.day

1 Cal = 4.186 J

For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of kJ/m^2/day or kJ/m^2/hour. Solar power is expressed in terms of W/m^2 or kW/m^2.

3.2 SOLAR CONSTANT

The measure of the solar electromagnetic radiation in a meter squared at Earth's distance from the sun is called a solar constant. To quantify the rate at the unit surface of a solar panel in which the energy is received upon the solar constant is used. In this case, the solar constant is absorbed at a given point and provides a total measurement of the sun's radiant energy. Though it is called a constant, the solar constant is just nearly constant. Once every eleven years, the relative constant varies by 0.2% in a cycle that peaks. In 1838, Claude Pouillet made the first attempt to estimate the solar constant at 1.228 kW/m^2. At a solar minimum of 1.361 kW/m^2 and a solar maximum of 1.362 kW/m^2, the constant is rated.

The Dimensional formula for solar constant

The solar constant is the incident ray of solar energy per unit area per second on the earth surface.

Solar constant = Energy / (Unit area x Unit time)

$= ML^2T^{-2} / (L^2T)$

$= MT^{-3}$

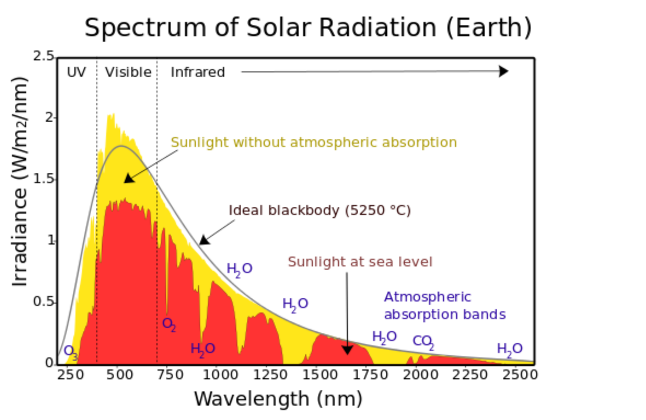
Solar Constant Value

The time per unit of area on a theoretical surface that is perpendicular to the rays of the Sun and at Earth's mean distance from the Suns is said to be the most accurate measurement that is measured from satellites where atmospheric effects are absent. The value of the constant is approximately said to be 1.366 kilowatts per square metre.

The "solar constant" is fairly constant, increasing by only 0.2 per cent at the peak of each 11-year solar cycle. The sunspots usually block out the light and reduce the emission by a few tenths of a percent but the bright spot, also known as the plagues that are associated with the solar activity, is more extensive and longer-lived. Moreover, as the Sun burns up its hydrogen presence, the solar constant increases by about 10 percent every billion years.

3.3 SOLAR SPECTRUM

The Sun emits radiation from X-rays to radio waves, but the irradiance of solar radiation peaks in the visible wavelengths. Common units of irradiance are Joules per second per m^2 of surface that is illuminated per nm of wavelength (e.g., between 300 nm and 301 nm), or W m^{-2} nm^{-1} for the plot below. These units are the units of spectral irradiance, which is also simply called irradiance, but as a function of wavelength. To get the total irradiance in units of W m^{-2}, the spectral irradiance should be integrated over all the wavelengths.

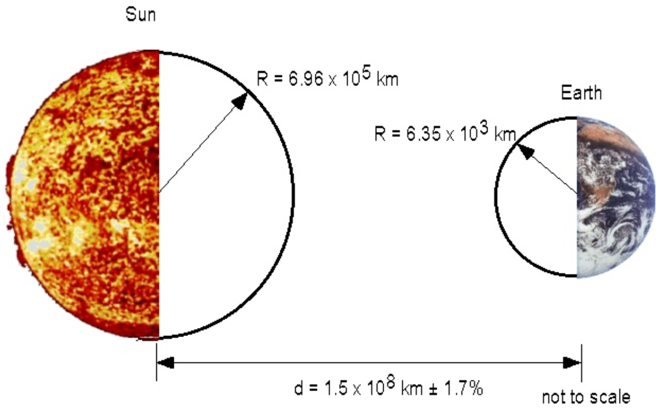


Solar spectrum and atmospheric absorbing gases from 240 nm to 2.5 μm wavelengths.

Credit: Nick84 [CC BY-SA 3.0], via Wikimedia Commons

3.4 SOLAR RADIATIONS OUTSIDE AND INSIDE EARTHS ATMOSPHERE

The solar radiation outside the earth's atmosphere is calculated using the radiant power density (Hsun) at the sun's surface (5.961 x 107 W/m2), the radius of the sun (Rsun), and the distance between the earth and the sun. The calculated solar irradiance at the Earth's atmosphere is about 1.36 kW/m2. The geometrical constants used in the calculation of the solar irradiance incident on the Earth are shown in the figure below.



Geometrical constants for finding the Earth's solar irradiance. The diameter of the Earth is not needed but is included for the sake of completeness.

The actual power density varies slightly since the Earth-Sun distance changes as the Earth moves in its elliptical orbit around the sun, and because the sun's emitted power is not constant. The power variation due to the elliptical orbit is about 3.4%, with the largest solar irradiance in January and the smallest solar irradiance in July. An equation which describes the variation throughout the year just outside the earth's atmosphere is:

$$\frac{H}{H_{constant}} = 1 + 0.033 \cos\left(\frac{360(n-2)}{365}\right)$$

Where:

H is the radiant power density outside the Earth's atmosphere (in W/m^2); $H_{constant}$ is the value of the solar constant, 1.353 kW/m^2; and n is the day of the year.

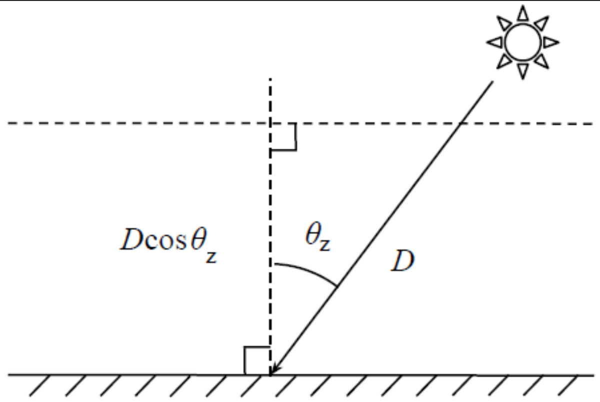
These variations are typically small and for photovoltaic applications the solar irradiance can be considered constant. The value of the solar constant and its spectrum have been defined as a standard value called air mass zero (AM0) and takes a value of 1.366 kW/m^2.

While the solar radiation incident on the Earth's atmosphere is relatively constant, the radiation at the Earth's surface varies widely due to:

- atmospheric effects, including absorption and scattering;
- local variations in the atmosphere, such as water vapor, clouds, and pollution;
- latitude of the location; and
- The season of the year and the time of day.

The above effects have several impacts on the solar radiation received at the Earth's surface. These changes include variations in the overall power received, the spectral content of the light and the angle from which light is incident on a surface. In addition, a key change is that the variability of the solar radiation at a particular location increases dramatically. The variability is due to both local effects such as clouds and seasonal variations, as well as other effects such as the length of the day at particular latitude. Desert regions tend to have lower variations due to local atmospheric phenomena such as clouds. Equatorial regions have low variability between seasons. The amount of energy reaching the surface of the Earth every hour is greater than the amount of energy used by the Earth's population over an entire year.

A term called the air mass (AM) is often used as a measure of the distance travelled by beam radiation through the atmosphere before it reaches a location on the earth's surface. It is defined as the ratio of the mass of the atmosphere through which the beam radiation passes to the mass it would pass through if the sun is directly overhead (i.e. at its zenith). The zenith angle θ_Z is the angle made by the sun's rays with the normal to horizontal surface. It can be shown approximately that for locations at sea level and zenith angles from 0 to 70°, the air mass is equal to the secant of the zenith angle. Thus air mass zero (AM0) corresponds to extra-terrestrial radiation, air mass one (AM1) corresponds to the case of the sun at its zenith, and air mass two (AM2) corresponds to the case of a zenith angle of 60°.



: Atmospherical path length D of solar radiation at zenith angle θ_z.

Extensive studies have been made on the mechanisms of absorption and scattering, and on the determination of attenuation coefficients for various substances. Nevertheless, it is in general not possible to predict, to reasonable degree of accuracy, the variation with time of the beam and diffuse radiation which might be expected at a specified location on the earth's surface. Thus the designer of solar process equipments has to resort to one of the following options

1. Make measurements over a period of time at the location in question where the solar equipment is to be installed.
2. Use measurements available for some other location where the climate is known to be reasonably similar to the location under consideration.
3. Use empirical predictive equations which link the values of solar radiation with other meteorological parameters whose values are known for the location under consideration. Examples of such parameters are the number of hours of sunshine received per day, the precipitation, the cloud cover etc.

CHECK YOUR PROGRESS

1. Write the units of Solar power and energy.
2. What is solar constant?
3. Write the dimensional formula for solar constant.

LET US SUM UP

In this unit, we have learnt about

- Solar energy
- Solar constant and its spectrum

- Solar radiation on earths atmosphere

ANSWERS TO CHECK YOUR PROGRESS

1. For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of $kJ/m^2/day$ or $kJ/m^2/hour$. Solar power is expressed in terms of W/m^2 or kW/m^2.
2. **Solar constant**, the total radiation energy received from the Sun per unit of time per unit of area on a theoretical surface perpendicular to the Sun's rays and at Earth's mean distance from the Sun.
3. Solar constant = Energy / (Unit area x Unit time)
    a. $= ML^2T^{-2} / (L^2T)$
    b. $= MT^{-3}$

UNIT END EXERCISE

1. State and explain Solar constant and derive its dimensional formula.
2. Illustrate the solar radiation inside and outside the earth's atmosphere.

SUGGESTED READINGS

1. Solar Energy-principles of thermal collection and storage- S.P.SUKHAME-tata- McGraw-Hill publishing company ltd.
2. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.
3. Solar Energy Engineering: Processes and Systems Kalogirou S.A.,, 2nd Edition, Academic Press, 2013.

WEB RESOURCES

1. Solar thermal energy - Appropedia
2. Solar Thermal Energy - YouTube

UNIT 4

SOLAR RADIATION GEOMETRY

OVERVIEW

In this unit, we will learn about solar radiation geometry, principle of liquid flat plate collector and evacuated tube collector.

OBJECTIVES

After studying this unit, we will be able to

- Understand the solar radiation geometry
- Know the solar collectors and its types

4.1 INTRODUCTION

The sun is a spherical source of about 1.39 million km diameter, at an average distance (1 astronomical unit) of 149.6 million km from earth. The direct portion of the solar radiation is collimated with an angle of approximately 0.53° (full angle), while the "diffuse" portion is incident from the hemispheric sky and from ground reflections and scatter. The "global" irradiation, the sum of the direct and diffuse components, is essentially uniform. Since there is a strong forward distribution in aerosol scattering, high aerosol loading of the atmosphere leads to considerable scattered radiation appearing to come from a small annulus around the solar disk, the solar aureole. This radiation mixed with the direct beam is called circumsolar radiation.

4.2 SOLAR RADIATION GEOMETRY

In order to find the beam energy falling on a surface having any orientation, it is necessary to convert the value of the beam flux coming from the direction of the sun to an equivalent value corresponding to the normal direction to the surface.

If 'Ө' is the angle between an incident beam of flux 'I_{bn}' and the normal to a plane surface, then the equivalent flux falling normal to the surface is given by $I_{bn}Cos\Theta$. The angle 'Ө' can be related by a general equation to 'ϕ' latitude , 'β' the slope 'γ' the surface azimuth angle, 'δ' the declination and 'ω' the hour angle.

The Latitude 'ϕ' of a location is the angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane. It varies from – 90^o to $+90^o$. By convention, the latitude is measured as positive for the northern hemisphere.

The slope 'β' is the angle made by the plane surface with the horizontal. It varies from 0 to 180^o.

The surface Azimuth Angle 'γ' is the angle made in the horizontal plane between the horizontal line due south and the projection of the normal to the surface on the horizontal plane. It varies from -180^o to $+ 180^o$.

We adopt the convention that the angle is positive, if the normal is East of South and Negative if West of South.

The Declination 'δ' is the angle made by the line joining the centers of the Sun and the Earth with the projection of this line on the equatorial plane.

$$\delta = 23.45 \sin\left(360\frac{284+n}{365}\right)$$

Where, *n* is the day of the year (or Day Number).

The hour angle 'ω' is an angular measure of time. It varies from -90^o to $+90^o$.

It is the angle through which the earth must be rotated to bring the meridian of plane directly under the sun. In order words, it is the angular displacement of sun east and west of the local meridian, due to the rotation of the earth on its axis 15^o per hour. The hour angle is zero at solar noon, negative in the morning and positive in the afternoon for northern hemisphere and vice-versa for southern hemisphere. Expression for hour angle by ω= (ST-12) 15^o.

It can be shown that

$$\cos \varphi = \sin \varphi\ (\sin \delta \cos \beta + \cos \delta \cos \gamma \cos \omega \sin \beta)$$

$$+ \cos \varphi\ (\cos \delta \cos \omega \cos\ \beta - \sin \delta \cos \gamma\ \sin \beta)$$

$$+ \cos \delta\ \sin \omega\ \sin \beta \sin_{\gamma}$$

Some special cases

(i) For Vertical Surface β= 90◦

cos θ =sin φ cos δ cos ω cos γ –cos φ sin δ cos γ +cos δ sin γ sin ω

(ii) For Horizontal surface β = 0◦ {sun Altitude Angle (α)]

sin α =cos θ_Z = sin φ sin δ +cos φ cos δ cos ω

The angle ' θ' in this case is the zenith angle θ_Z . It is also called as the solar altitude.

(iii) For Inclined surface facing due south, γ = 0◦

cos φ =sin φ (sin δ cos β + cos δ cos ω sin β)

+cos φ (cos δ cos ω cos β -sin δ sin β)

= sin δ sin (φ- β) + cos δ cos ω cos (φ- β)

(iv) For vertical surface facing due south , β =90◦ and γ = 0◦

cos θ = sin φ cos δ cos ω – cos φ sin δ

(v) For Inclined surface facing due north γ = 180◦,

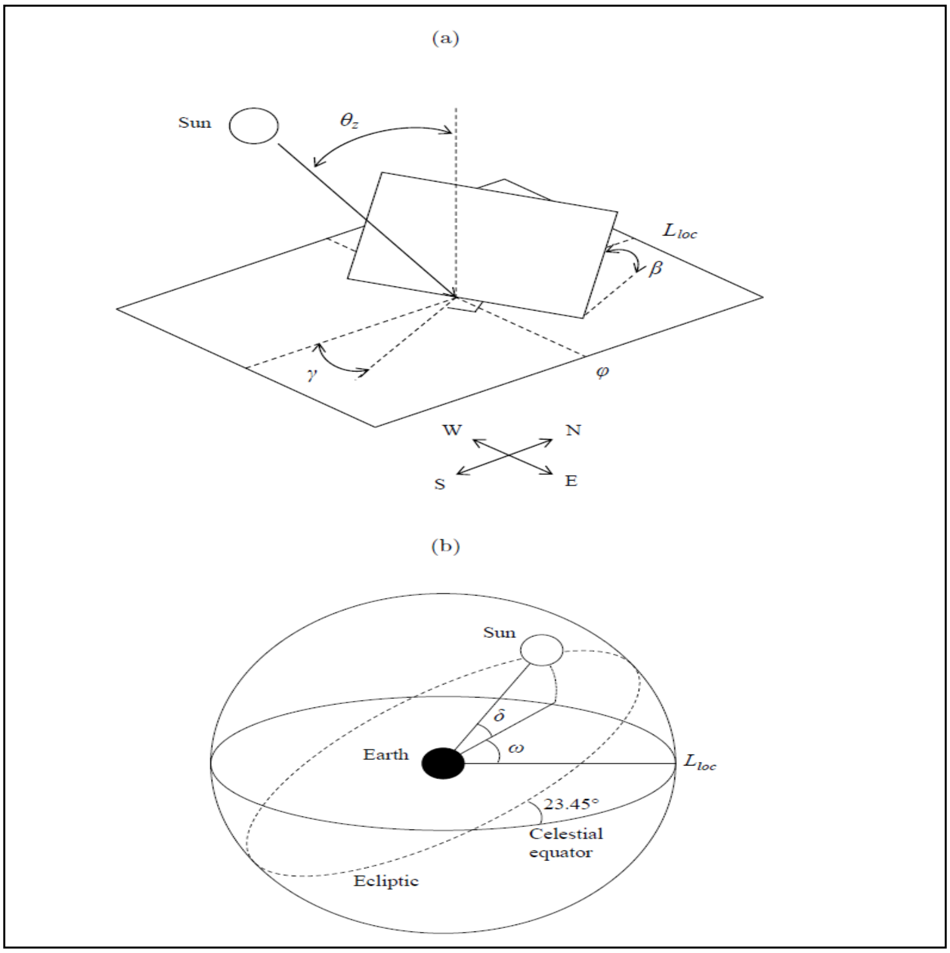
cos θ = sin δ sin (φ+β) + cos δ cos ω cos (φ+ β)

"Braun" and "Mitchell" have shown that the angle of incidence 'θ ' can also be expressed in terms of θ_Z, the zenith angle, β the slop, the surface azimuthal angle , and γs the solar azimuth angle given by,

$$\cos \theta = \cos \theta Z \ \cos \beta + \sin \theta Z \sin \beta \cos (\gamma s - \gamma)$$

The solar azimuth angle γ_s is the angle made in the horizontal plane between the horizontal line due south and the projection of the line of sight of the sun on the horizontal plane.

$$\cos \gamma s = (\cos \theta Z \ \sin \varphi - \sin \delta) / \sin \theta Z \cos \varphi$$



Solar angles used in the calculations. In (a) the angles that define the location and orientation of the tilted plane are shown. These are the plane tilt β, the azimuth angle γ and the latitude φ. Also shown are the longitude Lloc and the zenith angle θz. In (b) the angles defining the Sun's position relative to Earth and the celestial sphere are shown; the declination δ and the hour angle ω.

4.3 BASIC PRINCIPLE OF LIQUID FLAT PLATE COLLECTOR

Solar collectors are the key component of active solar-heating systems. Solar collectors gather the sun's energy, transform its radiation into heat, and then transfer that heat to water, solar fluid, or air. The solar thermal energy can be used in solar water heating systems, solar pool heaters, and solar space-heating systems. There are several types of solar collectors:

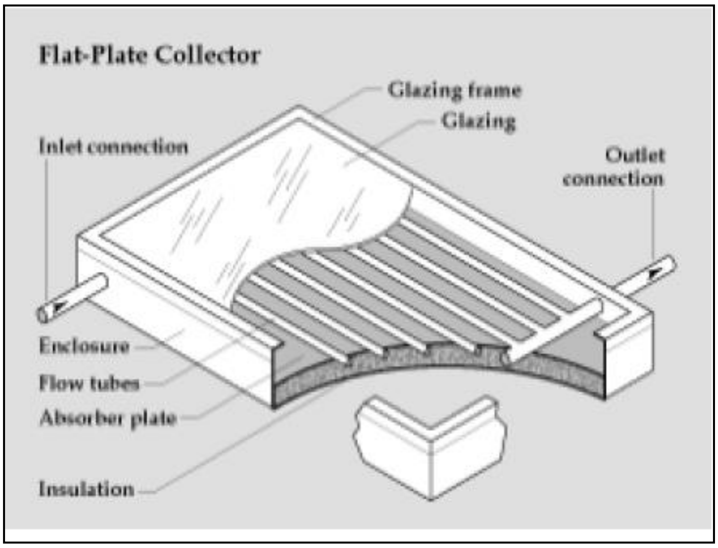
(i) Flat-plate collectors

(ii) Evacuated-tube collectors

Residential and commercial building applications that require temperatures below 200°F typically use flat-plate collectors, whereas those requiring temperatures higher than 200°F use evacuated-tube collectors.

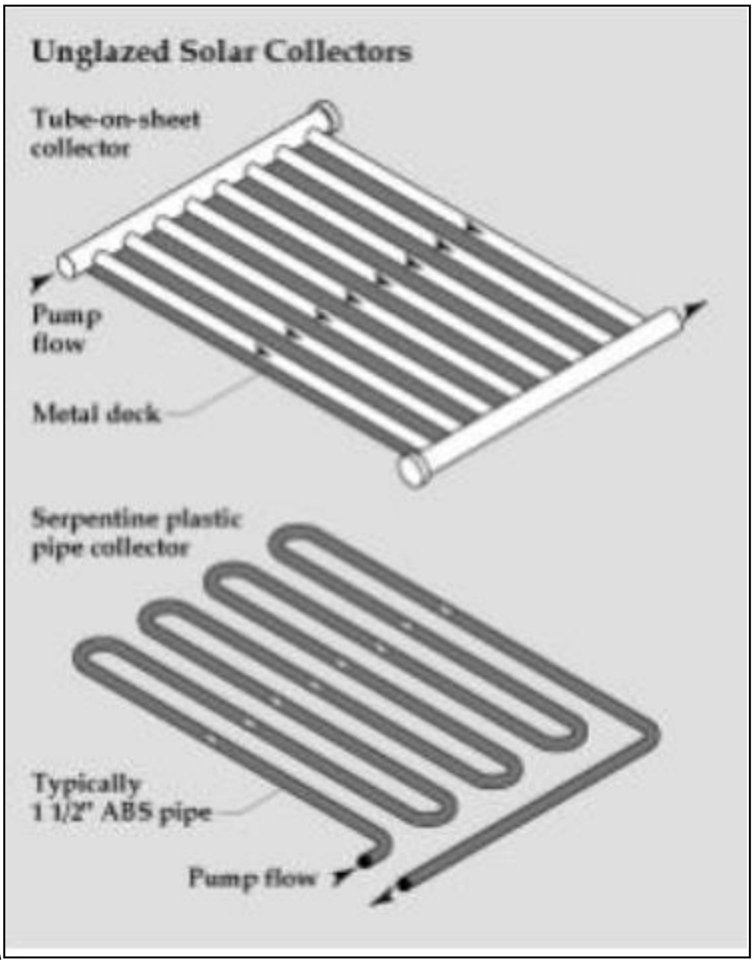
Flat-plate collectors

Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 180°F. Flat-plate collectors are used for residential water heating and hydronic space-heating installations.



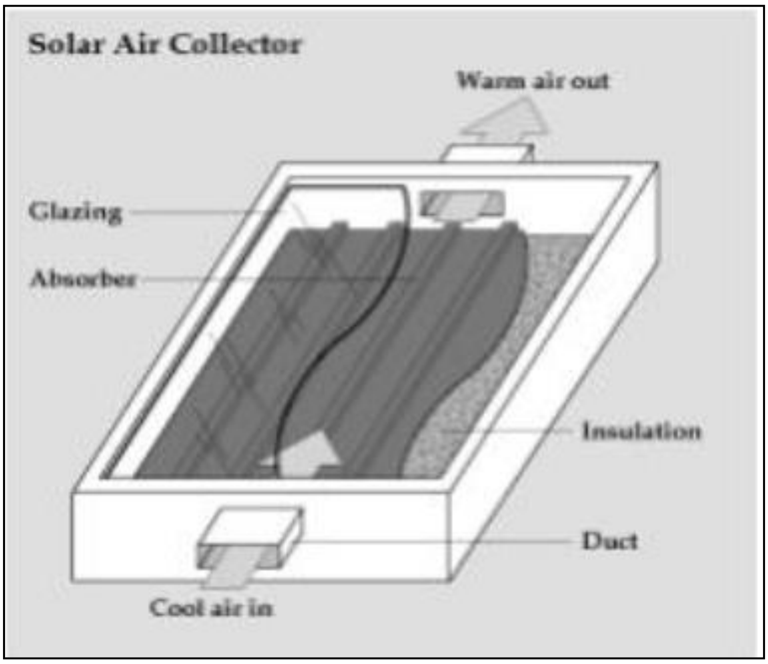
Liquid flat-plate collectors heat liquid as it flows through tubes in or adjacent to the absorber plate. The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house. Solar pool heating this home in

Nevada has integral collector storage (ICS) system to provide hot water. Also uses liquid flat-plate collector technology, but the collectors are typically unglazed as in figure below.



Unglazed solar collectors typically used for swimming pool heating.

Air flat-plate collectors are used primarily for solar space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or non-metallic materials. The air flows past the absorber by using natural convection or a fan. Because air conducts heat much less readily than liquid does, less heat is transferred from an air collector's absorber than from a liquid collector's absorber, and air collectors are typically less efficient than liquid collectors.



Air flat-plate collectors are used for space heating.

Evacuated-tube collectors

Evacuated-tube collectors can achieve extremely high temperatures (170°F to 350°F), making them more appropriate for cooling applications and commercial and industrial application. However, evacuated-tube collectors are more expensive than flat-plate collectors, with unit area costs about twice that of flat-plate collectors. Evacuated-tube collectors are efficient at high temperatures. The collectors are usually made of parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin is covered with a coating that absorbs solar energy well, but which inhibits radiative heat loss. Air is removed, or evacuated, from the space between the two glass tubes to form a vacuum, which eliminates conductive and convective heat loss. A new evacuated-tube design is available from the Chinese manufacturers, such as: Beijing Sunda Solar Energy Technology Co. Ltd. The "dewar" design features a vacuum contained between two concentric glass tubes, with the absorber selective coating on the inside tube. Water is typically allowed to thermo syphon down and back out the inner cavity to transfer the heat to the storage tank. There are no glass-to-metal seals. This type of evacuated tube has the potential to become cost-competitive with flat plates.

CHECK YOUR PROGRESS

1. Define declination angle.

2. What are the types of solar collector?
3. Brief note on air flat plate collector.

LET US SUM UP

In this unit, we have learnt about

- Solar radiation geometry
- Solar collector and its types

ANSWERS TO CHECK YOUR PROGRESS

1. The Declination 'δ' is the angle made by the line joining the centers of the Sun and the Earth with the projection of this line on the equatorial plane.

$$\delta = 23.45 \sin\left(360\frac{284+n}{365}\right)$$

Where, *n* is the day of the year (or Day Number).

The hour angle 'ω' is an angular measure of time. It varies from -90° to +90°.

2. **There are several types of solar collectors:**

Flat-plate collectors

Evacuated-tube collectors

Residential and commercial building applications that require temperatures below 200°F typically use flat-plate collectors, whereas those requiring temperatures higher than 200°F use evacuated-tube collectors.

3. **Air flat-plate collectors** are used primarily for solar space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or non-metallic materials. The air flows past the absorber by using natural convection or a fan. Because air conducts heat much less readily than liquid does, less heat is transferred from an air collector's absorber than from a liquid collector's absorber, and air collectors are typically less efficient than liquid collectors.

UNIT END EXERCISE

1. State and derive the solar radiation geometry.

2. Explain the principle of liquid flat plate collector.

SUGGESTED READINGS

1. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.
2. Solar Energy Engineering: Processes and Systems Kalogirou S.A.,, 2nd Edition, Academic Press, 2013.
3. Handbook of Renewable Energy Technology,Zobaa A.F.and Ramesh Bansal, World Scientific, 2011.

WEB RESOURCE

1. Solar thermal energy - Appropedia
2. Solar Thermal Energy - YouTube

UNIT 5

APPLICATION OF SOLAR ENERGY

OVERVIEW

In this unit, we will learn about various application of solar energy radiation including solar distillation, solar disinfection, solar water heating systems etc.

OBJECTIVES

After studying this unit, we will be able to

- Know the solar energy application
- Understand their principle and working
- Know their uses

5.1 INTRODUCTION

The main uses for which solar energy radiation has potential are: Water Heating House Heating Agricultural Crop Drying Electricity Generation using Photovoltaic Cells Thermal Electric Power Generation Water heating to moderate temperatures may be used for homes, hospitals, small industries, etc.

5.2 SOLAR DISTILLATION

Introduction

Solar distillation is a relatively simple treatment of brackish (i.e. contain dissolved salts) water supplies. Distillation is one of many processes that can be used for water purification and can use any heating source. Solar energy is a low tech option. In this process, water is evaporated; using the energy of the sun then the vapour condenses as pure water. This process removes salts and other impurities.

Solar distillation is used to produce drinking water or to produce pure water for lead acid batteries, laboratories, hospitals and in producing commercial products such as rose water. It is recommended that drinking water has 100 to 1000 mg/l of salt to maintain electrolyte levels and for taste. Some saline water may need to be added to the distilled water for acceptable drinking water.

Solar water distillation is a very old technology. An early large-scale solar still was built in 1872 to supply a mining community in Chile with drinking water. It has been used for emergency situations including navy introduction of inflatable stills for life boats.

There are a number of other approaches to desalination, such as photovoltaic powered reverse-osmosis, for which small-scale commercially available equipment is available; solar distillation has to be compared with these options to determine its appropriateness to any situation. If treatment of polluted water is required rather than desalination, slow sand filtration is a low cost option.

Energy requirements for water distillation

The energy required to evaporate water, called the latent heat of vaporisation of water, is 2260 kilojoules per kilogram (kJ/kg). This means that to produce 1 litre (i.e. 1kg as the density of water is 1kg/litre) of pure water by distilling brackish water requires a heat input of 2260kJ. This does not allow for the efficiency of the system sued which will be less than 100%, or for any recovery of latent heat that is rejected when the water vapour is condensed.

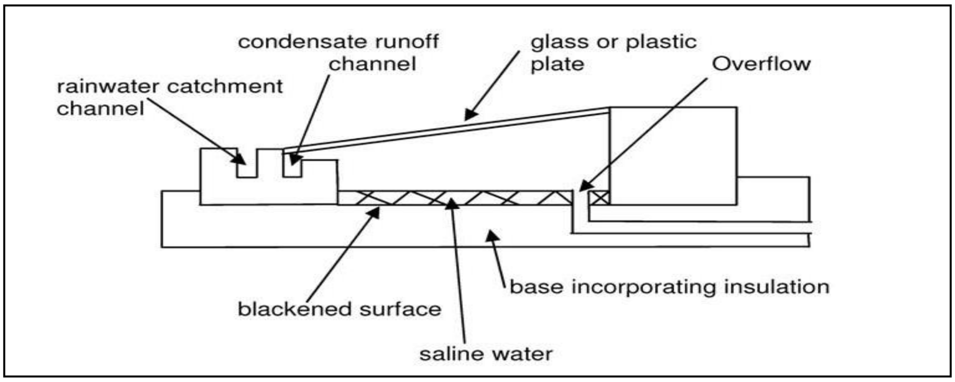
It should be noted that, although 2260kJ/kg is required to evaporate water, to pump a kg of water through 20m head requires only 0.2kJ/kg.

Distillation is therefore normally considered only where there is no local source of fresh water that can be easily pumped or lifted.

How a simple solar still works

Figure shows a single-basin still. The main features are the same for all solar stills. The solar radiation is transmitted through the glass or plastic cover and captured by a black surface at the bottom of the still. A shallow layer of water absorbs the heat which then produces vapour within the chamber of the still. This layer should be 20mm deep for best performance.

The vapour condenses on the glass cover, which is at a lower temperature because it is in contact with the ambient air, and runs down into a gutter from where it is fed to a storage tank.



Schematic of a single-basin still. Illustration: Otto Ruskulis for Practical Action.

Design objectives for an efficient solar still

- For high efficiency the solar still should maintain
- a high feed (undistilled) water temperature
- a large temperature difference between feed water and condensing surface
- low vapour leakage.

A high feed water temperature can be achieved if:

- a high proportion of incoming radiation is absorbed by the feed water as heat. Hence low absorption glazing and a good radiation absorbing surface are required
- heat losses from the floor and walls are kept low
- the water is shallow so there is not so much to heat.

A large temperature difference can be achieved if:

- the condensing surface absorbs little or none of the incoming radiation
- Condensing water dissipates heat which must be removed rapidly from the condensing surface by, for example, a second flow of water or air, or by condensing at night.

Hybrid designs - There are a number of ways in which solar stills can usefully be combined with another function of technology. Three examples are given:

- Rainwater collection. By adding an external gutter, the still cover can be used for rainwater collection to supplement the solar still output.
- Greenhouse-solar still. The roof of a greenhouse can be used as the cover of a still.
- Supplementary heating. Waste heat from an engine or the condenser of a refrigerator can be used as an additional energy input.

Output of a solar still

An approximate method of estimating the output of a solar still is given by:

Q = E x G x A

2.3

where:

Q = daily output of distilled water (litres/day)

E = overall efficiency

G = daily global solar irradiation (MJ/m^2)

A = aperture area of the still ie, the plan areas for a simple basin still (^{2})

In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m^2 (5 kWh/m^2). A simple basin still operates at an overall efficiency of about 30%. Hence the output per square metre of area is:

daily output = <u>0.30 x 18.0 x 1</u>

2.3

= 2.3 litres (per square metre)

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0 litres/m²/day is typical; the yearly output of a solar still is often therefore referred to as approximately one cubic metre per square metre, $1 m^3/m^2/year$.

Advantages	Disadvantages
Can be used with salt water	Impractical as a primary drinking water source
Simple to maintain	Very slow treatment rate
	May be difficult to acquire glass or Plexiglas

5.3 SOLAR DISINFECTION

Introduction

Solar disinfection, or SODIS as it is known, is one of the simplest and least expensive methods for providing acceptable quality drinking water. It is an ideal method for use when economic and socio cultural conditions in the community are not amenable to other treatment or disinfection alternatives, such as filtration or chlorination, even though these are also acknowledged to be simple and inexpensive. This chapter looks into several low-cost solar disinfection alternatives, particularly ones that can be used in rural communities. These can be broken down into batch and continuous disinfection processes, according to the mechanism used. It should be pointed out that solar disinfection is a more appropriate water treatment method for households or a small number of houses than for use in conventional or more complex systems. Furthermore, it is obviously possible only where convenient solar radiation exists.

Properties of solar disinfection and description of the method

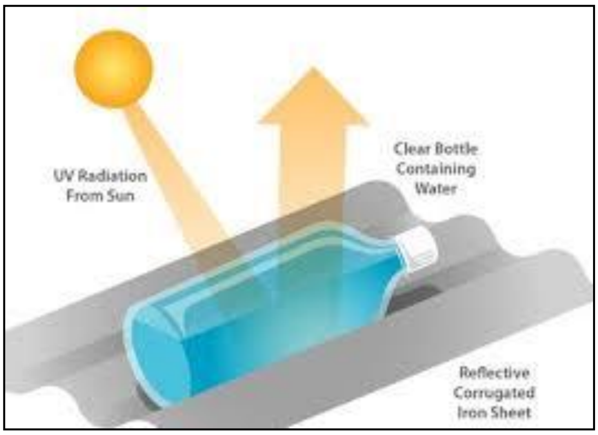
Solar disinfection is a thermal process consisting of raising water temperature for a long enough period of time in containers that have been prepared to absorb the heat generated by solar radiation. These containers are made of a heat-conducting material and should preferably be black, for this color absorbs heat better than light colors, which, because of their reflective properties hold less heat. Use of a dark color permits the water temperature to rise rapidly and to remain hot for a longer period of time. SODIS has never become very popular, although the method is interesting and its requirements are few. Too many variables affect its efficiency and the eventual safety of the treated water. Parameters that could interfere with perfect disinfection include geographic latitude and altitude, season, number of hours of exposure, time of the day, clouds, and temperature; volume and material of vessels containing the water; and water turbidity and color. The World Health Organization considers SODIS to be a valid option, but only as a "lesser and experimental method." Even so, in areas where no other means are available to disinfect water, this method can improve the bacteriological quality of water considerably. It constitutes a further example bearing out the assertion made in the first chapter that if perfection is not attainable, then a step toward "improvement" is better than nothing. It should be noted that in communities where this disinfection method has been promoted, the best results have been obtained when the measure was promoted and monitored by health officials or trained and dedicated personnel (e.g. volunteers from a community-based NGO).

Solar disinfection mechanisms

A couple of studies maintain that SODIS owes a large part of its disinfection power to photochemical action. Since ultraviolet radiation has the power to destroy microorganisms, as we will see in a later chapter, it has been claimed that the ultraviolet segment accompanying the visible portion when water is exposed to sunlight is responsible for the germicidal action. The truth is that only a very minor truly germicidal portion of the ultraviolet component, in the range of UV-C (100- 280 nm), is present in solar radiation. Assuming that the germicidal portion were large enough to offer some disinfection power, most materials, including those that are transparent in sunlight, like glass and plastic, have been scientifically proven to be completely opaque in the case of ultraviolet radiation. That is why, as the pertinent chapter explains, the ultraviolet pipes that are used for disinfection are cased in protective sleeves made of quartz, the only material that is truly transparent to this type of radiation (teflon, used in some equipment, is the only partially transparent plastic). The conclusion to be reached in this simple analysis is that if water is exposed to poor radiation and a filter that is almost opaque to that UV is inserted between the two, the disinfecting capacity of that radiation will be practically nil or, in the best of cases, negligible. Obviously, then, SODIS does not operate on the basis of photochemistry, but of a thermal process, pasteurization. High temperatures strongly affect all microorganisms; vegetative cells perish as proteins are denatured and other components undergo hydrolysis. Although some bacteria in the water are capable of forming spores, making them particularly heat-resistant, most are generally killed off at between 40 and 100ºC, while algae, protozoa and fungi perish at between 40 and 60ºC. Disinfection by boiling consists of raising the water temperature to 100 °C and keeping it at that level from one to five minutes. Most, if not all, of the microorganisms present are eliminated as a result. Pasteurization, on the other hand, is defined as exposing a substance (generally a food, including water) "for a long enough period to a temperature high enough to destroy the microorganisms that can cause illness or spoil food." Although heat tolerance is affected by factors such as water turbidity, cell concentration, physiological state and other parameters, pasteurization destroys coliforms and other non heat-tolerant bacteria; this is fortunate, because most pathogens are not heat-tolerant. In the case of water, an effort has been made to determine the optimum relationship between length of time and temperature needed to destroy pathogenic germs. As a rule of thumb, although not an exact one, either of the following ratios will ensure a reasonable level of safe disinfection of clear water (with a turbidity of less than 5 NTU):

65 °C for 30 minutes or 75 °C for 15 minutes.

From a highly practical and operational viewpoint, these conditions are ensured in sunny zones with four to five hours of exposure during the period of maximum radiation (from 11:00 to 16:00 hours).



5.4 SOLAR DRYING

A **solar dryer** is another application of solar energy, used immensely in the food and agriculture industry. Though sun is still used as the direct source for drying food items and clothes in certain parts of the world. An indirect source of solar power can also be used for the same purpose in the form of a solar dryer. The main disadvantage of drying directly under the sun is contamination – dirt, animals, insects etc. Also there is a fear of sudden change in weather conditions like wind or rain.

The basic principles employed in a solar dryer are:

- Converting light to heat: Any black on the inside of a solar dryer will improve the effectiveness of turning light into heat.
- Trapping heat: Isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it

possible to reach similar temperatures on cold and windy days as on hot days.

- Moving the heat to the food. Both the natural convection dryer and the forced convection dryer use the convection of the heated air to move the heat to the food.

Types of solar dryers

Integrated solar dryers

An integrated solar dryer is one in which solar energy collection and drying take place in a single unit. Cabinet dryers, rack dryers, tunnel dryers, greenhouse dryers, and multi-rack dryers fall under this category. Normally, these dryers are small in size and are stand-alone units.

Distributed solar dryers

A solar dryer in which solar energy collection and drying take place in separate units is known as a distributed solar dryer. This type of solar dryer has two parts: (1) a flat-plate air heater and (2) a drying chamber. Air is heated in the flat-plate heater placed on the roof of the building or on the ground. Hot air from the air heater is circulated in the drying chamber with the help of a blower. These dryers can be designed in different sizes with various configurations, depending upon the temperature of hot air, airflow rate, types of products to be dried, etc.

Mixed-mode solar dryers

A solar dryer in which solar energy collection takes place in both air heater and drying unit, and drying takes place only in the drying unit, is known as a mixed-mode solar dryer. In this dryer, solar energy is collected through flat-plate solar collectors and also by the roof of the drying chamber. In large industrial drying systems, the solar-heated air is combined with air heated by conventional energy; this adds to the reliability of the system and at the same time helps in significantly reducing conventional energy consumption.

Uses of solar dryer

- Solar dryers can be utilized for various domestic purposes. They also find numerous applications in industries such as textiles, wood, fruit and food processing, paper, pharmaceutical, and agro-industries. Solar driers have the following advantages.
- Solar dryers are more economical compared to dryers that run on conventional fuel/electricity.
- The drying process is completed in the most hygienic and eco-friendly way.
- Solar drying systems have low operation and maintenance costs.
- Solar dryers last longer. A typical dryer can last 15-20 years with minimum maintenance

Limitations

- Drying can be performed only during sunny days, unless the system is integrated with a conventional energy-based system.
- Due to limitations is solar energy collection, the solar drying process is slow in comparison with dryers that use conventional fuels.
- Normally, solar dryers can be utilized only for drying at 40-50ºC.

5.5 SOLAR COOKER (BOX TYPE)

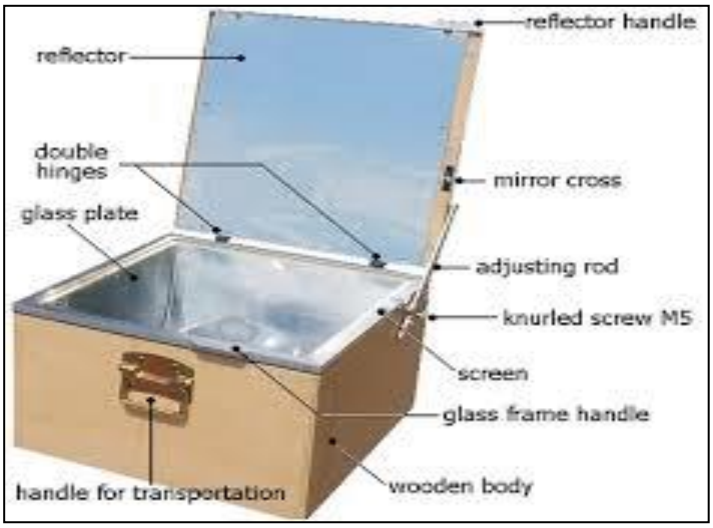
The main parts of a box type solar cooker are:

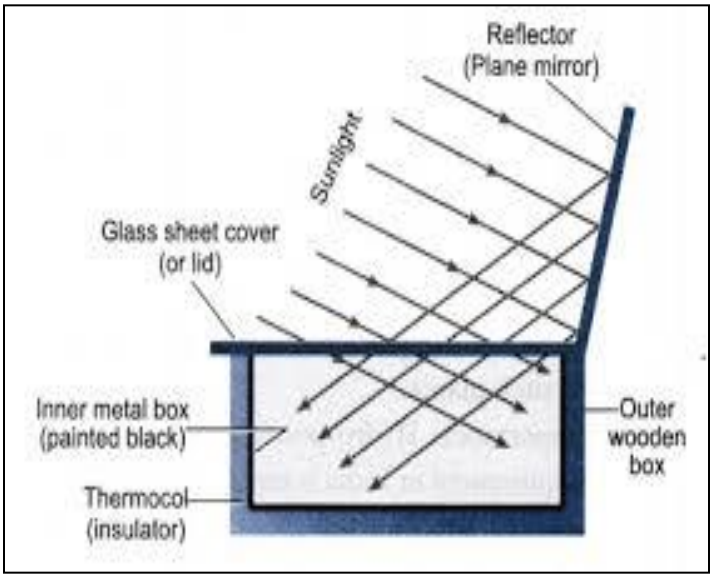
- An insulated metal box painted black from inside.
- A glass sheet.
- A plane mirror as reflector.

Principle and Working of Box Type Solar Cooker

It is well known fact that a black coloured surface absorbs more heat than a white surface. So, the inner walls and bottom of metallic box to be used for making solar cooker are painted black to increase absorption of heat. This box is covered by a thick transparent sheet of glass. When the box with glass cover is placed in the sunlight, the glass cover allows the infra red rays present in sunlight to pass into the box. Most of these infra red rays are then absorbed by black surface of the box and the box becomes hot. But, after sometime when the black surface becomes hot it starts radiating out heat in the form of infra red rays. But, the glass sheet cover placed over the box does not allow the heat radiated by the black surface to go out from the box. In this way, the glass cover enables the cooker to entrap the heat inside it.

Usually, a plane mirror reflector is also attached on the top of the box. The plane mirror reflector increases the efficiency of solar cooker by reflecting more and more sunlight inside the box.It should be noted that the temperature inside box type solar cooker can go from 100^{0}C to 140^{0}C within 2 to 3 hours when placed in sunlight. So, this type of solar cooker is used to cook only those food materials which require gentle heating.





Advantages:

1. Pollution-free.
2. They don't use fuel.
3. Solar energy is freely available.
4. Very low management cost.

Disadvantages:

1. We can use solar energy at a certain time during the day.
2. We cannot use it at night, erring the rainy season, or during foggy winters.
3. It is time-consuming as compared to the normal cookers.

5.6 SOLAR WATER HEATING SYSTEM

A solar thermal device captures and transfers the heat energy available in solar radiation which can be used for meeting the requirements of heat in different temperature ranges. Three main temperature ranges used are –

Low temperature	Hot water - 60°C to 80°C
Medium temperature	Drying - 80°C to 140°C
High temperature	Cooking & power generation -> 140°C

Configuration

Solar water heating system (SWHS) is a device which supplies hot water at 60°C to 80°C using only solar thermal energy without any other fuel.

It has three main components, namely,

1. Solar Collector
2. Insulated hot water storage tank and
3. Cold water tank with required insulated hot water pipelines and accessories.

In the case of smaller systems (100 – 2000 litres per day), the hot water reaches the user end, by natural (thermo – siphon) circulation for which the storage tank is located above the collectors. In higher capacity systems, a pump may be used for forced circulation of water.

Working Principle In a typical solar water heater, water is heated by the solar thermal energy absorbed by the collectors. The hot water with lower density moves upwards and cold water with higher density moves down from the tank due to gravity head. A bank of collectors can be arranged in a series – parallel combination to get higher quantity of hot water. A typical 100 liters insulated tank with a 2 m2 collector area, will supply water at a temperature of 60 - 80°C. Solar water heaters are typically described according to the type of collector and the circulation system.

Batch collectors also called Integrated Collector-Storage (ICS) systems, heat water in dark tanks or tubes within an insulated box, storing water until drawn. Water can remain in the collector for long periods of time if household demand is low, making it very hot. A tempering valve is your protection from scalding at the tap. The tempering valve mixes in cold water to decrease the water's temperature before it's delivered to the tap. Batch collectors are incompatible with closed-loop circulation systems. Thus, they are generally not recommended for cold climates.

Flat-plate collectors typically consist of copper tubes fitted to flat absorber plates. The most common configuration is a series of parallel tubes connected at each end by two pipes, the inlet and outlet manifolds. The flat plate assembly is contained within an insulated box, and covered with tempered glass.

Flat plate collectors are typically sized to contain 40gallons of water. Two collectors provide roughly half of the hot water needed to serve a family of four.
Evacuated tube collectors are the most efficient collectors available. Each evacuated tube is similar to a thermos in principle. A glass or metal tube containing the water or heat transfer fluid is surrounded by a larger glass tube. The space between them is a vacuum, so very little heat is lost from the fluid.

These collectors can even work well in overcast conditions and operate in temperatures as low as -40°F. Individual tubes are replaced as needed. Evacuated tube collectors can cost twice as much per square foot as flat plate collectors.

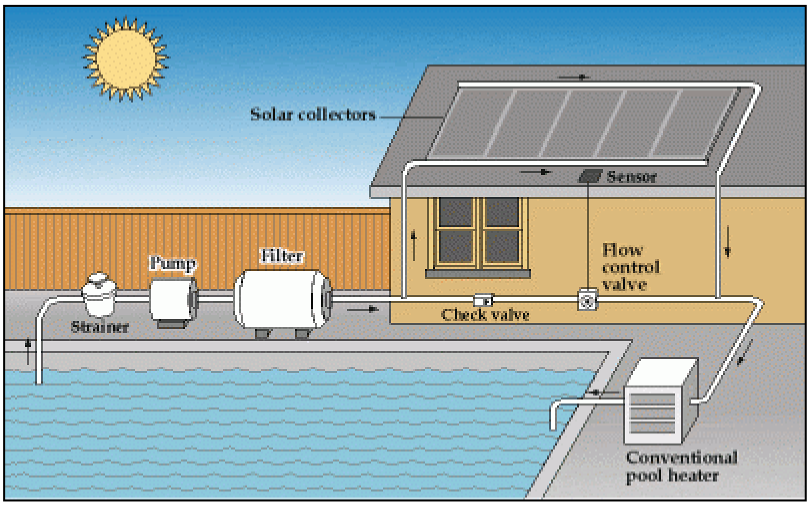
Closed-loop, or indirect, systems use a non-freezing liquid to transfer heat from the sun to water in a storage tank. The sun's thermal energy heats the fluid in the solar collectors. Then, this fluid passes through a heat exchanger in the storage tank, transferring the heat to the water. The non-freezing fluid then cycles back to the collectors. These systems make sense in freezing climates.

Circulation Systems
Direct systems circulate water through solar collectors where it is heated by the sun. The heated water is then stored in a tank, sent to a tank less water heater, or used directly. These systems are preferable in climates where it rarely freezes. Freeze protection is necessary in cold climates.
Closed-loop, or indirect, systems use a non –freezing liquid to transfer heat from the sun to water in a storage tank. The suns thermal energy heats the fluid in the solar collectors. Then, this fluid passes through a heat exchanger in the storage tank, transferring the heat to the Water. Thr non- freezing fluid then cycles back to the collectors. These systems make sense in freezing climates.
Active, or **forced-circulation**, systems use electric pumps, valves and controllers to move water from the collectors to the storage tank. These are common in the U.S.
Passive systems require no pumps. Natural convection moves water from the collectors to the storage tank as it heats up.

5.7 SWIMMING POOL

Most solar pool heating systems include the following:

- A solar collector -- the device through which pool water is circulated to be heated by the sun
- A filter -- removes debris before water is pumped through the collector
- A pump -- circulates water through the filter and collector and back to the pool
- A flow control valve -- automatic or manual device that diverts pool water through the solar collector.



Pool water is pumped through the filter and then through the solar collector(s), where it is heated before it is returned to the pool. In hot climates, the collector(s) can also be used to cool the pool during peak summer months by circulating the water through the collector(s) at night.

Some systems include sensors and an automatic or manual valve to divert water through the collector(s) when the collector temperature is sufficiently greater than the pool temperature. When the collector temperature is similar to the pool temperature, filtered water simply bypasses the collector(s) and is returned to the pool.

Solar pool collectors are made out of different materials. The type you'll need depends on your climate and how you intend to use the collector. If you'll only be using your pool when temperatures are above freezing, then you'll probably only need an unglazed collector system. Unglazed collectors don't include a glass covering (glazing). They are generally made of heavy-duty rubber or plastic treated with an ultraviolet (UV) light inhibitor to extend the life of the panels. Because of their inexpensive parts and simple design, unglazed collectors are usually less expensive than glazed collectors. These unglazed systems can even work for indoor pools in cold climates if the system is designed to drain back to the pool when not in use. Even if you have to shut the system down during cold weather, unglazed collectors may be more cost effective than installing a more expensive glazed collector system.

CHECK YOUR PROGRESS

1. Explain the principle of box type solar cooker?
2. Describe the types of solar dryers?
3. Sketch the output of the solar still in water distillation.

LET US SUM UP

In this unit, we have learnt about

- Solar distillation
- Solar disinfection
- Water heating systems
- Swimming pool

ANSWERS TO CHECK YOUR PROGRESS

It is well known fact that a black coloured surface absorbs more heat than a white surface. So, the inner walls and bottom of metallic box to be used for making solar cooker are painted black to increase absorption of heat. This box is covered by a thick transparent sheet of glass. When the box with glass cover is placed in the sunlight, the glass cover allows the infra red rays present in sunlight to pass into the box. Most of these infra red rays are then absorbed by black surface of the box and the box becomes hot. But, after sometime when the black surface becomes hot it starts radiating out heat in the form of infra red rays. But, the glass sheet cover placed over the box does not allow the heat radiated by the black surface to go out from the box. In this way, the glass cover enables the cooker to entrap the heat inside it.

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Integrated solar dryers - An integrated solar dryer is one in which solar energy collection and drying take place in a single unit. Cabinet dryers, rack dryers, tunnel dryers, greenhouse dryers, and multi-rack dryers fall under this category. Normally, these dryers are small in size and are stand-alone units.

Distributed solar dryers - A solar dryer in which solar energy collection and drying take place in separate units is known as a distributed solar dryer. This type of solar dryer has two parts: (1) a flat-plate air heater and (2) a drying chamber. Air is heated in the flat-plate heater placed on the roof of the building or on the ground. Hot air from the air heater is circulated in the drying chamber with the help of a blower. These dryers can be designed in different sizes with various configurations, depending upon the temperature of hot air, airflow rate, types of products to be dried, etc.

Mixed-mode solar dryers - A solar dryer in which solar energy collection takes place in both air heater and drying unit, and drying takes place only in the drying unit, is known as a mixed-mode solar dryer. In this dryer, solar energy is collected through flat-plate solar collectors and also by the roof of the drying chamber. In large industrial drying systems, the solar-heated air is combined with air heated by conventional energy; this adds to the reliability of the system and at the same time helps in significantly reducing conventional energy consumption.

Output of a solar still

An approximate method of estimating the output of a solar still is given by:

Q = E x G x A 2.3

where:

Q = daily output of distilled water (litres/day)

E = overall efficiency

G = daily global solar irradiation (MJ/m^2)

A = aperture area of the still ie, the plan areas for a simple basin still (^{2})

In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m^2 (5 kWh/m^2). A simple basin still operates at an overall efficiency of about 30%. Hence the output per square metre of area is:

daily output = $\frac{0.30 \times 18.0 \times 1}{2.3}$

= 2.3 litres (per square metre)

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0 $litres/m^2/day$ is typical; the yearly output of a solar still is often therefore referred to as approximately one cubic metre per square metre, $1m^3/m^2/year$.

UNIT END EXERCISE

1. Write a short note on solar disinfection.
2. Explain the concept of solar water heating system.

SUGGESTED READINGS

1. Non conventional Energy sources, Rai G. D, 4th Edition, Khanna Publishers, 2010.
2. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.
3. Solar Energy Engineering: Processes and Systems Kalogirou S.A., , 2nd Edition, Academic Press, 2013.

WEB RESOURCE

1. Solar thermal energy - Appropedia
2. Solar Thermal Energy - YouTube

BLOCK III PHOTOVOLTAIC SYSTEMS

Unit 6 Photovoltaic Principle

Unit 7 Types of Solar Cells

UNIT 6

PHOTOVOLTAIC PRINCIPLE

Structures

OVERVIEW

In this unit, we will learn about photovoltaic systems its principle, power output and conversion efficiency and its limitation.

OBJECTIVES

After studying this unit, we will be able to

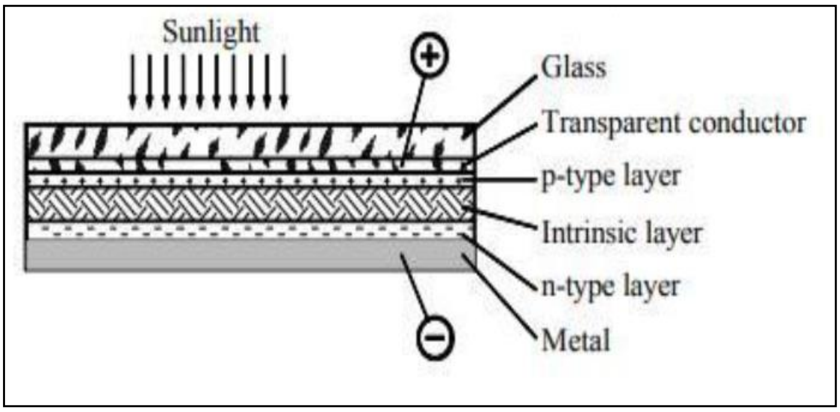
- Understand the photovoltaic systems
- Know its principle
- Understand its efficiency and limitations

6.1 INTRODUCTION

Solar power is worth considering for its sustainable, renewable and emissions reducing qualities. Modern residential solar power systems use photovoltaic (PV) to collect the sun's energy. "Photo" means produced by light and "voltaic" is electricity produced by a chemical reaction PV cells use solar energy to generate a chemical reaction that produces electricity. Each cell contains a semiconductor; most commonly silicon in one of several forms (single-crystalline, multi-crystalline, or thin-layer), with impurities (either boron or phosphorus) diffused throughout, and is covered with a silk screen. Cells are joined together by a circuit and frame into a module. Semiconductors allow the electrons freed from impurities by the sun's rays to move rapidly and into the circuit, generating electricity. Commercial residential PV modules range in power output from 10 watts to 300 watts, in a direct current. A PV module must have an inverter to change the DC electricity into alternating current energy in order to be usable by electrical devices and compatible with the electric grid. Using PV modules to generate electricity can significantly reduce pollution.

6.2 PHOTOVOLTAIC PRINCIPLE

The most useful way of harnessing solar energy is by directly converting it into DC electricity by means of solar photo-voltaic cells. Energy conversion devices which are used to convert sun light to electricity by the use of photo-voltaic effect are called solar cells. A typical photovoltaic cell consists of semiconductor material (usually silicon) having a pn junction as shown in Figure .Sunlight striking the cell raises the energy level of electrons and frees them from their atomic shells. The electric field at the pn junction drives the electrons into the n region while positive charges are driven to the p 4region. A metal grid on the surface of the cell collects the electrons while a metal back-plate collects the positive charges.



Photovoltaic is a well-established, proven technology with a substantial international industry network. And PV is increasingly more cost-effective compared with either extending the electrical grid or using generators in remote locations. The cost per peak watt of today's PV power is about $7. Local supply conditions, including shipping costs and import duties, vary and may add to the cost. PV systems are very economical in providing electricity at remote locations on farms, ranches, orchards and other agricultural operations. A "remote" location can be as little as 15 meters from an existing power source. PV systems can be much cheaper than installing power lines and step-down transformers in applications such as electric fencing, area or building lighting, and water pumping – either for livestock watering or crop irrigation.

6.3 BASIC SILICON SOLAR CELL

Solar cells can be manufactured from different semiconductor materials and their combinations. The voltage generated by a solar cell depends on the intensity of solar radiation and the cell surface area receiving the radiations. The maximum achievable power is about 100 W/m2 of solar cell surface area. The main types of solar cells are monocrystalline silicon cells, poly crystalline silicon cells, amorphous silicon cells, gallium arsenide (GaAs), and Copper indium dieseline (CID) cells.

At present, silicon solar cells occupy 60% of the world market. Basic types of silicon solar cells are: (i) Mono crystalline silicon solar cells, (ii) poly crystalline silicon solar cells, and (iii) thin film or Amorphous silicon solar cells.

Types of solar cells

Mono crystalline silicon solar cells

A silicon solar cell of size 10cm×10cm produces a voltage of 0.5V and power output of 1 W at a solar radiation intensity of 1000 W/m^2. The solar cells are formed into modulus by enclosing in an air tight casing with a transparent cover of synthetic glass. These modulus posses high efficiency between 15 and 18% and are used in medium and large size plants.

Poly crystalline silicon solar cells: The higher efficiency of solar module is 12 to 14%.

Thin-film solar cells: The crystalline solar cells are labour and energy intensive in manufacturing. The thin film cells are produced from amorphous silicon. It has the capacity to absorb more solar radiation due to irregular atom arrangement. The efficiency is 5 to 8%. These are very cheap to manufacture. Cell efficiency is defined as the ratio of electric power output of the cell, module, or array to the power content of sunlight over its total exposed area. The maximum theoretical efficiency of solar cells is around 47 percent.

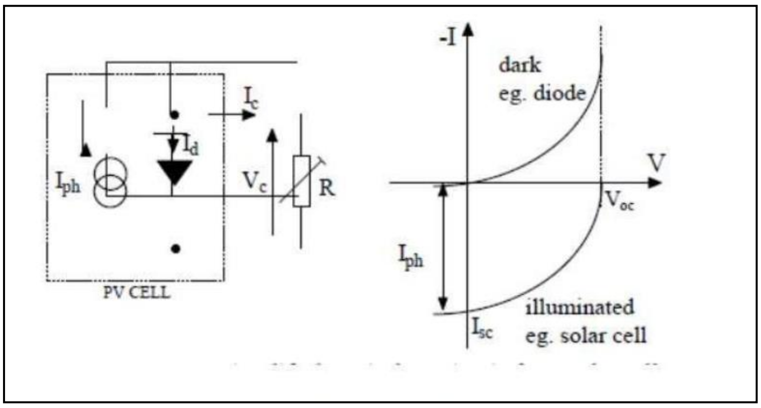
6.4 POWER OUTPUT AND CONVERSION EFFICIENCY

A simplified equivalent circuit of a solar cell consists of a current source in parallel with a diode as shown in Figure. A variable resistor is connected to the solar cell generator as a load. When the terminals are short-circuited, the output voltage and also the voltage across the diode are both zero. The entire photocurrent (Iph) generated by the solar radiation then flows to the output. The solar cell current has its maximum (Isc). If the load resistance is increased, which results in an increasing voltage across the pn junction of the diode, a portion of the current flows through the diode and the output current decreases by the same amount. When the load resistor is open circuited, the output current is zero and the entire photocurrent flows through the diode. The relationship between current and voltage may be determined from the diode characteristic equation:

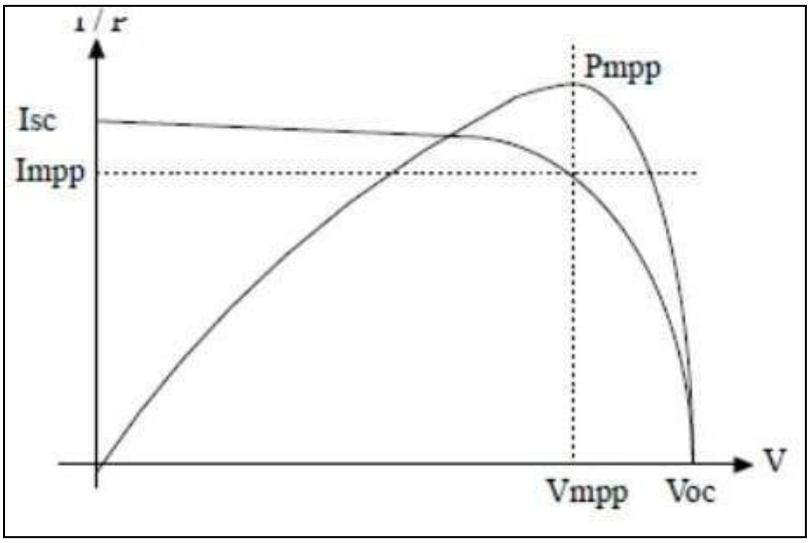
$$I = I_{ph} - I_0 \left(e^{\frac{qv}{kt}} - 1\right) = I_{ph} - I_d$$

Where q is the electron charge, k is the Boltzmann constant, Iph is photocurrent, I0 is the reverse saturation current, Id is diode current, and T is the solar cell operating temperature (K). The current versus voltage (I-V) of a solar cell is thus equivalent to an ‘‘inverted’’diode.

Characteristic curve shown



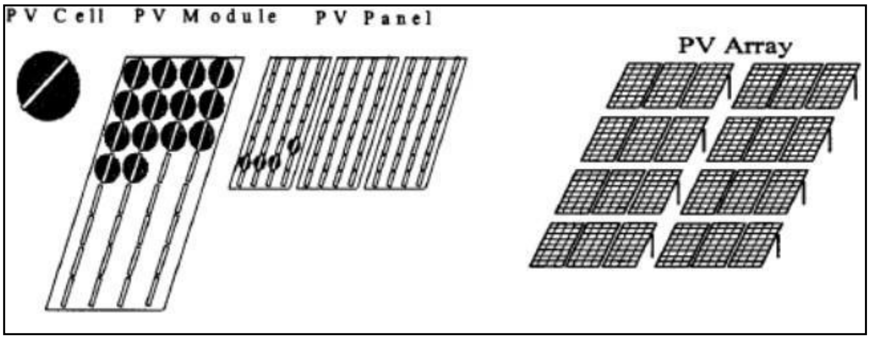
A solar cell can be operated at any point along its characteristic current–voltage curve, as shown in Figure. Two important points on this curve are the open circuit voltage (Voc) and short-circuit current (Isc). The open-circuit voltage is the maximum voltage at zero current, whereas the short circuit current is the maximum current at zero voltage. For a silicon solar cell under standard test conditions, Voc is typically 0.6–0.7 V, and Isc is typically 20–40mA for every square centimeter of the cell area. To a good approximation, Isc is proportional to the illumination level, whereas Voc is proportional to the logarithm of the illumination level.



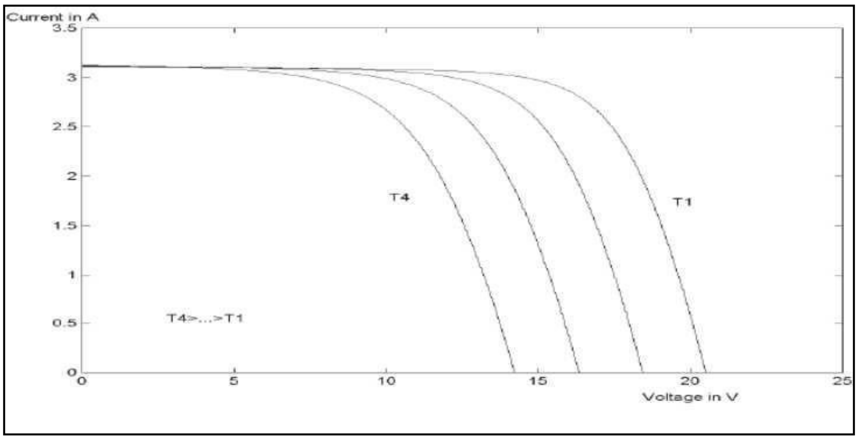
A plot of power (P) against voltage (V) for this device (Fig. 3) shows that there is a unique point on the I-V curve at which the solar cell will generate maximum power. This is known as the maximum power point (Vmp, Imp). To maximize the power output, steps are usually taken during fabrication to maximize the three basic cell parameters: open-circuit voltage, short-circuit current, and fill factor (FF)—a term describing how ‘‘square’’ the I-V curve is, given by

Fill Factor = Vmp Imp / Voc Isc

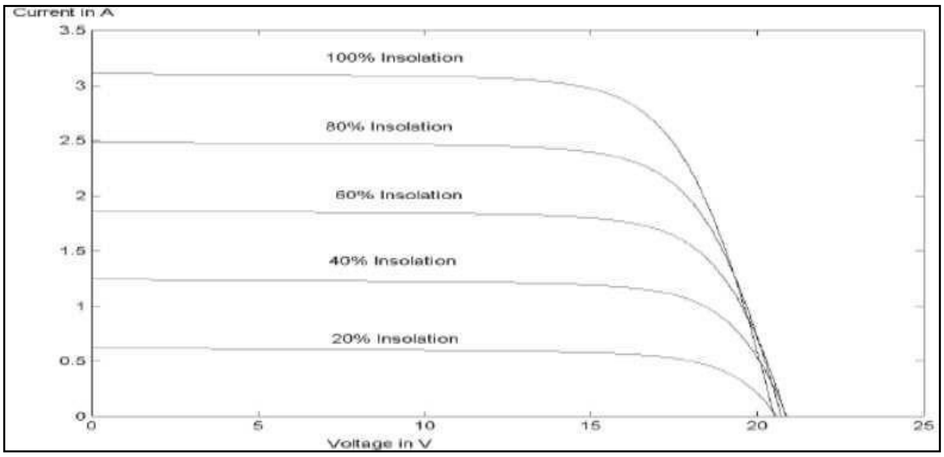
For a silicon solar cell, FF is typically 0.6–0.8.Because silicon solar cells typically produce only about 0.5 V, a number of cells are connected in series in a PV module. A panel is a collection of modules physically and electrically grouped together on a support structure. An array is a collection of panels



The effect of temperature on the performance of a silicon solar module is illustrated in Figure



Note that Isc slightly increases linearly with temperature, but Voc and the maximum power Pm decrease with temperature.



From Figures, it can be seen that the I - V characteristics of solar cells at a given insolation and temperature consist of a constant-voltage segment and a constant-current segment. The current is limited, as the cell is short-circuited. The maximum power condition occurs at the knee of the characteristic where the two segments meet.

6.5 LIMITATION TO PHOTOVOLTAIC EFFICIENCY

Manufacture of silicon crystals is labour and energy intensive.

- High cost.
- The insolation is unreliable and therefore storage batteries are needed
- Solar power plants require very large land areas.
- Electrical generation cost is very high.
- The energy spent in the manufacture of solar cells is very high.
- The initial cost of the plant is very high and still requires a long gasification period.

6.6 ADVANTAGES AND DISADVANTAGES

Advantages

- Absence of moving parts.
- Direct conversion of light to electricity at room temperature.
- Can function unattended for long time. Low maintenance cost.
- No environmental pollution.
- Very long life. Highly reliable.
- Solar energy is free and no fuel required.
- Can be started easily as no starting time is involved.
- Easy to fabricate. These have high power-to-weight ratio, therefore very useful for space application.
- Decentralized or dispersed power generation at the point of power consumption can save power transmission and distribution costs.
- These can be used with or without sun tracking

Disadvantages

- The efficiency of solar panels is low compared to other renewable sources of energy.
- Energy from the sun is intermittent and unpredictable and can only be harnessed in the presence of sunlight. Also, the power

generated gets reduced during cloudy weather.

- Long-range transmission of solar energy is inefficient and difficult to carry. The current produced is DC in nature and the conversion of DC current to AC current involves the use of additional equipment such as inverters.
- Photovoltaic panels are fragile and can be damaged relatively easily. Additional insurance costs are required to ensure a safeguard to the investments.

CHECK YOUR PROGRESS

1. What are the types of silicon solar cell?
2. State the limitation of photovoltaic efficiency?

LET US SUM UP

In this unit, we have learnt about

- Photovoltaic system
- Basic solar cell and its types
- Efficiency and its limitations

ANSWERS TO CHECK YOUR PROGRESS

1. **Types of silicon solar cells**

Mono crystalline silicon solar cells

A silicon solar cell of size 10cm×10cm produces a voltage of 0.5V and power output of 1 W at a solar radiation intensity of 1000 W/m^2. The solar cells are formed into modulus by enclosing in an air tight casing with a transparent cover of synthetic glass. These modulus posses high efficiency between 15 and 18% and are used in medium and large size plants.

Poly crystalline silicon solar cells: The higher efficiency of solar module is 12 to 14%.

Thin-film solar cells: The crystalline solar cells are labour and energy intensive in manufacturing. The thin film cells are produced from amorphous silicon. It has the capacity to absorb more solar radiation due to irregular atom arrangement. The efficiency is 5 to 8%. These are very cheap to manufacture. Cell efficiency is defined as the ratio of electric power output of the cell, module, or array to the power content of sunlight over its total exposed area. The maximum theoretical efficiency of solar cells is around 47 percent.

2. Manufacture of silicon crystals is labour and energy intensive.

High cost.

The insolation is unreliable and therefore storage batteries are needed

Solar power plants require very large land areas.

Electrical generation cost is very high.

UNIT END EXERCISE

1. Derive the power output and conversion efficiency.
2. Give some merits and demerits of photovoltaic efficiency.

SUGGESTED READINGS

1. Solar Photvoltaics Fundamentals, Technologies and Applications,Chetan Singh Solanki, 2ndEdition, PHI Learning Private Limited, 2011.
2. Non conventional Energy sources, Rai G. D, 4th Edition, Khanna Publishers, 2010.
3. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.

WEB RESOURCE

1. Lecture - 15 Solar Thermal Energy Conversion - YouTube
2. Fundamentals of Solar Photovoltaic Systems - YouTube

UNIT 7

SOLAR CELL AND ITS APPLICATION

Structures

OVERVIEW

In this unit, we will learn about solar cells and its types and application of photovoltaic cells.

OBJECTIVES

After studying this unit, we will be able to

- Understand the Solarcell and its types.
- Know the application of photovoltaic cells

7.1 INTRODUCTION

Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photodetector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. Solar cells are often bundled together to make larger units called solar modules, themselves coupled into even bigger units known as solar panels. Just like the cells in a battery, the cells in a solar panel are designed to generate electricity; but where a battery's cells make electricity from chemicals, a solar panel's cells generate power by capturing sunlight instead.

7.2 TYPES OF SOLAR CELLS

There are three types of Solar Cells with each having distinguished features. They are as follows:

1. **First-Generation Solar Cells:** About 90 percent of the world's solar cells are made from wafers of crystalline silicon (abbreviated c-Si), sliced from large ingots, which are grown in super-clean laboratories in a process that can take up to a month to complete. The ingots either take the form of single crystals (monocrystalline or mono-Si) or contain multiple crystals (polycrystalline, multi-Si or poly c-Si).

2. **Second-Generation Solar Cells:** Classic solar cells are relatively thin wafers—usually a fraction of a millimeter deep (about 200 micrometers, 200μm, or so). But they're absolute slabs compared to second-generation cells, popularly known as thin-film solar cells or thin-film photovoltaics which are about 100 times thinner again (several micrometers or millionths of a meter deep). Although most are still made from silicon (a different form known as amorphous silicon, a-Si, in which atoms are arranged randomly instead of precisely ordered in a regular crystalline structure), some are made from other materials, notably cadmium-telluride and copper indium gallium diselenide.

3. **Third-Generation Solar Cells:** The latest technologies combine the best features of first and second generation cells. Like first-generation cells, they promise relatively high efficiencies (30 percent or more). Like second-generation cells, they're more likely to be made from materials other than "simple" silicon, such as amorphous silicon, organic polymers perovskite crystals, and feature multiple junctions.

7.3 PV POWERED FAN

A **solar fan** is a mechanical fan powered by solar panels. The solar panels are either mounted on the device or are installed independently.

Solar fans mostly do not require secondary power sources other than solar power, as most of them are used for cooling purposes during day time. Some types are also used for heating purposes. It runs the fastest when it is the hottest outside providing savings on air conditioning costs.

Attic heat is caused by the sun baking down on the roof surface. A solar powered attic fan is an effective way to remove attic heat using only the power of the sun to run the fan. Two types of Attic fans

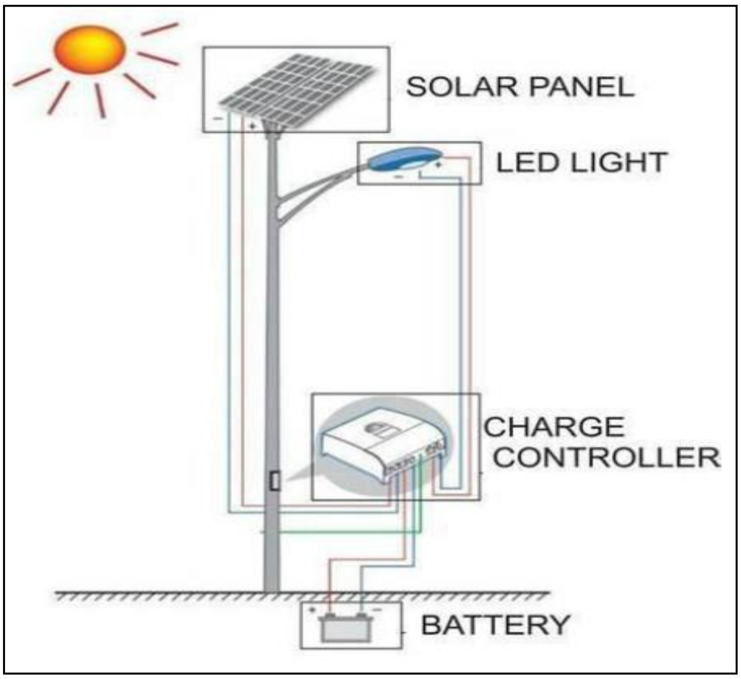
- Solar-Powered attic fan-roof mounted
- Solar-Powered attic fan- gable mounted

Advantages

- A solar fan is more environmentally friendly.
- Though initially the installation may be costlier, in the long term it would turn out to be cheaper because it does not use power from the utility grid and may provide savings up to 30 percent on air conditioning costs.
- Risk of electric accidents are eliminated as there are no electric cords attached to the solar fan.
- A cordless appliance offers much more mobility compared to conventional fans.

7.4 LIGHTING SYSTEM

Solar street lights are raised light sources which are powered by solar panels generally mounted on the lighting structure or integrated in the pole itself. The solar panels charge a rechargeable battery, which powers a fluorescent or LED lamp during the night. The system is provided with battery storage backup sufficient to operate the light for 10-11 hours daily. Solar street lights are designed for outdoor application in un-electrified remote rural areas. This system is an ideal application for campus and village street lighting.



Advantages of solar street lights

Solar street lights are independent of the utility grid. Hence, the operation costs are minimized.

- Solar street lights require much less maintenance compared to conventional street lights.
- Since external wires are eliminated, risk of accidents are minimized.
- This is a non polluting source of electricity
- Separate parts of solar system can be easily carried to the remote areas
- It allows the saving of energy and also cost.

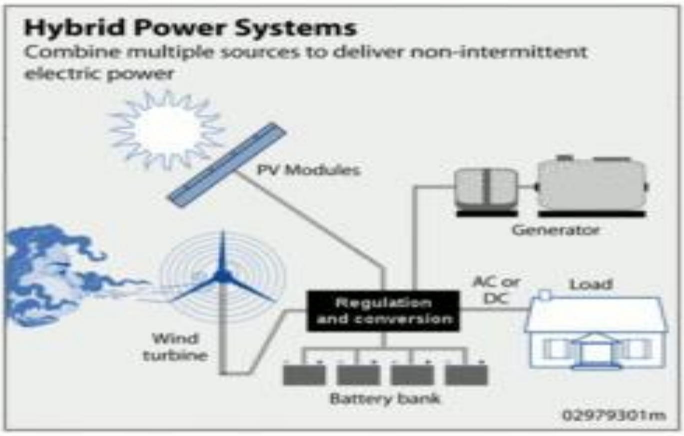
Disadvantages of solar street lights

- Initial investment is higher compared to conventional street lights.
- Risk of theft is higher as equipment costs are comparatively higher.
- Snow or dust, combined with moisture can accumulate on horizontal PV-panels and reduce or even stop energy production.
- Rechargeable batteries will need to be replaced several times over the lifetime of the fixtures adding to the total lifetime cost of the light.

7.5 A HYBRID SYSTEM

Solar hybrid systems are power systems that combine solar power from a photovoltaic system with another energy source. One of the most common hybrid systems being PV diesel hybrid system, coupling PV and diesel generators, also known as diesel gensets. The diesel generators are used to steadily fill in the gap between the load and the power generated by the PV system. Battery storages can be used to enhance the overall system performance to ensure that the amount of energy meets the demand. An energy management system can also be included to optimize the system as the diesel gensets capacity is limited and the solar energy production is inconsistent.

A common type is a **photovoltaic diesel hybrid system,** combining PV and diesel generators, or diesel gensets, as PV has hardly any marginal cost and is treated with priority on the grid. The diesel gensets are used to constantly fill in the gap between the present load and the actual generated power by the PV system.



Photovoltaic (solar) diesel hybrid system work

Depending on the consumer and their situation the main energy can be the grid power, the PV system or the diesel genset. When it is tied to the grid we would talk about on grid system and when it's isolated, this is an off-grid system. (Poor grid to link). In any case, those energy sources are used to complements one another. Whether the goal is to fill in the gap made by grid failure or to reduce fuel expenditure, the PV system can supply additional energy. Batteries can also be used to store the excess energy to be used later on. An energy management system like e Power Control can ensure fuel saving and optimal operation of the overall system.

There are multiples benefits to solar-diesel hybrid system.

- Increased PV penetration: Voltage can be driven to unacceptable volatility or out-of-range values by PV solar systems, eOS solutions can be used to support the integration of distributed PV solar on their grids.
- No wasted Energy: With the right equipment, the energy generated during the day is not wasted or fed back into the grid. It can be stored and used whenever needed.
- Uninterruptable Power: When the grid fails or when the PV production isn't enough the system still keep going.
- Hybrid Systems can be programmed: With the help of a EMS like the ePower Control, hybrid systems can computer control their whole system and balance the available sources of energy. Elum Energy's engineer can provide a custom control and monitoring solution giving more reliability and more savings as it reduce operating and maintenance cost in the long term.
- Environment-friendly: The use of sustainable resources reduces CO^2 emissions.

Components of a photovoltaic diesel hybrid system

Diesel genset - Diesel Gensets provide energy through fuel consumption. They are most of the time used in poor-grid (recurring power outage) or off-grid sites as a backup or the main energy resource. Their operating cost is high because of the constant need for fuel to power all the connected equipment but can even increase because of the fuel cost which fluctuates.

Energy System management (EMS) - The eOS system is an EMS which can be used to monitor, control, and optimize the performance of the generation or transmission system, being the bridge between the PV systems, the gensets and loads. The ePowerControl can not only ensure maximum security but also minimizes CO2 emissions, fuel and maintenance costs. The ePowerMonitor enables the user to monitor their installations and to analyze the current load and grid condition.

Photovoltaic system - A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels. PV panels are designed to absorb the sun's rays as a source of energy for generating electricity. They use the solar photovoltaic (PV) technology that converts solar radiation into direct current.

Solar inverters - A solar inverter is one of the most important elements of the solar electric power system. It converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into the alternating 240V current (AC).

Batteries - Batteries can be added to store the excess energy provided by the PV system. Thus being used when there is a lack of or no PV production.

CHECK YOUR PROGRESS

1. State first generation solar cell.
2. Give a brief note on PV powered fan.
3. What are the components of PV hybrid system?

LET US SUM UP

In this unit, we have learnt about

- Solar cells
- Types
- Application

ANSWERS TO CHECK YOUR PROGRESS

1. **First-Generation Solar Cells:** About 90 percent of the world's solar cells are made from wafers of crystalline silicon (abbreviated c-Si), sliced from large ingots, which are grown in super-clean laboratories in a process that can take up to a month to complete. The ingots either take the form of single crystals (monocrystalline or mono-Si) or contain multiple crystals (polycrystalline, multi-Si or poly c-Si).
2. A **solar fan** is a mechanical fan powered by solar panels. The solar panels are either mounted on the device or are installed independently. Solar fans mostly do not require secondary power sources other than solar power, as most of them are used for cooling purposes during day time. Some types are also used for heating purposes. It runs the fastest when it is the hottest outside providing savings on air conditioning costs. Attic heat is caused by the sun baking down on the roof surface. A solar powered attic fan is an effective way to remove attic heat using only the power of the sun to run the fan. Two types of Attic fans

- Solar-Powered attic fan-roof mounted
- Solar-Powered attic fan- gable mounted.

3. **Components of a photovoltaic diesel hybrid system**

   Diesel genset - Diesel Gensets provide energy through fuel consumption. They are most of the time used in poor-grid (recurring power outage) or off-grid sites as a backup or the main energy resource. Their operating cost is high because of the constant need for fuel to power all the connected equipment but can even increase because of the fuel cost which fluctuates.

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Batteries - Batteries can be added to store the excess energy provided by the PV system. Thus being used when there is a lack of or no PV production.

UNIT END EXERCISE

1. State and illustrate the lighting system in solar cell.
2. What is Hybrid system and explain its components.

SUGGESTED READINGS

1. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.
2. Solar Energy Engineering: Processes and Systems Kalogirou

S.A., , 2nd Edition, Academic Press, 2013.

3. Handbook of Renewable Energy Technology,Zobaa A.F.and Ramesh Bansal, World Scientific, 2011.

WEB RESOURCE

1. Fundamentals of Solar Photovoltaic Systems - YouTube
2. Solar Photovoltaic (PV) Systems, Scope, NEC 2020 - [690.1], (39min:21sec) - YouTube

BLOCK IV BIOMASS ENERGY

Unit 8: Biomass

Unit 9: Biogas Generation

Unit 10: Methods for Obtaining Energy from Biomass

UNIT 8

BIOMASS

OVERVIEW

In this unit, we will learn about biomass energy, classification and its conversion technologies.

OBJECTIVES

After studying this unit, we will be able to

- Understand the concept of Biomass energy
- Know the classification of Biomass
- Know the conversion technologies

8.1 INTRODUCTION

As a pending global energy crisis appears more and more imminent, it is important to consider many different options for new energy sources. Renewable energy sources are ideal because they are more efficient, environmentally friendly and, ultimately, better for consumers. Biomass can be converted into fuels through a number of different processes, including solid fuel combustion, digestion, pyrolysis, and fermentation and catalyzed reactions. Electricity is generated in many places through solid fuel combustion. The majority of America's electricity is fueled by coal combustion. However, many states, especially California, are encouraging companies to use biomass fuels to generate electricity. These products are usually wood matter, vegetation, waste from lumber yards, and the like. Power plants burn such fuels to heat a boiler, and the resulting steam powers turbines & generators. This process still releases a lot of carbon dioxide and other polluting gases into the environment, but helps eliminate waste efficiently.

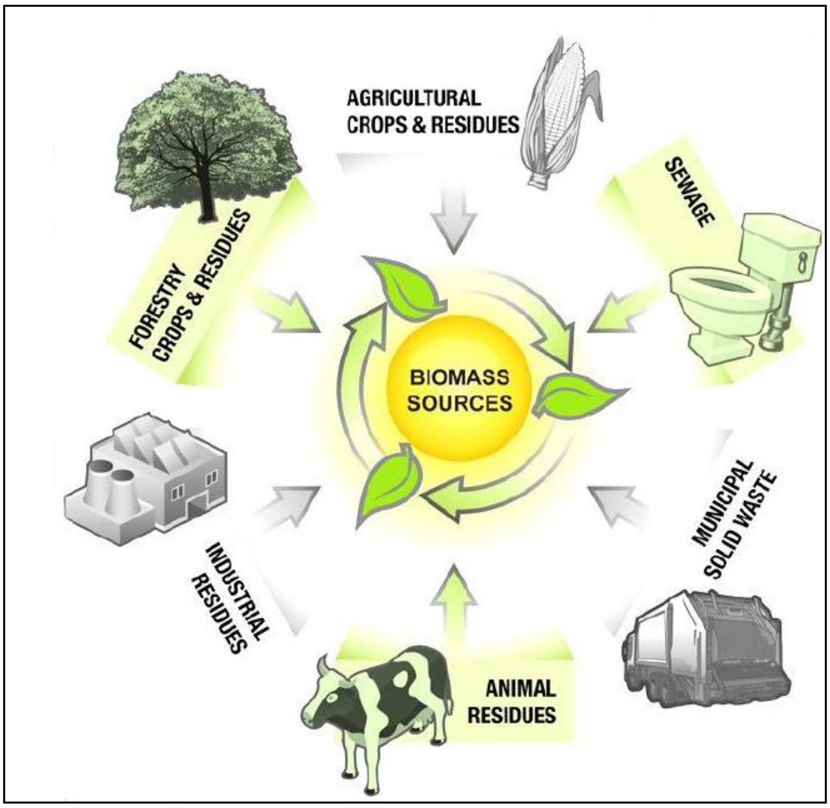
Digestion is another process that makes use of existing waste. The term is a misnomer. Digestion is the naturally occurring process of bacteria feeding on decaying matter and making it decompose. It is that which releases gases like methane, hydrogen, carbon monoxide, etc. In many landfills, owners are experimenting with set-ups to best collect the gases produced by such bacteria. The standard system includes pipelines running through the waste to collect the gases. Animal feed lots and other facilities are also exploring tapping such resources. A zoo in upstate New York is using their elephant manure to do the same thing. Benefits of this process include the relative lack of impurities in the gases produced and the fact that the synthesis gases (carbon monoxide and hydrogen) can be converted to any kind of hydrocarbon fuel.

A third process, Pyrolysis creates a product much like charcoal, with double the energy density of the original biomass, making the fuel highly transportable and more efficient. Anhydrous pyrolysis heats the biomass at intense temperatures in the absence of oxygen or water. Scientists assume that this is the process that originally produced fossil fuels (under different conditions). Most industrial processes of pyrolysis convert the biomass under pressure and at temperatures above 800° F (430° C). A liquid fuel can also be produced using this process.

The most widely used alternative fuel, ethanol, is created through fermentation of organic materials. Ethanol has a current capacity of 1.8 billion gallons per year, based on starch crops such as corn. Again, the fuel conversion process takes advantage of a natural process. Microorganisms, especially bacteria and yeasts, ferment starchy, sugary biomass products (like corn), yielding products like ethanol, which can be used as fuels in a variety of applications.

Biodiesel is an increasingly popular fuel, especially in the transportation sector. This mono alkyl ester is formed by combining fuel-grade oil, processed from sources like vegetable oil, animal fats, algae and even used cooking grease, with an alcohol (like methanol or ethanol), using a catalyst. It shows great promise as both a neat fuel (used alone) and as an additive to petroleum diesel.

Using biomass could be the answer to the energy questions made more imminent by the recent crises that have further threatened our oil supply. The current technologies take advantage of many natural, long-utilized processes in order to create "new" kinds of fuel. Upon further observation, one realizes that these fuels are very basic, using the most readily available energy sources with very simple, standardized processes that greatly reduce pollution and offer hope for the future.



8.2 BIOMASS CLASSIFICATION

Types of Biomass

Biomass comes from a variety of sources. Some of the different types of biomass example are:

Agriculture Residues

These are the Biomass sources or materials that are left in an agricultural field or orchard after the cro harvesting. The residues include stubble like leaves, stems, stalks, and seed pods. These residues are used as biomass for bioenergy production.

Animal Wastes

Animal waste is an important source of nutrients and renewable energy and is a valuable biomass feedstock. Animal waste has chemical energy stored in it just like plants and when it is burnt, it releases bioenergy in the form of heat and fuel. Animal wastes are generally the excreted materials from living animals and can also include hay, straw, organic debris and wood shavings.

Forestry Residues

It is the residue which is left over from logging operations that may include branches, tree tops, sawdust and stumps. These can be obtained in two forms including primary forestry residues and secondary forestry residues. Forest residues comprise of branches, tops and unmerchantable wood left after cleaning, final felling or thinning of forest stands. These are some of the important Biomass examples.

Wood Wastes

It is the portion of the waste stream which comprises discarded wood products, stumps, whole trees or pruned branches obtained during park or street maintenance. Therefore, a vast portion of wood waste can be collected to use as biomass and bioenergy production.

Industrial Wastes

It is defined as the waste which is generated by manufacturing or industrial processes. It includes a variety of waste including dirt, gravel, cafeteria garbage, concrete and masonry, scrap metals, oil solvents, trash, chemicals, wood, weed grass, trees, etc. A careful selection of the industrial waste to generate bioenergy is advised for prevention to bad impact on human health.

Municipal Solid Wastes and Sewage

Also known as trash or garbage, it is the everyday items that we use and throw away such as grass clippings, furniture, clothing, newspapers, appliances, paint, batteries, product packaging, kitchen waste, etc. Sewage sludge is a type of wastewater produced from a sewer or treatment plant. All of these are used as biomass feedstock for bioenergy production.

8.3 BIOMASS CONVERSION TECHNOLOGIES

Aerobic Digestion

Aerobic digestion of waste is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste. During oxidation process, pollutants are broken down into carbon dioxide (CO_2), water (H_2O), nitrates, sulphates and biomass (microorganisms). By operating the oxygen supply with aerators, the process can be significantly accelerated. Of all the biological treatment methods, aerobic digestion is the most widespread process that is used throughout the world.

Biological and chemical oxygen demand

Aerobic bacteria demand oxygen to decompose dissolved pollutants. Large amounts of pollutants require large quantities of bacteria; therefore the demand for oxygen will be high.

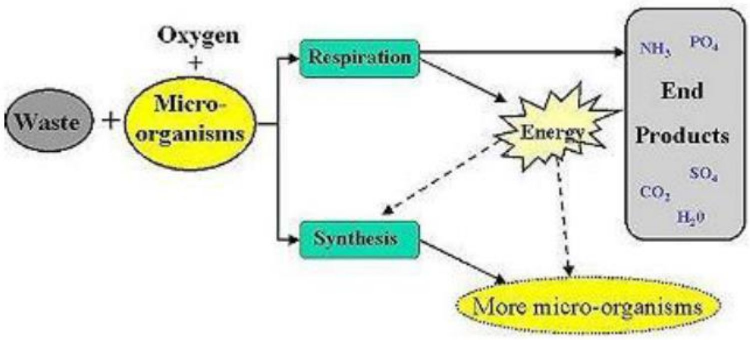
The Biological Oxygen Demand (BOD) is a measure of the quantity of dissolved organic pollutants that can be removed in biological oxidation by the bacteria. It is expressed in mg/l.

The Chemical Oxygen Demand (COD) measures the quantity of dissolved organic pollutants than can be removed in chemical oxidation, by adding strong acids. It is expressed in mg/l.

The BOD/COD gives an indication of the fraction of pollutants in the wastewater that is biodegradable.

Advantages of Aerobic Digestion

Aerobic bacteria are very efficient in breaking down waste products. The result of this is; aerobic treatment usually yields better effluent quality that that obtained in anaerobic processes. The aerobic pathway also releases a substantial amount of energy. A portion is used by the microorganisms for synthesis and growth of new microorganisms.



Path of Aerobic Digestion

Aerobic Decomposition

A biological process, in which, organisms use available organic matter to support biological activity. The process uses organic matter, nutrients, and dissolved oxygen, and produces stable solids, carbon dioxide, and more organisms. The microorganisms which can only survive in aerobic conditions are known as aerobic organisms. In sewer lines the sewage becomes anoxic if left for a few hours and becomes anaerobic if left for more than 1 1/2 days. Anoxic organisms work well with aerobic and anaerobic organisms. Facultative and anoxic are basically the same concept.

Anoxic Decomposition

A biological process in which a certain group of microorganisms use chemically combined oxygen such as that found in nitrite and nitrate. These organisms consume organic matter to support life functions. They use organic matter, combined oxygen from nitrate, and nutrients to produce nitrogen gas, carbon dioxide, stable solids and more organisms.

Anaerobic Digestion

Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require little or no oxygen to live. During this process, a gas that is mainly composed of methane and carbon dioxide, also referred to as biogas, is produced. The amount of gas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition and gas production.

Anaerobic digestion occurs in four steps:

Hydrolysis : Complex organic matter is decomposed into simple soluble organic molecules using water to split the chemical bonds between the substances.

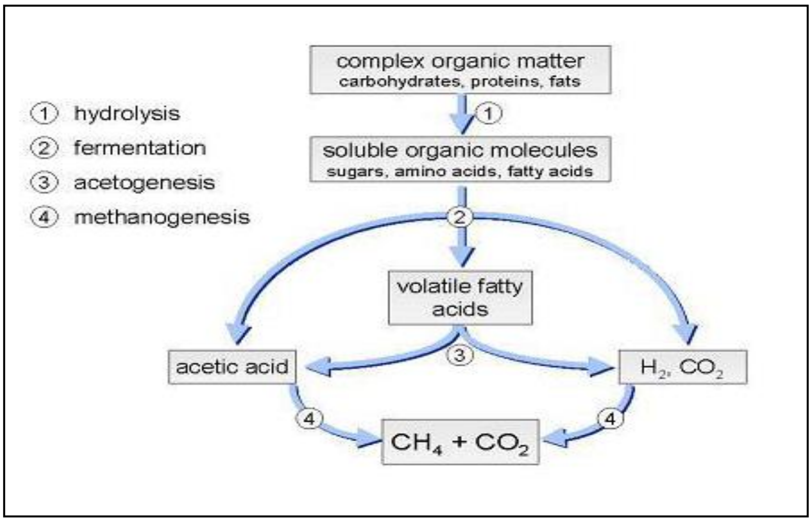
Fermentation or Acidogenesis: The chemical decomposition of carbohydrates by enzymes, bacteria, yeasts, or molds in the absence of oxygen.

Acetogenesis: The fermentation products are converted into acetate, hydrogen and carbon dioxide by what are known as acetogenic bacteria.

Methanogenesis: Is formed from acetate and hydrogen/carbon dioxide by methanogenic bacteria.

The acetogenic bacteria grow in close association with the methanogenic bacteria during the fourth stage of the process. The reason for this is that the conversion of the fermentation products by the acetogens is thermodynamically only if the hydrogen concentration is kept sufficiently low. This requires a close relationship between both classes of bacteria.

The anaerobic process only takes place under strict anaerobic conditions. It requires specific adapted bio-solids and particular process conditions, which are considerably different from those needed for aerobic treatment.



Advantages of Anaerobic Digestion

Wastewater pollutants are transformed into methane, carbon dioxide and smaller amount of bio-solids. The biomass growth is much lower compared to those in the aerobic processes. They are also much more compact than the aerobic bio-solids.

Anaerobic Decomposition

A biological process, in which, decomposition of organic matter occurs without oxygen. Two processes occur during anaerobic decomposition. First, facultative acid forming bacteria use organic matter as a food source and produce volatile (organic) acids, gases such as carbon dioxide and hydrogen sulfide, stable solids and more facultative organisms. Second, anaerobic methane formers use the volatile acids as a food source and produce methane gas, stable solids and more anaerobic methane formers. The methane gas produced by the process is usable as a fuel. The methane former works slower than the acid former, therefore the pH has to stay constant consistently, slightly basic, to optimize the creation of methane. You need to constantly feed it sodium bicarbonate to keep it basic.

CHECK YOUR PROGRESS

1. Define aerobic digestion.
2. What are the steps occurs in anerobic digestion.
3. What are industrial wastes in biomass?

LET US SUM UP

In this unit, we have learnt about

- Biomass energy
- Biomass Classification
- Biomass Conversion Technologies

ANSWERS TO CHECK YOUR PROGRESS

1. Aerobic digestion of waste is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste. During oxidation process, pollutants are broken down into carbon dioxide (CO_2), water (H_2O), nitrates, sulphates and biomass (microorganisms). By operating the oxygen supply with aerators, the process can be significantly accelerated.
2. **Hydrolysis**: Complex organic matter is decomposed into simple soluble organic molecules using water to split the chemical

bonds between the substances.

Fermentation or Acidogenesis: The chemical decomposition of carbohydrates by enzymes, bacteria, yeasts, or molds in the absence of oxygen.

Acetogenesis: The fermentation products are converted into acetate, hydrogen and carbon dioxide by what are known as acetogenic bacteria.

Methanogenesis: Is formed from acetate and hydrogen/carbon dioxide by methanogenic bacteria.

3. It is defined as the waste which is generated by manufacturing or industrial processes. It includes a variety of waste including dirt, gravel, cafeteria garbage, concrete and masonry, scrap metals, oil solvents, trash, chemicals, wood, weed grass, trees, etc. A careful selection of the industrial waste to generate bioenergy is advised for prevention to bad impact on human health.

UNIT END EXECRCISE

1. Explain the types and classification of biomass.
2. Explain the technologies of biomass conversion.

SUGGESTED READINGS

1. Renewable energy sources and emerging Technologies,Kothari D.P., K.C. Singal and Rakesh Ranjan, Prentice Hall of India, 2008.
2. Solar Energy-principles of thermal collection and storage-S.P.SUKHAME-tata- McGraw-Hill publishing company ltd.
3. Handbook of Renewable Energy Technology,Zobaa A.F.and Ramesh Bansal, World Scientific, 2011.

WEB RESOURCE

1. Biomass crops are energy efficient and climate friendly | ERC (europa.eu)
2. Biomass Energy Basics | NREL

UNIT 9

BIOGAS GENERATION

Structure

OVERVIEW

In this unit, we will learn about biogas generation, types of biogas plants which includes floating dome and fixed dome type plants.

OBJECTIVES

After studying this unit, we will be able to

- Understand what is biogas
- Understand the concept of biogas generation
- Know the classification of biogas plants

9.1 INTRODUCTION

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen and produce biogas.The biogas so obtained is a mixture of methane (CH_4): 55-65% and Carbon dioxide (CO_2) : 30-40%. The biogas contains traces of H_2, H_2S and N_2.

The calorific value of biogas ranges from 5000 to 5500 Kcal/Kg (18.8 to 26.4 MJ /m3).

Digestion is biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at temperatures (35-70ºC) and atmospheric pressure. The container in which, this process takes place is known as digester.

9.2 TYPES OF BIOGAS PLANTS

Types of biogas plants

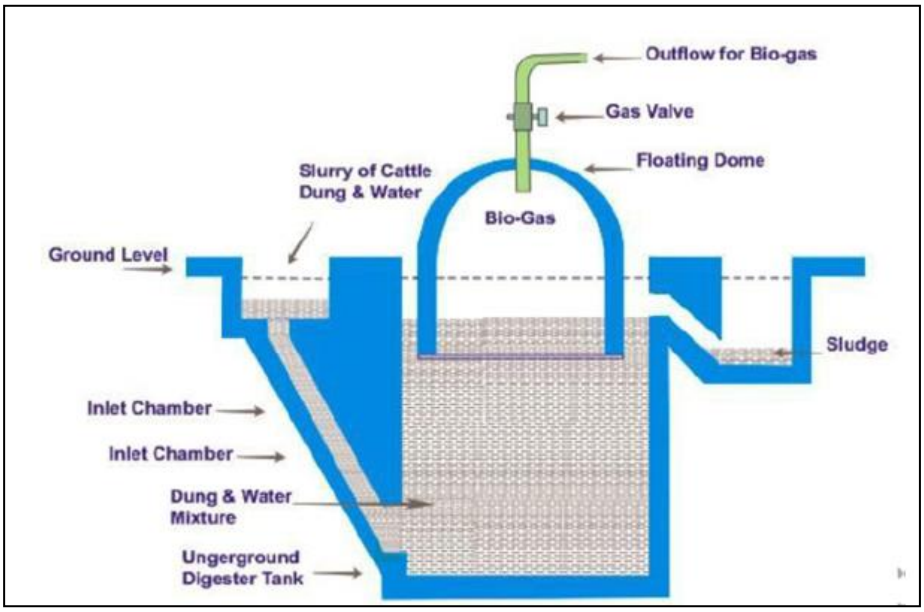
Biogas plants basically are two types

1. Floating dome type

- The floating-drum plant with a cylindrical digester (KVIC model)

Floating dome type

Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

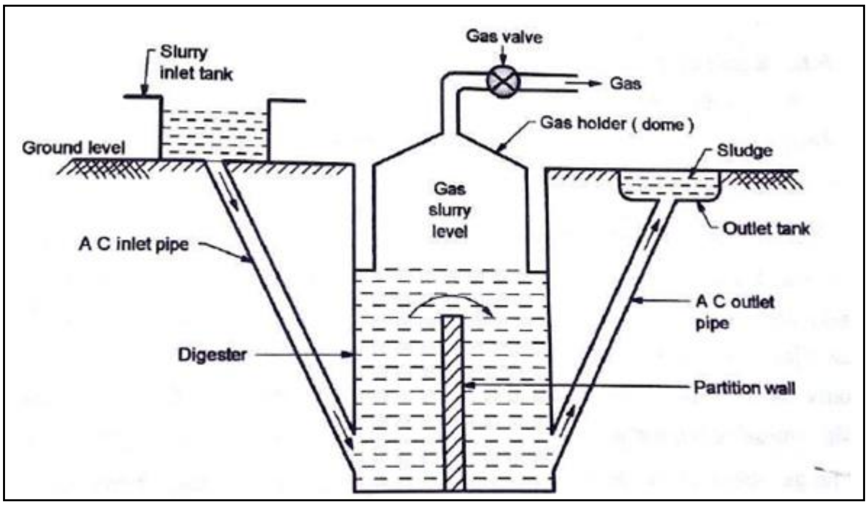


Drum:-In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogascollects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

Size:-Floating-drum plants are used chiefly for digesting animal and human feces on a continuous feed mode of operation, i.e. with daily input. They are used most frequently by small-to middle-sized farms (digester size: 5-15m^3) or in institutions and larger agro-industrial estates (digester size: 20-100m^3).

KVIC type biogas plant

This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas. Digester is 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter. There is a partition wall in the center, which divides the digester vertically and submerges in the slurry when it is full. The digester is connected to the inlet and outlet by two pipes. Through the inlet, the dung is mixed with water (4:5) and loaded into the digester. The fermented material will flow out through outlet pipe. The outlet is generally connected to a compost pit. The gas generation takes place slowly and in two stages. In the first stage, the complex, organic substances contained in the waste are acted upon by a certain kind of bacteria, called acid formers and broken up into small-chain simple acids. In the second stage, these acids are acted upon by another kind of bacteria, called methane formers and produce methane and carbon dioxide.



Gas holder:-The gas holder is a drum constructed of mild steel sheets. This is cylindrical in shape with concave. The top is supported radically with angular iron. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this purpose. When gas is generated the holder rises and floats freely on the surface of slurry. A central guide pipe is provided to prevent the holder from tilting. The holder also acts as a seal for the gas. The gas pressure varies between 7 and 9 cm of water column. Under shallow water table conditions, the adopted diameter of digester is more and depth is reduced. The cost of drum is about 40% of total cost of plant. It requires periodical maintenance. The unit cost of KVIC model with a capacity of 2 m^3/day costs approximately Rs.14, 000.

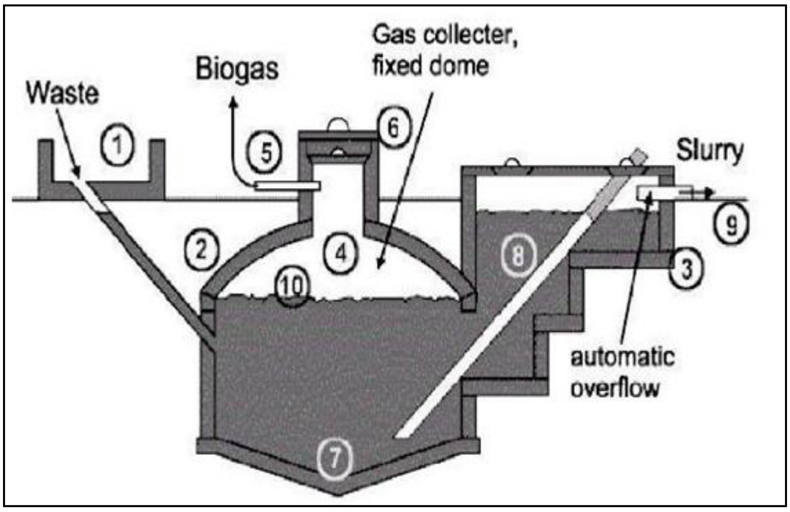
Advantages and Disadvantages of floating dome plants

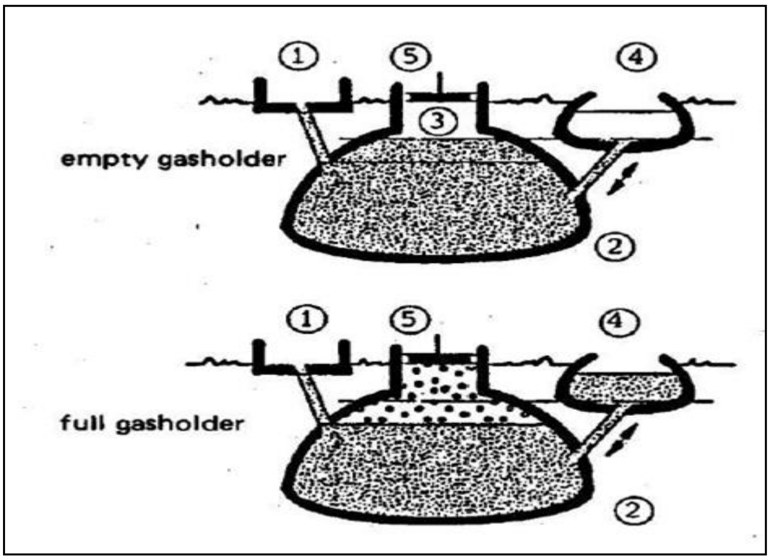
Advantages	**Disadvantages**
Simple, easily understood operation	High material costs of the steel drum
Volume of stored gas is directly visible	Susceptibility of steel parts to corrosion floating drum plants have a shorter life span than fixed-dome plants
The gas pressure is constant, determined by the weight of the gas holder.	Regular maintenance costs for the painting of the drum
The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield.	

Fixed dome type

- The fixed-dome plant with a brick reinforced, moulded dome (Janata model)
- The fixed-dome plant with a hemisphere digester (Deenbandhu model)

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.





a) **Function** - A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

Digester - The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cementexist. Main parameters for the choice of material are:

- Technical suitability (stability, gas- and liquid tightness)
- Cost-effectiveness
- Availability in the region and transport costs
- Availability of local skills for working with the particular building material.

  Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

b) Gas Holder - The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering are not gas-tight. The gas space must therefore be painted with a gas-tight layer (e.g. 'Water-proofer', Latex or synthetic paints). A possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester. This "ring" is a flexible joint between the lower (water-proof) and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas-holder.

Advantages and Disadvantages of fixed dome plants

Advantages	Disadvantages
Low initial costs and long useful life-span.	Masonry gas-holders require special sealants and high technical skills for gas-tight construction.
No moving or rusting parts involved	Masonry gas-holders require special sealants and high technical skills for gas-tight construction.

Basic design is compact, saves space and is well insulated.	Amount of gas produced is not immediately visible, plant operation not readily understandable
Construction creates local employment	Fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.
The underground construction saves space and protects the digester from temperature changes	

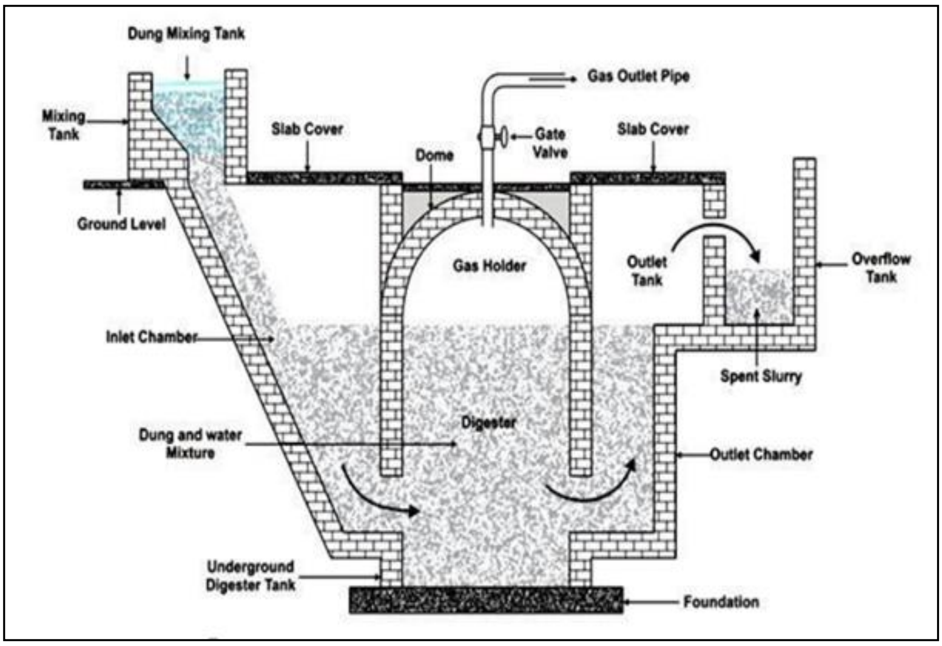
Types of Fixed Dome Plants

Janata model

The design of this plant is of Chinese origin but it has been introduced under the name “Janata biogas plant” by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part in it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas.

Substrates other than cattle dung such as municipal waste and plant residues can also be used in janata type plants.

The plant consists of an underground well sort of digester made of bricks and cement having a dome shaped roof which remains below the ground level is shown in Fig 3.5.At almost middle of the digester, there are two rectangular openings facing each other and coming up to a little above the ground level, act as an inlet and outlet of the plant. Dome shaped roof is fitted with a pipe at its top which is the gas outlet of the plant. The principle of gas production is same as that of KVIC model. The biogas is collected in the restricted space of the fixed dome, hence the pressure of gas is much higher, which is around 90 cm of water column.

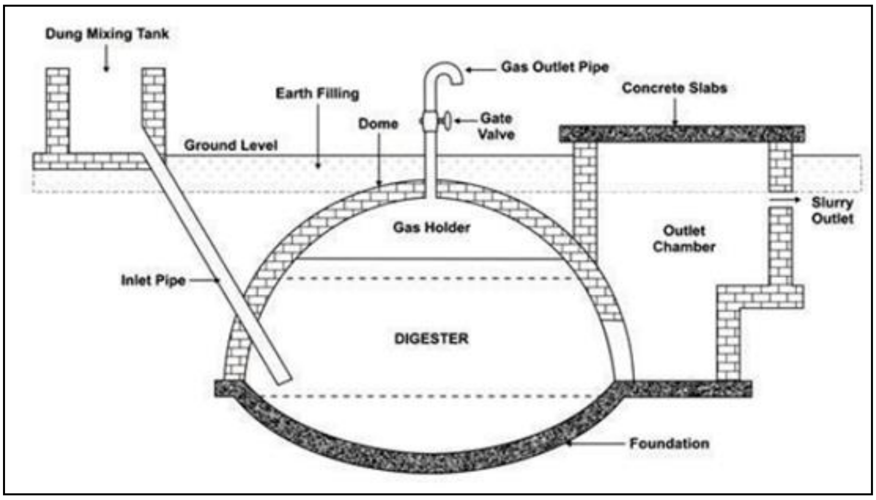


Deenbandhu Model

Deenbandhu model biogas plant was developed by AFPRO (Action for Food Production, New Delhi) in 1984. The world Deenbandhu is meant as the friend of the poor. This plant is designed on the principle that the surface area of biogas plants is reduced (minimized) to reduce their installation cost without sacrificing the efficiency of the plant. The design consists of segments of two spheres of different diameters, joined at their bases. The structure thus formed act as the digester as fermentation chamber as well as the gas storage chamber. The higher compressive strength of the brick masonry and concrete makes it preferable to go in for a structure which could always be kept under compression. A spherical structure loaded from the convex side will be under compression and therefore, the internal load will not have any residual effect on the structure.

The digester is connected with the inlet pipe and the outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced out of the digester with the generation and accumulation of biogas and is called outlet displacement chamber. The size of these plants is recommended up to 6 m^3 per day.

The different components of Deenbandhu model biogas plant are show in



CHECK YOUR PROGRESS

1. What is digestion?
2. What are the two classification of fixed dome type biogas plant

LET US SUM UP

In this unit, we have learnt about

- Biogas generation
- Floating dome type plant
- Fixed dome type plant

ANSWERS TO CHECK YOUR PROGRESS

1. Digestion is biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at temperatures (35-70ºC) and atmospheric pressure. The container in which, this process takes place is known as digester.
2. Janata model (The fixed-dome plant with a brick reinforced, moulded dome)
3. Deenbandhu model (The fixed-dome plant with a hemisphere digester)

UNIT END EXERCISE

1. Illustrate the working of fixed dome biogas plant.
2. Give some advantages and disadvantages of floating dome biogas plants.

SUGGESTED READINGS

1. Renewable energy sources and emerging Technologies,Kothari D.P., K.C. Singal and Rakesh Ranjan, Prentice Hall of India, 2008.
2. Solar Energy-principles of thermal collection and storage- S.P.SUKHAME-tata- McGraw-Hill publishing company ltd.

WEB RESOURCE

1. Biomass crops are energy efficient and climate friendly | ERC (europa.eu)
2. Biomass Energy Basics | NREL

UNIT 10

METHODS FOR OBTAINING ENERGY FROM BIOMASS

Structure

OVERVIEW

In this unit, we will learn about methods of obtaining energy from biomass, thermal conversion process of biomass, gasifiers and its types and producer gas application

OBJECTIVES

After studying this unit, we will be able to

- Know the method of energy conversion of biomass
- Understand the thermal conversion process
- know what is combustion, prylosis
- Know the concept if gasification

10.1 INTRODUCTION

Biomass can either be utilized directly as a fuel, or can be converted into liquid or gaseous fuels, which can also be as feedstock for industries. Most biomass in dry state can be burned directly to produce heat, steam or electricity. On the other hand biological conversion technologies utilize natural anaerobic decay processes to produce high quality fuels from biomass. Various possible conversion technologies for getting different products from biomass is broadly classified into three groups viz. (i) thermo-chemical conversion, (ii) bio-chemical conversion and (iii) oil extraction.

Thermo-chemical conversion includes processes like combustion, gasification and pyrolysis. Combustion refers to the conversion of biomass to heat and power by directly burning it, as occurs in boilers. Gasification is the process of converting solid biomass with a limited quantity of air into producer gas, while pyrolysis is the thermal decomposition of biomass in the absence of oxygen. The products of pyrolysis are charcoal, condensable liquid and gaseous products.

Combustion, gasification and pyrolysis are all thermochemical processes to convert biomass into energy. In all of them, the biomass is heated to evaporate water and then to cause pyrolysis to occur and to produce volatiles.

Thermal conversion processes for biomass involve some or all of the following processes:

Pyrolysis: Biomass →heat charcoal, gas and oil

Gasification: Biomass →limited oxygen fuel gas

Combustion: Biomass → Stoichiometric O_2 hot combustion products

10.2 COMBUSTION

Combustion is a process whereby the total or partial oxidation of carbon and hydrogen converts the chemical energy of biomass into heat. This complex chemical reaction can be briefly described as follows:

Burning fuel = Products from reaction + heat

During the combustion process, organic matter decomposes in phases, i.e. drying, pyrolysis/gasification, ignition of volatile substances and charcoal combustion. Generally speaking, these phases correspond to two reaction times: release of volatile substances and respective combustion, followed by charcoal combustion.

Wood, agricultural residues, wood pulping liquor, municipal solid waste (MSW) and refuse derived fuel are examples of feed stocks for combustion. Combustion requires high temperatures for ignition, sufficient turbulence to mix all of the components with the oxidant, and time to complete all of the oxidation reactions. The moisture content of the feedstock should be low and pre-drying may be necessary in some cases.

Biomass combustion starts by heating and drying the feedstock. After all of the moisture has been removed, temperature rises for pyrolysis to occur in the absence of oxygen. The major products are hydrogen, CO, CO_2, CH_4 and other hydrocarbons. In the end, char and volatile gases are formed and they continue to react independently. The volatile gases need oxygen in order to achieve complete flame combustion. Mostly CO2 and H2O result from complete combustion. When combusting biomass in a furnace, hot gases are released. They contain about 85% of the fuel's potential energy. The heat can be used either directly or indirectly through a heat exchanger, in the form of hot air or water. Boiler used for biomass combusting transfers the produced heat into steam. The steam can be used for producing electricity, mechanical energy or heat.

10.3 GASIFICATION

Gasification is a process whereby organic matter decomposes through thermal reactions, in the presence of stoichiometric amounts of oxidising agents. The process generates a combustible gas mix, essentially composed of carbon monoxide, hydrogen, carbon dioxide, methane, steam and, though in smaller proportions, other heavier hydrocarbons and tars. The process is aimed at converting the energy potential of a solid fuel into a gas product, whose energy content has the form of chemical energy with the capacity to generate work.

Gasification is carried out in two steps. First, the biomass is heated to around 600 degrees. The volatile components, such as hydrocarbon gases, hydrogen, CO, CO2, H2O and tar, vaporize by various reactions. The remaining by-products are char and ash. For this first endothermic step, oxygen is not required. In the second step, char is gasified by reactions with oxygen, steam and hydrogen in high temperatures. The endothermic reactions require heat, which is applied by combusting some of the unburned char. Main products of gasification are synthesis gas, char and tars. The content depends on the feedstock, oxidizing agent and the conditions of the process. The gas mainly consists of CO, CO_4, H_2O, CH_4 and other hydrocarbons. The synthesis gas can be utilized for heating or electricity production. It can also be used for the production of ethanol, diesel and chemical feed stocks.

10.4 PYROLYSIS

In pyrolysis, biomass is heated in the absence of air. The process results liquid, solid and gaseous fractions, mainly gases, bio-oil and char. The gases and the bio-oil are from the volatile fraction of biomass, while the char is mostly the fixed carbon component. In the first step, temperature is increased to start the primary pyrolysis reactions. As a result, volatiles are released and char is formed. Finally, after various reactions, pyrolysis gas is formed. The main product of slow pyrolysis, thousands of years old process, is char or charcoal. In slow pyrolysis biomass is heated to around 500 degrees for 5 to 30min.Fast pyrolysis results mainly in bio-oil. The biomass is heated in the absence of oxygen and the residence time is 0, 5 to 5s. Vapours, aerosols and char are generated through decomposition. After cooling, bio-oil is formed. The remaining non condensable gases can be used as a source of energy for the pyrolysis reactor. Calculated by weight, fast pyrolysis results in 60%-75% liquid bio-oil, 15%-25% solid char, and 10%-20% non-condensable gases.

10.5 GASIFIERS

Gasification of wood and other agricultural cellulosic residues was a common practice at the beginning of this century to produce low calorie fuel gas. Gasifiers can be suitably used for thermal decomposition of a wide range of feed materials from forestry products, agricultural residues, and aquatic biomass to municipal solid wastes.

However, some important points which should be taken into consideration while undertaking any biomass gasification system:

- A gasifier itself is of little use. It is used either to generate a combustible gas to provide heat or to generate a fuel gas which can be used in an internal combustion engine as a petroleum oil substitute.
- Some of the gaseous, liquid and solid products of combustion are not only harmful to engines and burners, but also to human beings. That is why these gases are not used as cooking gas.

- A gasifier must have an effective gas cleaning train if the gas is to be used for internal combustion engines. A maximum limit of 5-15 mg solids and tar per kg of gas may be allowed for the use of the gas in an internal combustion engine.
- A gasification system may not be of much advantage to generate a combustible gas, as far as fossil fuel savings, economies and ease of operation are concerned.

10.6 TYPES OF GASIFIERS

Gasifiers are generally classified on the basis of the physical conditions of the feed stocks in the reactors. The gasifiers may be grouped into the following types:

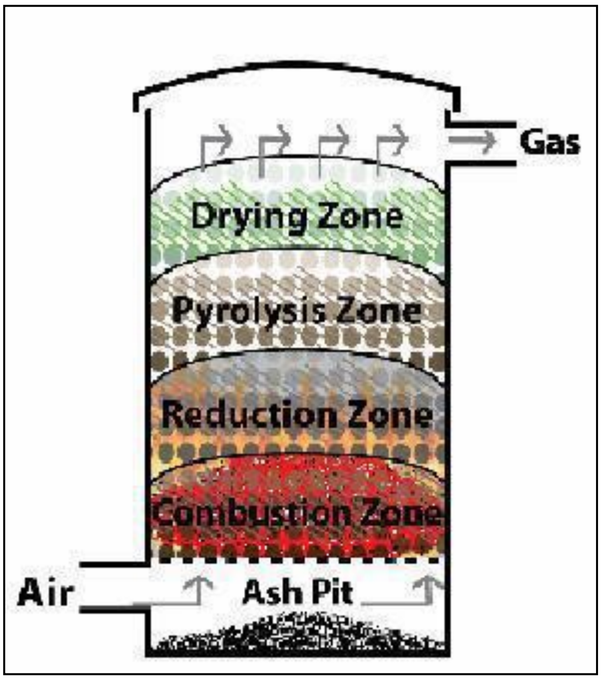
a) Dense phase reactors
b) Lean phase reactors

a) Dense phase reactors

In dense phase reactors, the feedstock fills most of the space in the reactor. They are common, available in different designs depending upon the operating conditions, and are of three types: downdraft, updraft, and cross-draft.

(i) Downdraft or co-current gasifiers

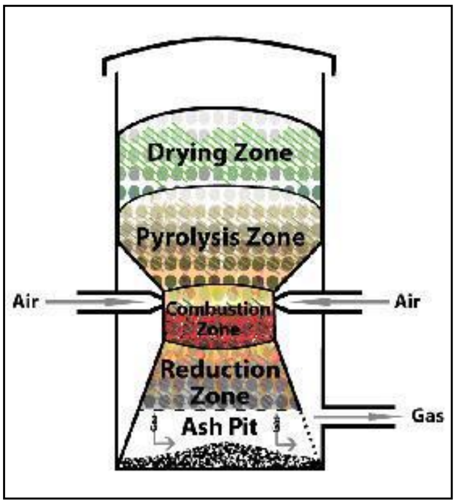
The downdraft (also known as co-current) gasifier is the most common type of gasifier. In downdraft gasifiers, the pyrolysis zone is above the combustion zone and the reduction zone is below the combustion zone. Fuel is fed from the top. The flow of air and gas is downwards (hence the name) through the combustion and reduction zones. The term co-current is used because air moves in the same direction as that of fuel, downwards. A downdraft gasifier is so designed that tar, which is produced in the pyrolysis zone, travels through the combustion zone, where it is broken down or burnt. As a result, the mixture of gases in the exit stream is relatively clean. The position of the combustion zone is thus a critical element in the downdraft gasifier, its main advantage being that it produces gas with low tar content, which is suitable for gas engines.



Downdraft gasifier

(ii) Updraft or counter-current gasifier

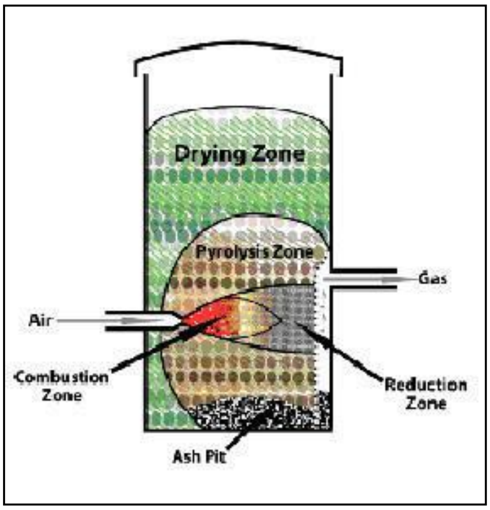
In updraft gasifiers (also known as counter-current), air enters from below the grate and flows upwards, whereas the fuel flows downwards. An updraft gasifier has distinctly defined zones for partial combustion, reduction, pyrolysis, and drying. The gas produced in the reduction zone leaves the gasifier reactor together with the products of pyrolysis from the pyrolysis zone and steam from the drying zone. The resulting combustible producer gas is rich in hydrocarbons (tars) and, therefore, has a higher calorific value, which makes updraft gasifiers more suitable where heat is needed, for example in industrial furnaces. The producer gas needs to be thoroughly cleaned if it is to be used for generating electricity.



Up-draft gasifier

(iii) Cross-draft gasifier

In a cross-draft gasifier, air enters from one side of the gasifier reactor and leaves from the other. Cross-draft gasifiers have a few distinct advantages such as compact construction and low cleaning requirements. Also, cross-draft gasifiers do not need a grate; the ash falls to the bottom and does not come in the way of normal operation.



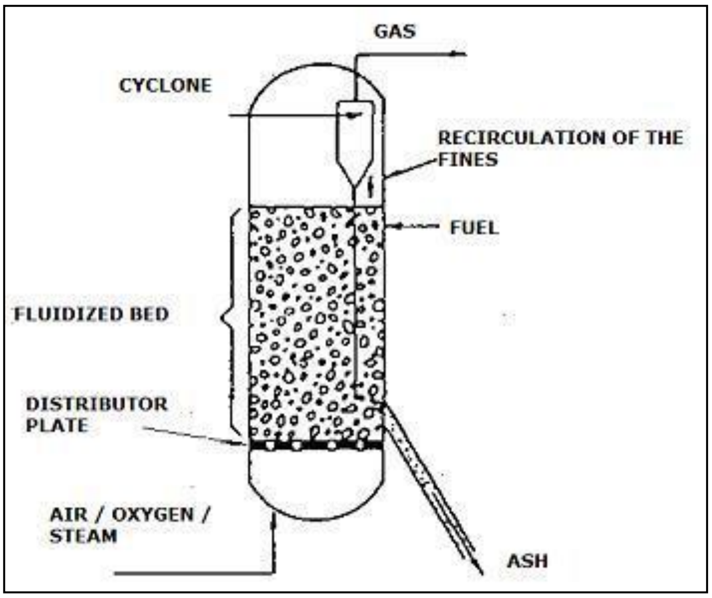
Cross-draft gasifier

b) Lean phase reactors

Lean phase gasifiers lack separate zones for different reactions. All reactions – drying,combustion, pyrolysis, and reduction – occur in one large reactor chamber. Lean phase reactors are mostly of two types, fluidized bed gasifiers and entrained-flow gasifiers.

(i) Fluidized bed gasifiers

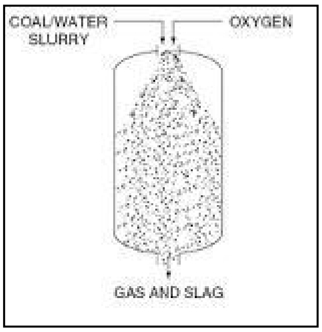
In fluidized bed gasifiers, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). The fuel is fed into the fluidized system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities. During normal operation, the bed media is maintained at a temperature between 550 °C and 1000 °C. When the fuel is introduced under such temperature conditions, its drying and pyrolyzing reactions proceed rapidly, driving off all gaseous portions of the fuel at relatively low temperatures. The remaining char is oxidized within the bed to provide the heat source for the drying and devolatilizing reactions to continue. Fluidized bed gasifiers are better than dense phase reactors in that they produce more heat in short time due to the abrasion phenomenon between inert bed material and biomass, giving a uniformly high (800–1000 ºC) bed temperature. A fluidized bed gasifier works as a hot bed of sand particles agitated constantly by air. Air is distributed through nozzles located at the bottom of the bed.



Fluidized bed gasifiers

(ii) Entrained-flow gasifiers

In entrained-flow gasifiers, fuel and air are introduced from the top of the reactor, and fuel is carried by the air in the reactor. The operating temperatures are 1200–1600 °C and the pressure is 20–80 bar. Entrained-flow gasifiers can be used for any type of fuel so long as it is dry (low moisture) and has low ash content. Due to the short residence time (0.5–4.0 seconds), high temperatures are required for such gasifiers. The advantage of entrained-flow gasifiers is that the gas contains very little tar.



Entrained-flow gasifiers

Advantages and disadvantages of different gasifier types

Some of the advantages and disadvantages of different types of gasifiers are shown in Table

Gasifier	Advantages	Disadvantages
Updraft	Simple design	Simple design
	High amount of tar and pyrolysis	High amount of tar and pyrolysis
	High fuel to gas conversion efficiency	
	Accepts fuels with higher moisture content	
	Accepts fuels of different sizes	
Downdraft	Low tar Limited scale-up	Low tar Limited scale up
	Best option for usage in gas engines	At low temperatures, more tar produced
		High amounts of ash and dust
		Fuel requirements are strict

Cross-draft	Applicable for small-scale operations	High amount of tar produced
	Due to high temperatures, gas cleaning requirements are low	
Fluidized bed	Uniform temperature profile	Gas stream contains fine particles of dust
	Accepts fuel size variation	Complex system due to low Biomass hold up in the fuel bed
	High ash melting point of biomass does not lead to clinker formation	Variety of biomass can be used but fuel flexibility is applicable for biomass of 0.1 cm to 1 cm size
Entrained-flow	Applicable to large systems	High investment
	Short residence time for biomass	Strict fuel requirements

10.7 PRODUCER GAS APPLICATION

The producer gas obtained can be used either to produce heat or to generate electricity.

Thermal applications

Producer gas can also be burnt directly in open air, much like Liquid Petroleum Gas (LPG), and therefore can be used for cooking, boiling water, producing steam, and drying food and other materials.

- **Dryer:** The hot gas after combustion can be mixed with the right quantity of secondary air to lower its temperature to the desired level for use in dryers in the industries such as tea drying, cardamom drying etc.

- **Kilns**: Firing of tiles, pottery articles, limestone and refractories, where temperatures of 800–950 °C are required.
- **Boilers**: Producer gas can be used as fuel in boilers to produce steam or hot water.

Power applications

Producer gas can be used for generating motive power to run either dual-fuel engines (which run on a mixture of gas and diesel, with gas replacement of up to 85% of diesel) or engines that run on producer gas alone (100% diesel replacement). In general, the fuel-to electricity efficiency of gasification is much higher than that of direct combustion: The conversion efficiency of gasification is 35%–45% whereas that of combustion is only 10%– 20%. Generated electricity can be fed into the grid or can be used for farm operations, irrigation, chilling or cold storage, and other commercial and industrial applications.

CHECK YOUR PROGRESS

1. Define Combustion
2. Define Gasification
3. State Thermal application of producer gas

LET US SUM UP

In this unit, we have learnt about

- Combustion
- Gasification
- Pyrolysis
- Types of gasifiers

ANSWERS TO CHECK YOUR PROGRESS

1. Combustion is a process whereby the total or partial oxidation of carbon and hydrogen converts the chemical energy of biomass into heat. This complex chemical reaction can be briefly described as follows:

   Burning fuel = Products from reaction + heat

2. Gasification is a process whereby organic matter decomposes

through thermal reactions, in the presence of stoichiometric amounts of oxidising agents. The process generates a combustible gas mix, essentially composed of carbon monoxide, hydrogen, carbon dioxide, methane, steam and, though in smaller proportions, other heavier hydrocarbons and tars.

3. Thermal applications

Producer gas can also be burnt directly in open air, much like Liquid Petroleum Gas (LPG), and therefore can be used for cooking, boiling water, producing steam, and drying food and other materials.

Dryer: The hot gas after combustion can be mixed with the right quantity of secondary air to lower its temperature to the desired level for use in dryers in the industries such as tea drying, cardamom drying etc.

Kilns: Firing of tiles, pottery articles, limestone and refractories, where temperatures of 800–950 °C are required.

Boilers: Producer gas can be used as fuel in boilers to produce steam or hot water.

UNIT END EXERCISE

1. Write a short note on Gasifiers and illustrate its types.
2. State and Explain the process of combustion.

SUGGESTED READINGS

1. Solar Energy-principles of thermal collection and storage-S.P.SUKHAME-tata- McGraw-Hill publishing company ltd.
2. Solar Photvoltaics Fundamentals, Technologies and Applications,Chetan Singh Solanki, 2ndEdition, PHI Learning Private Limited, 2011.

WEB RESOURCE

1. Biomass crops are energy efficient and climate friendly | ERC (europa.eu)
2. Biomass Energy Basics | NREL

BLOCK V WIND ENERGY AND OTHER ENERGY

Unit 11 Wind Energy

Unit 12 Other Energies

UNIT -11

WIND ENERGY

Structure

OVERVIEW

In this unit, we will learn about the wind energy, factors affecting the wind, suitable places for wind, classification and application.

OBJECTIVES

After studying this unit, we will be able to

- Understand the concept of wind energy
- know its working and principle
- Know its classification
- Know its application

11.1 INTRODUCTION

Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates. Energy derived from wind velocity is wind energy. It is a non-conventional type of energy, which is renewable with suitable devices. This energy can be used as a perennial source of energy. Wind energy is obtained with the help of wind mill. The minimum wind speed of 10kmph is considered to be useful for working wind mills for agricultural purpose. Along the sea coast and hilly areas, wind mills are likely to be most successful in Karnataka, Maharastra and Gujarat.

The wind energy over earth is estimated to be 1.6×10^7 M.W, which is equivalent to the energy consumed. But, the wind energy is available in dilute form. The conversion machines are large. The wind energy varies from time to time and place to place. Due to this reason some storage facility is required. The kinetic energy of wind is converted into useful shaft power by wind mills. General applications of wind mills are pumping water, fodder cutting, grain grinding, generation of power etc. In India, wind speed lies between 5 kmph-20 kmph. The high wind velocity is seasonal. The wind energy, if used for power generation, it will be uncertain to generate power. In India, wind power can be used for lifting water in rural areas for drinking and for irrigation purpose.

11. 2 FACTORS AFFECTING THE WIND

- Latitude of the place
- Altitude of the place.
- Topography of the place 4. Scale of the hour, month or year

11.3 SUITABLE PLACES FOR THE ERECTION OF WIND MILLS

- Off-shore and on the sea coast: An average value is 2400 kWH/m^2/year
- Mountains: An average value is 1600 KWH/m2/year
- Plains: An average value is 750 KWH/m2/year

11.4 PLACES SUITABLE FOR WIND MILLS

- Humid equatorial region- there is virtually no wind energy
- Warm, windy countries, wind energy may not be usual because of the frequency of cyclones

11.5 ADVANTAGES AND DISADVANTAGES OF WINDMILLS

Advantages	Disadvantages
It is a renewable source of energy	The available wind energy is dilute and fluctuating in nature
It is non-polluting and no adverse influence on the environment	Unlike water energy, wind energy requires storage capacity because of its irregularity
No fuel and transportation is required	Wind energy operating machines are noisy in operation
The cost of electricity under low production is comparatively low	Large areas are required for wind mill
	The present wind mills are neither maintenance free nor practically reliable

11.6 CLASSIFICATION AND DESCRIPTION OF WIND MACHINES

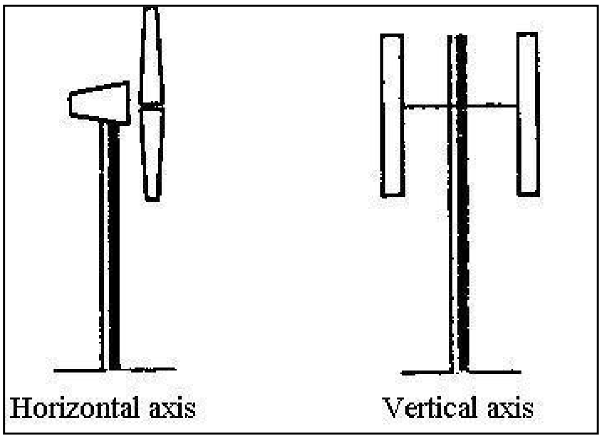
There are two types of wind machines (turbines) used today based on the direction of the rotating shaft (axis): horizontal–axis wind machines and vertical-axis wind machines. The size of wind machines varies widely. Small turbines used to power a single home or business may have a capacity of less than 100 kilowatts. Some large commercial sized turbines may have a capacity of 5 million watts, or 5 megawatts. Larger turbines are often grouped together into wind farms that provide power to the electrical grid.

- Vertical axis wind mills
  - a) Savonius or S type wind mill (low wind velocity)
  - b) Darrius wind mill (high wind velocity)
- Horizontal axis wind mills
  - a) Single blade wind mills
  - b) Double blade wind mills
  - c) Multi blade wind mills

d) Bicycle multiblade type i.e., Sail type

Vertical axis wind mills

Vertical axis machines are of simple design as compared to the horizontal axis. The axis of rotation of vertical axis wind turbine is vertical to the ground and almost perpendicular to the wind direction. These turbines can receive wind from any direction. Hence complicated yaw devices can be eliminated. The generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical. Moreover, the maintenance of these turbines can be done at the ground level. The major disadvantage of vertical axis machines are that, these turbines usually not self-starting. Additional mechanism may be required to push and start the turbine, once it is stopped.



a) Savonius wind mil

It works on the principle of cup anemometer. This machine has become popular, since it requires low wind velocity for operation. It consists of two half cylinders, which are mounted on a vertical axis perpendicular to the direction of wind, with a gap at the axis between the two cylinders. Two half cylinders facing each other forming an „s" shaped cross-section. Irrespective of the wind direction, the rotor rotates such as to make the convex sides of the buckets head into the wind. From the rotor shaft, we can tap power for our use like water pumping, battery charging, grain winnowing etc.

The main action of the wind is very simple, the force of the wind is greater on the cupped face than on rounded face. A low pressure is created on the convex sides of drums. Torque is produced by the pressure difference between the two sides of the half cylinders facing the wind. This design is efficient but requires a large surface area. A savonius wind energy conversion system has a vertical axis which eliminate the expensive power transmission system from the rotor to the axis. Since it is a vertical axis machine it does not matters much about the wind direction. The machine performs even at lower wind velocity ranges (i.e., 8 kmph).

b) Darrieus wind mill

Added advantage with this mill is that it supports its blades in such a way that minimizes bending stresses in normal operation. It requires less surface area as compared to Savonius type. In this machine, the blades are curved and attached to the hubs on the vertical shaft at both ends to form a cage-like structure. The blades look like an egg beater. Darrieus rotors have three symmetrical aerofoil blades, both ends of which are attached to a vertical shaft. Thus, the force in the blade due to rotation is pure tension. This provides a stiffness to withstand the wind forces it experiences. The blades are made lighter than in the propeller type. When rotating, these aerofoil blades provide a torque about the central shaft in response to a wind direction. This shaft torque. is transmitted to a generator at the base of the central shaft for power generation. Both Savonius and darrieus type rotors run independently of the direction of wind because they rotate about a vertical axis. Major advantage of darrieus wind mill is that the rotor blades can accept the wind from any point of the compass. The machine can be mounted on the ground eliminating the tower structures. Disadvantage is that, it may experience lower velocity wind when compared to tower mounted conventional wind energy conversion system.

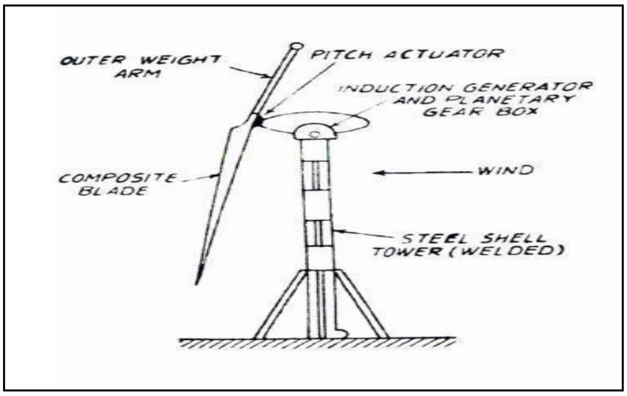
Horizontal axis type wind mills

Horizontal axis wind turbines have their axis of rotation horizontal to the ground and almost parallel to the wind stream. Most of the commercial wind turbines fall under this category. Horizontal axis machines have some distinct disadvantages such as low cut-in speed and easy furling. In general, they show relatively high-power coefficient. However, the generator and gearbox of these machines are to be placed over the tower which makes its design more complex and expensive. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed.

The horizontal type wind mills have thin cross-section or more efficient thick cross-section of aerofoil blade. The blade is designed such that the tip of the blades makes a small angle with the plane of rotation and almost at right angles to the direction of wind. In a modern wind turbine, the velocity of blades is six times the wind velocity. Ideally, the blade should be twisted, but because of construction difficulties this is not always achieved. The horizontal axis wind mills generally have better performance. These are mainly used for electric power generation and pumping water.

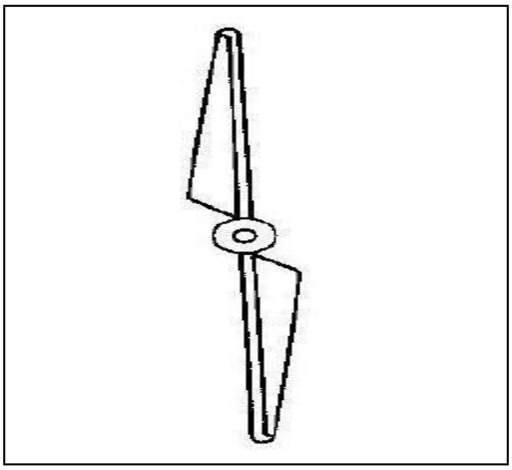
a) Horizontal axis propeller type wind mill with single blade

In this type of machine, a long blade is mounted on a rigid hub. Induction generator and gear box are arranged. If extremely long blades (60 m) are mounted on the hub, large blade root bending moments may occur due to tower shadow, gravity and sudden shifts in the wind directions. To reduce rotor cost, use of low cost counter weight is recommended for balancing long blade centrifugally.



b) Horizontal axis - two blade wind mill

In this type of design, rotor drives a generator through a step-up gear box. The blade rotor is designed to be oriented downwind of the tower. The components are mounted on a bedplate, which is attached on a pintle at the top of the tower. The arrangement is shown in Figure. The rotor blades are continuously flexed by unsteady aerodynamic, gravitational and inertial loads, when the machine is in operation. If the blades are made of metal, flexing reduces their life due to fatigue loading. With rotor, the tower is also subjected to above loads, which may cause serious damage. If the vibrational modes of the rotor happen to coincide with one of the natural mode of vibration of the tower, then the mill may get damaged. Due to high cost of blades, the rotor with more than two blades is not recommended. Rotors more than two, say 3 or 4 blades would have slightly higher coefficient.

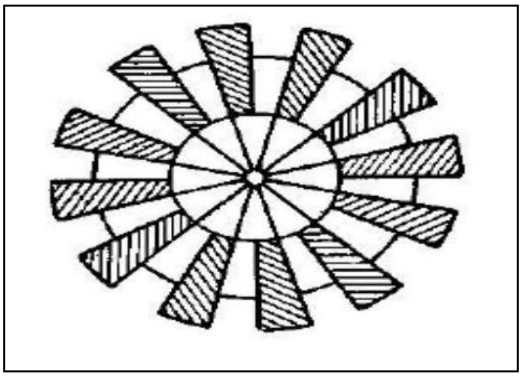


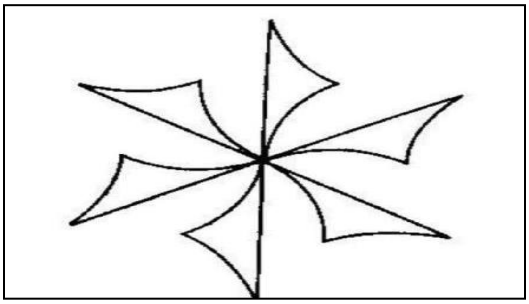
c) Horizontal axis-multi blade type wind mill

This type of design for multi blades made from sheet metal or aluminum. The rotors have high strength to weight ratios and are strong enough to with stand a wind speed of 60 Kmph. This type of wind mills have good power coefficient, high starting torque, simple and are low in cost.

d) Sail type wind mill

It is recent development in wind mills. The blades are made by stretching out triangular pieces of canvas cloth or nylon or plastics. There is also variation in the number of sails used. It runs at 60 to 80 rpm.





Schematic diagram of horizontal axis sail type wind mill

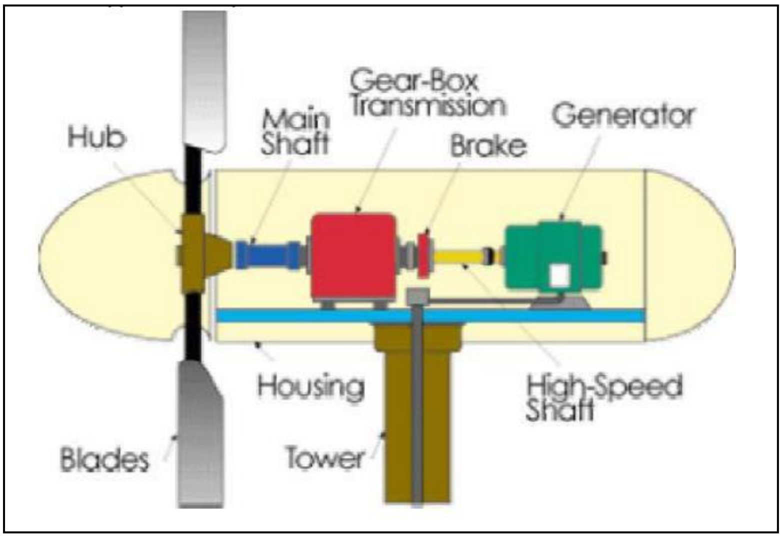
11.7 MAIN COMPONENTS OF A WIND MILL

Rotor:

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.

Drag Design:

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping, sawing or grinding work. For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.



Lift Design:

The lift blade design employs the same principle that enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation.

Tip Speed Ratio:

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1.Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. It is because of this requirement that most wind turbine shave only two or three blades on their rotors.

Generator:

The generator is what converts the turning motion of a wind turbines blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbines blades because more energy is captured by longer blades.

It is important to select the right type of generator to match intended use. Most home and office appliances operate on 240 volt, 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can bead apted to run on DC. Storage systems using batteries store DC and usually are configured at voltages of between 12 volts and 120 volts.

Generators that produce AC are generally equipped with features to produce the correct voltage of 240 V and constant frequency 50 cycles of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Transmission:

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production. Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Tower:

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect. These towers cost less than freestanding towers, but require more land area to anchor the guy wires. Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top. This simplifies not only installation, but maintenance as well. Towers can be constructed of a simple tube, a wooden pole or a lattice of tubes, rods, and angle iron. Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt-up towers.

Towers must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the wind turbine. Their costs will vary widely as a function of design and height.

Operating Characteristics of wind mills:

All wind machines share certain operating characteristics, such as cut-in, rated and cutout wind speeds.

Cut-in Speed:

Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

Rated Speed:

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with wind speed.

Cut-out Speed:

At very high wind speeds, typically between 72 and 128 kmph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm's, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

Betz Limit:

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbines rotor is approximately 59%. This value is known as the Betz limit. If the blades were 100%efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59%.A more typical efficiency is 35% to 45%. A complete wind energy system, including rotor, transmission, generator, storage and other devices, which all have less than perfect efficiencies, will deliver between 10% and 30% of the original energy available in the wind.

11.8 APPLICATION OF WIND ENERGY

Mechanical application: mainly (water pumping) Multi-blade windmill used for water pumping

Electricity generation: Wind turbines vary in size and type. They are commercially available for electricity generation. Size of wind turbines (400 Watt-5 MW)

Industrial Applications

The number of dedicated industrial applications for wind power continues to grow. Small wind power systems are ideal for applications where storing and shipping fuel is uneconomical or impossible. Wind power is currently being used for the following applications:

- Telecommunications
- Radar
- Pipeline control
- Navigational aids
- Cathodic protection
- Weather stations/seismic monitoring
- Air-traffic control

Wind machines in industrial applications typically encounter more extreme weather than home power systems and must be designed to be robust with very minimal maintenance.

CHECK YOUR PROGRESS

1. Explain the factors affecting the wind mill.
2. What are the suitable places for the wind mill?
3. Give any two application of wind energy.

LET US SUM UP

In this unit, we have learnt about

- wind energy
- factors affecting the wind
- suitable places for wind mill
- application

ANSWERS TO CHECK YOUR PROGRESS

1. Latitude of the place

   Altitude of the place.

   Topography of the place

   Scale of the hour, month or year

2. Humid equatorial region- there is virtually no wind energy

   Warm, windy countries, wind energy may not be usual because of the frequency of cyclones

3. **Mechanical application**: mainly (water pumping) Multi-blade windmill used for water pumping

   Electricity generation: Wind turbines vary in size and type. They are commercially available for electricity generation. Size of wind turbines (400 Watt-5 MW)

UNIT END EXERCISE

1. Explain the main components of wind mill.
2. Explain the classification and description of wind machines.

SUGGESTED READINGS

1. Solar Energy-principles of thermal collection and storage- S.P.SUKHAME-tata- McGraw-Hill publishing company ltd.

2. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.

WEB RESOURCE

1. Wind Energy Basics | NREL
2. Sources of Energy — Vikaspedia
3. Wind energy facts, advantages, and disadvantages | Caltech Science Exchange

UNIT 12

OTHER ENRGIES

Structure

OVERVIEW

In this unit, we will learn about other forms of energies like ocean thermal energy, tidal energy, wave energy etc.

OBJECTIVES

After studying this unit, we will be able to

- know the other energies.
- understand the concept of wave energy, tidal energy etc.

12.1 INTRODUCTION

Non-conventional sources are turning out to be significant sources of energy for humanity. With global warming a certainty, it is imperative that we turn to non-polluting and renewable sources of energy.

12.2 OCEAN THERMAL ENERGY

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters. A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 283C. Deep, cold water, meanwhile, forms at higher latitudes and descends to Show along the sea shoor toward the equator. The warm surface layer, which extends to depths of about 100,200m, is separated from the deep cold water by a thermo cline. The temperature difference, *T*, between the surface and thousand-meter depth ranges from 10 to 253C, with larger differences occurring in equatorial and tropical waters is that a differential of about 203C is necessary to sustain viable operation of an OTEC facility.

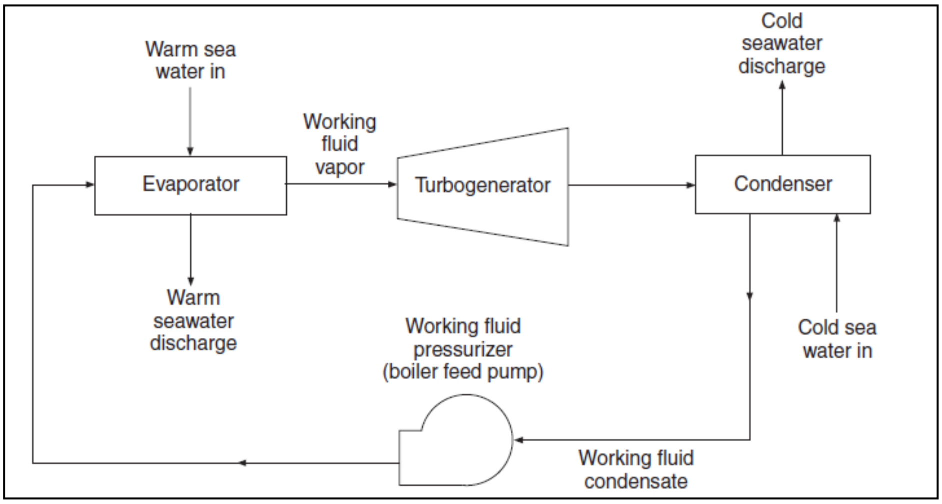
Since OTEC exploits renewable solar energy, recurring costs to generate electrical power are minimal. However, the fixed or capital costs of OTEC systems per kilowatt of generating capacity are very high because large pipelines and heat exchangers are needed to produce relatively modest amounts of electricity. These high fixed costs dominate the economics of OTEC to the extent that it currently cannot compete with conventional power systems, except in limited niche markets. Considerable effort has been expended over the past two decades to develop OTEC by-products, such as fresh water, air conditioning, and Mari culture that could offset the cost penalty of electricity generation.

OTEC power systems operate as cyclic heat engines. They receive thermal energy through heat transfer from surface sea water warmed by the sun, and transform a portion of this energy to electrical power. The Second Law of Thermodynamics precludes the complete conversion of thermal energy in to electricity. A portion of the heat extracted from the warm sea water must be rejected to a colder thermal sink. The thermal sink employed by OTEC systems is sea water drawn from the ocean depths by means of a submerged pipeline. A steady-state control volume energy analysis yields the result that net electrical power produced by the engine must equal the difference between the rates of heat transfer from the warm surface water and to the cold deep water. The limiting (i.e., maximum) theoretical Carnot energy conversion efficiency of a cyclic heat engine scales with the difference between the temperatures at which these heat transfers occur. For OTEC, this difference is determined by *T* and is very small; hence, OTEC efficiency is low. Although viable OTEC systems are characterized by Carnot efficiencies in the range of 6-8%, state-of-the-art combustion steam power cycles, which tap much higher temperature energy sources, are theoretically capable of converting more than 60% of the extracted thermal energy into electricity.

The low energy conversion efficiency of OTEC means that more than 90% of the thermal energy extracted from the ocean's surface is 'wasted' and must be rejected to the cold, deep sea water. This necessitates large heat exchangers and seawater Sow rates to produce relatively small amounts of electricity. In spite of its inherent inefficiency, OTEC, unlike conventional fossil energy systems, utilizes a renewable resource and poses minimal threat to the environment. In fact, it has been suggested that widespread adoption of OTEC could yield tangible environmental benefits through avenues such as reduction of greenhouse gas CO_2 emissions; enhanced uptake of atmospheric CO_2 by marine organism populations sustained by the nutrient-rich, deep OTEC sea water; and preservation of corals and hurricane amelioration by limiting temperature rise in the surface ocean through energy extraction and artificial upwelling of deep water. Carnot efficiency applies only to an ideal heat engine. In real power generation systems, irreversibility's will further degrade performance. Given its low theoretical efficiency, successful implementation of OTEC power generation demands careful engineering to minimize ir-reversibilities. Although OTEC consumes what is essentially a free resource, poor thermodynamic performance will reduce the quantity of electricity available for sale and, hence, negatively affect the economic feasibility of an OTEC facility. An OTEC heat engine may be configured following designs by J.A. D'Arsonval, the French engineer who first proposed the OTEC concept in 1881, or G. Claude, D'Arsonval's former student. Their designs are known, respectively, as closed cycle and open cycle OTEC.

Closed Cycle OTEC

D'Arsonval's original concept employed a pure working fluid that would evaporate at the temperature of warm sea water. The vapor would subsequently expand and do work before being condensed by the cold sea water. This series of steps would be repeated continuously with the same working fluid, whose Sow path and thermodynamic process representation constituted closed loops and hence, the name 'closed cycle.' The specific process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. Figure 1 is a simplified schematic diagram of a closed cycle OTEC system. The principal components are the heat exchangers, turbo generator, and seawater supply system, which, although not shown, account for most of the parasitic power consumption and a significant fraction of the capital expense. Also not included are ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working fluid lost through leaks or contamination.



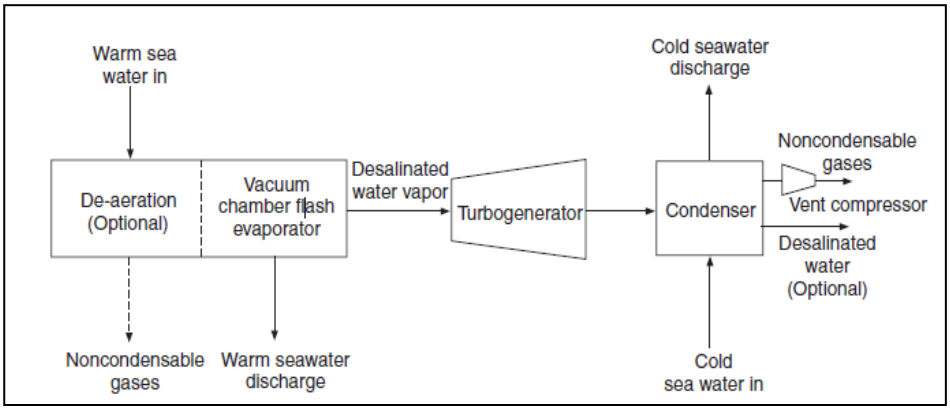
In this system, heat transfer from warm surface sea water occurs in the evaporator, producing a saturated vapor from the working fluid. Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle. The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional (e.g., combustion) Rankine systems, this yields net electrical power. For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. (One misconception about OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 1000 meters. In reality, the natural hydrostatic pressure gradient provides for most of the increase in the gravitational potential energy of a fluid particle moving with the gradient from the ocean depths to the surface.)

Irreversibility's in the turbo machinery and heat exchangers reduce cycle efficiency below the Carnot value. Irreversibility's in the heat exchangers occur when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperature established by the surface and deep sea water. Insofar as a large number of substances can meet this requirement (because pressures and the pressure ratio across the turbine and pump are design parameters), other factors must be considered in the selection of a working fluid including: cost and availability, compatibility with system materials, toxicity, and environmental hazard. Leading candidate working fluids for closed cycle OTEC applications are ammonia and various fluorocarbon refrigerants. Their primary disadvantage is the environmental hazard posed by leakage; ammonia is toxic in moderate concentrations and certain fluorocarbons have been banned by the Montreal Protocol because they deplete stratospheric ozone.

The Kalina, or adjustable proportion fluid mixture (APFM), cycle is a variant of the OTEC closed cycle. Whereas simple closed cycle OTEC systems use a pure working fluid, the Kalina cycle proposes to employ a mixture of ammonia and water with varying proportions at different points in the system. The advantage of a binary mixture is that, at a given pressure, evaporation or condensation occurs over a range of temperatures; a pure fluid, on the other hand, changes phase at constant temperature. This additional degree of freedom allows heat transfer-related irreversibilities in the evaporator and condenser to be reduced. Although it improves efficiency, the Kalina cycle needs additional capital equipment and may impose severe demands on the evaporator and condenser. The efficiency improvement will require some combination of higher heat transfer coefficients, more heat transfer surface area, and increased seawater Sow rates. Each has an associated cost or power penalty. Additional analysis and testing are required to confirm whether the Kalina cycle and assorted variations are viable alternatives.

Open Cycle OTEC

Claude's concern about the cost and potential bio-fouling of closed cycle heat exchangers led him to propose using steam generated directly from the warm sea water as the OTEC working fluid. The steps of the Claude, or open, cycle are: (1) flash evaporation of warm sea water in a partial vacuum; (2) expansion of the steam through a turbine to generate power; (3) condensation of the vapor by direct contact heat transfer to cold sea water; and (4) compression and discharge of the condensate and any residual non condensable gases. Unless fresh water is a desired by-product, open cycle OTEC eliminates the need for surface heat exchangers. The name 'open cycle' comes from the fact that the working fluid (steam) is discharged after a single pass and has different initial and final thermodynamic states; hence, the Sow path and process are 'open.'



entire system, from evaporator to condenser, operates at partial vacuum, typically at pressures of 1-3% of atmospheric. Initial evacuation of the system and removal of non condensable gases during operation are performed by the vacuum compressor, which, along with the sea water and discharge pumps, accounts for the bulk of the open cycle OTEC parasitic power consumption. The low system pressures of open cycle OTEC are necessary to induce boiling of the warm sea water. Flash evaporation is accomplished by exposing the sea water to pressures below the saturation pressure corresponding to its temperature.

This is usually accomplished by pumping it into an evacuated chamber through spouts designed to maximize heat and mass transfer surface area. Removal of gases dissolved in the sea water, which will come out of solution in the low-pressure evaporator and compromise operation, may be performed at an intermediate pressure prior to evaporation.

Vapor produced in the flash evaporator is relatively pure steam. The heat of vaporization is extracted from the liquid phase, lowering its temperature and preventing any further boiling. Flash evaporation may be perceived, then, as a transfer of thermal energy from the bulk of the warm sea water of the small fraction of mass that is vaporized. Less than 0.5% of the mass of warm sea water entering the evaporator is converted into steam.

The pressure drop across the turbine is established by the cold seawater temperature. At 43C, steam condenses at 813 Pa. The turbine (or turbine diffuser) exit pressure cannot fall below this value. Hence, the maximum turbine pressure drop is only about 3000Pa, corresponding to about a 3:1 pressure ratio. This will be further reduced to account for other pressure drops along the steam path and differences in the temperatures of the steam and seawater streams needed to facilitate heat transfer in the evaporator and condenser.

Condensation of the low-pressure steam leaving the turbine may employ a direct contact condenser (DCC), in which cold sea water is sprayed over the vapor, or a conventional surface condenser that physically separates the coolant and the condensate. DCCs are inexpensive and have good heat transfer characteristics because they lack a solid thermal boundary between the warm and cool fluids. Surface condensers are expensive and more difficult to maintain than DCCs; however, they produce a marketable freshwater by-product

Effluent from the condenser must be discharged to the environment. Liquids are pressurized to ambient levels at the point of release by means of a pump, or, if the elevation of the condenser is suitably high, can be compressed hydrostatically. As noted previously, non condensable gases, which include any residual water vapor, dissolved gases that have come out of solution and air that may have leaked into the system, are removed by the vacuum compressor. Open cycle OTEC eliminates expensive heat exchangers at the cost of low system pressures.

Partial vacuum operation has the disadvantage of making the system vulnerable to air in-leakage and promotes the evolution of non condensable gases dissolved in sea water. Power must ultimately be expended to pressurize and remove these gases. Furthermore, as a consequence of the low steam density, volumetric Sow rates are very high per unit of electricity generated. Large components are needed to accommodate these Sow rates. In particular, only the largest conventional steam turbine stages have the potential for integration into open cycle OTEC systems of a few megawatts gross generating capacity. It is generally acknowledged that higher capacity plants will require a major turbine development effort.

The mist lift and foam lift OTEC systems are variants of the OTEC open cycle. Both employ the sea water directly to produce power. Unlike Claude's open cycle, lift cycles generate electricity with a hydraulic turbine. The energy expended by the liquid to drive the turbine is recovered from the warm sea water. In the lift process, warm seawater is flash evaporated to produce a two-phase, liquid}vapor mixture and either a mist consisting of liquid droplets suspended in a vapor, or a foam, where vapor bubbles are contained in a continuous liquid phase. The mixture rises, doing work against gravity. Here, the thermal energy of the vapor is expended to increase the potential energy of the fluid. The vapor is then condensed with cold sea water and discharged back into the ocean. Flow of the liquid through the hydraulic turbine may occur before or after the lift process. Advocates of the mist and foam lift cycles contend that they are cheaper to implement than closed cycle OTEC because they require no expensive heat exchangers, and are superior to the Claude cycle because they utilize a hydraulic turbine rather than a low pressure steam turbine.

Hybrid Cycle OTEC

Some marketing studies have suggested that OTEC systems that can provide both electricity and water may be able to penetrate the marketplace more readily than plants dedicated solely to power generation. Hybrid cycle OTEC was conceived as a response to these studies. Hybrid cycles combine the potable water production capabilities of open cycle OTEC with the potential for large electricity generation capacities offered by the closed cycle.

Several hybrid cycle variants have been proposed. Typically, as in the Claude cycle, warm surface seawater is Sash evaporated in a partial vacuum. This low pressure steam flows into a heat exchanger where it is employed to vaporize a pressurized, low-boiling-point fluid such as ammonia. During this process, most of the steam condenses, yielding desalinated potable water. The ammonia vapor Sows through a simple closed-cycle power loop and is condensed using cold sea water. The uncondensed steam and other gases exiting the ammonia evaporator may be further cooled by heat transfer to either the liquid ammonia leaving the ammonia condenser or cold sea water. The non condensable are then compressed and discharged to the atmosphere. Steam is used as an intermediary heat transfer medium between the warm sea water and the ammonia; consequently, the potential for bio-fouling in the ammonia evaporator is reduced significantly. Another advantage of the hybrid cycle related to freshwater production is that condensation occurs at significantly higher pressures than in an open cycle OTEC condenser, due to the elimination of the turbine from the steam Sow path. This may, in turn, yield some savings in the amount of power consumed to compress and discharge the non condensable gases from the system.

These savings (relative to a simple Claude cycle producing electricity and water), however, are offset by the additional back work of the closed-cycle ammonia pump. One drawback of the hybrid cycle is that water production and power generation are closely coupled. Changes or problems in either the water or power subsystem will compromise performance of the other. Furthermore, there is a risk that the potable water may be contaminated by an ammonia leak. In response to these concerns, an alternative hybrid cycle has been proposed, comprising decoupled and water production components.

The basis for this concept lies in the fact that warm sea water leaving a closed cycle evaporator is still sufficiently warm, and cold seawater exiting the condenser is sufficiently cold, to sustain an independent freshwater production process. The alternative hybrid cycle consists of a conventional closed-cycle OTEC system that produces electricity and a downstream Sash-evaporation-based desalination system. Water production and electricity generation can be adjusted independently, and either can operate should a subsystem fail or require servicing. The primary drawbacks are that the ammonia evaporator uses warm seawater directly and is subject to bio fouling; and additional equipment, such as the potable water surface condenser, is required, thus increasing capital expenses.

12.3 TIDAL ENERGY

Tidal Power is the power of electricity generation achieved by capturing the energy contained in moving water mass due to tides. Two types of tidal energy can be extracted: **kinetic energy** of currents between ebbing and surging tides and **potential energy** from the difference in height between high and low tides.

All coastal areas experience high and low tide. If the difference between high and low tides is more than 16 feet, the differences can be used to produce electricity. There are approximately 40 sites on earth where tidal differences are sufficient. Tidal energy is more reliable than wave energy because it based on the moon and we can predict them. It is intermittent, generating energy for only 6-12 hours in each 24 hour period, so demand for energy will not always be in line with supply.

Types of Tidal Energy

Kinetic energy from the currents between ebbing and surging tides

This form is considered most feasible

Potential energy from height differences between high and low tide

Density of water is much higher than air, so ocean currents have much more energy than wind currents.

- Barrage or Dam

  Using a dam to trap water in a basin, and when reaches appropriate height due to high tide, release water to flow through turbines that turn an electric generator.

- Tidal Fence

  Turnstiles built between small islands or between mainland and islands. The turnstiles spin due to tidal currents to generate energy.

- Tidal turbine

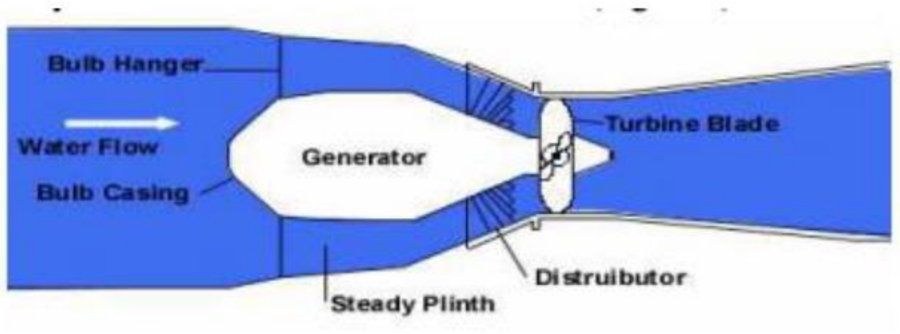
  Look like wind turbines, often arrayed in rows but are under water. Tidal currents spin turbines to create energy.

  Like wave energy, tidal energy is used for electricity, with the ultimate goal of connecting to local utility grids. A single 11-meter blade tidal turbine outside of Britain's Devon coast will be capable of generating300 kW of electricity (enough to power approximately 75 homes)

Tidal turbine

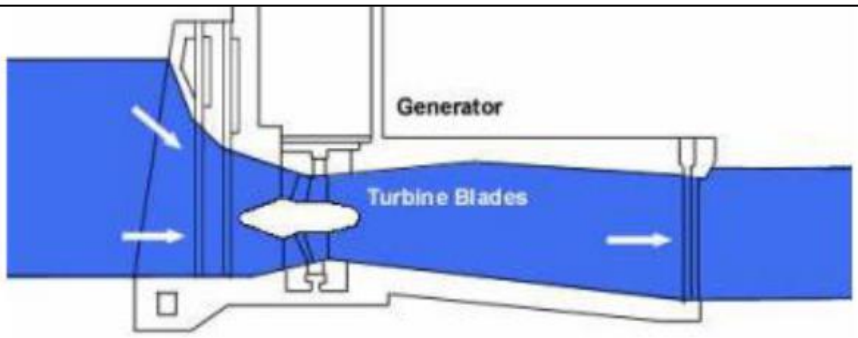
Tidal turbines look like wind turbines. They are arrayed underwater in rows, as in some wind farms. The turbines function best where coastal currents run at between 3.6 and 4.9 knots (4 and 5.5 mph). In currents of that speed, a 15-meter (49.2-feet) diameter tidal turbine can generate as much energy as a 60-meter (197-feet) diameter wind turbine. Ideal locations for tidal turbine farms are close to shore in water depths of 20–30 meters (65.5–98.5 feet).

There are different types of turbines that are available for use in a tidal barrage. A bulb turbine is one in which water flows around the turbine. If maintenance is required then the water must be stopped which causes a problem and is time consuming with possible loss of generation. The La Rance tidal plant near St Malo on the Brittany coast in France uses a bulb turbine.



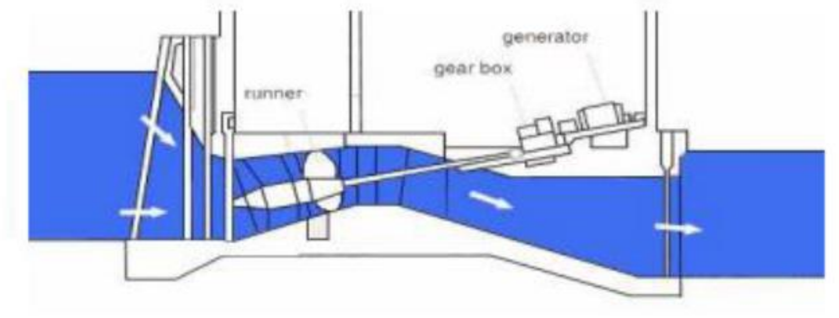
Bulb Turbine

When rim turbines are used, the generator is mounted at right angles to the to the turbine blades, making access easier. But this type of turbine is not suitable for pumping and it is difficult to regulate its performance. One example is the Straflo turbine used at Annapolis Royal in Nova Scotia.



Rim Turbine

Tubular turbines have been proposed for the UK's most promising site, The Severn Estuary, the blades of this turbine are connected to a long shaft and are orientated at an angle so that the generator is sitting on top of the barrage. The environmental and ecological effects of tidal barrages have halted any progress with this technology and there are only a few commercially operating plants in the world, one of these is the La Rance barrage in France.



Tubular turbines

Category of generation

Ebb generation

The basin is filled through the sluices and freewheeling turbines until high tide. Then the sluice gates and turbine gates are closed. They are kept closed until the sea level falls to create sufficient head across the barrage and the turbines generate until the head is again low. Then the sluices are opened, turbines disconnected, and the basin is filled again. The cycle repeats itself. Ebb generation (also known as outflow generation) takes its name because generation occurs as the tide ebbs.

Flood generation

The basin is emptied through the sluices and turbines generate at tide flood. This is generally much less efficient than Ebb generation because the volume contained in the upper half of the basin (which is where Ebb generation operates) is greater than the volume of the lower half (the domain of Flood generation).

Two-way generation

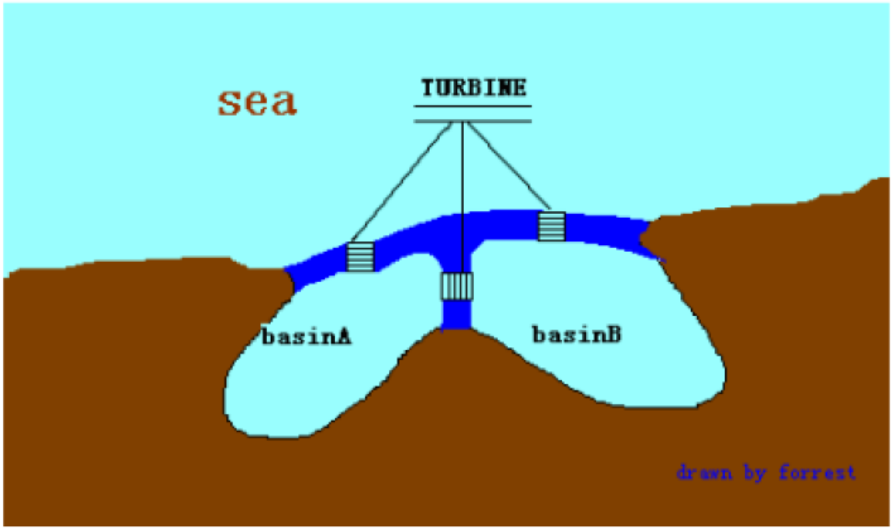
Generation occurs both as the tide ebbs and floods. This mode is only comparable to Ebb generation at spring tides, and in general is less efficient. Turbines designed to operate in both directions are less efficient.

Pumping

Turbines can be powered in reverse by excess energy in the grid to increase the water level in the basin at high tide (for Ebb generation and two-way generation). This energy is returned during generation

Two-basin schemes

With two basins, one is filled at high tide and the other is emptied at low tide. Turbines are placed between the basins. Two-basin schemes offer advantages over normal schemes in that generation time can be adjusted with high flexibility and it is also possible to generate almost continuously. In normal estuarine situations, however, two-basin schemes are very expensive to construct due to the cost of the extra length.



Schematic diagram of double basin tidal power generation

12.4 WAVE ENERGY

Wave energy is an irregular and oscillating low frequency energy source that can be converted to a 50 Hertz frequency and can then be added to the electric utility grid. Waves get their energy from the wind, which comes from solar energy. Waves gather, store, and transmit this energy thousands of kilometers with very little loss. Though it varies in intensity, it is available twenty four hours a day all round the year. Wave power is renewable, pollution free and environment friendly. Its net potential is better than wind, solar, small hydro or biomass power. Wave energy technologies rely on the up-and-down motion of waves to generate electricity. There are three basic methods for converting wave energy to electricity.

1. Float or buoy systems that use the rise and fall of ocean swells to drive hydraulic pumps. The object can be mounted to a floating raft or to a device fixed on the ocean bed. A

series of anchored buoys rise and fall with the wave. The movement is used to run an electrical generator to produce electricity which is then transmitted ashore by underwater power cables.

2. **Oscillating water column devices** in which the in-and-out motion of waves at the shore enters a column and force air to turn a turbine. The column fills with water as the wave rises and empties as it descends. In the process, air inside the column is compressed and heats up, creating energy. This energy is harnessed and sent to shore by electrical cable.
3. **Tapered channel** rely on a shore mounted structure to channel and concentrate the waves driving them into an elevated reservoir. Water flow out of this reservoir is used to generate electricity using standard hydropower technologies.

The advantages of wave energy are as follows:

1. Because waves originate from storms far out to sea and can travel long distances without significant energy loss, power produced from them is much steadier and more predictable day to day and season to season.
2. Wave energy contains about 1000 times the kinetic energy of wind.
3. Unlike wind and solar energy, energy from ocean waves continues to be produced round the clock.
4. Wave power production is much smoother and more consistent than wind or solar resulting in higher overall capacity factors.
5. Wave energy varies as the square of wave height whereas wind power varies with the cube of air speed. Water being 850 times as dense as air, this result in much higher power production from waves averaged over time.
6. Because wave energy needs only 1/200 the land area of wind and requires no access roads, infrastructure costs are less.

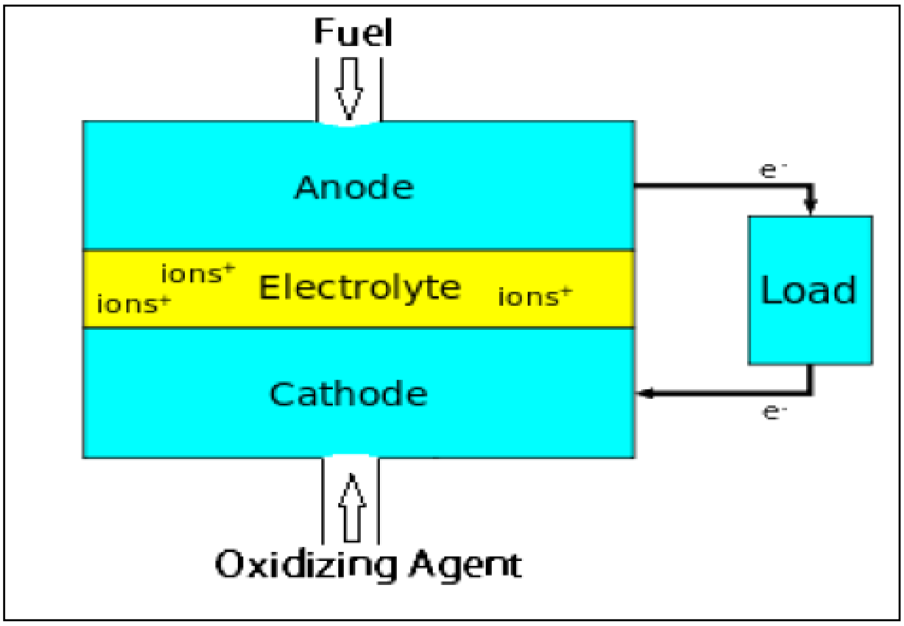
12.5 FUEL CELL

A fuel cell is an electric cell which produces electrical energy from chemical energy; through an oxidation reaction of provided fuel.

The main difference between normal secondary batteries and fuel cell is that; in secondary batteries the chemical energy is stored in the electrodes of the cell, but in Fuel cell the chemical energy is stored in a fuel. And the fuel, oxidizing agent are stored outside of the cell and fed into the cell when electricity is to be produced. Example of fuel cell is Hydrogen Fuel cell or Hydrogen-Oxygen Fuel cell.

Construction of a Fuel Cell:

A fuel cell consists of two porous electrodes separated by an electrolytic solution in between. The fuel which is usually Hydrogen or Carbon monoxide is fed into one of the electrodes and a Reacting agent; which is usually Oxygen or Air;is fed into another electrode. The electrodes are porous enough to pass through both fuels and electrolyte and also conduct electricity. The fuel and reacting agent reacts inside the fuel cell and produced electricity which can be obtained through terminals connected to the electrodes.



Advantages and Disadvantages of a Fuel Cell:

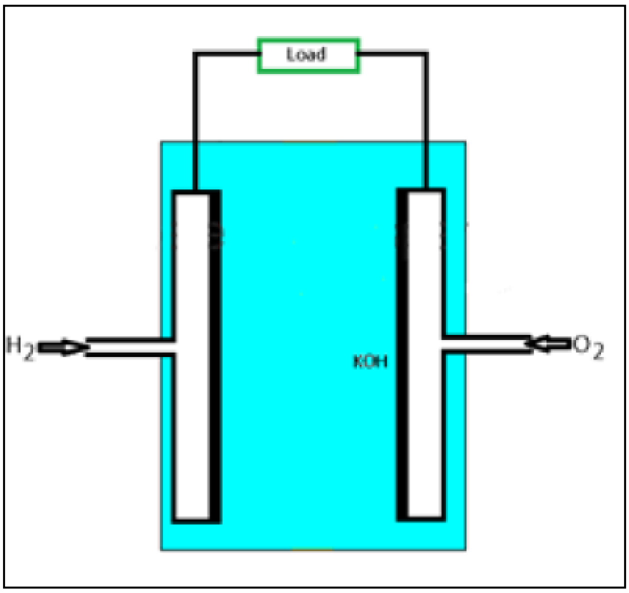
The electrode materials in a Fuel Cell are not changed during chemical reaction so a Fuel Cell does not requires recharging; they can be used as a continuous generator as long as the fuel and oxidizing agent are supplied. Also, fuel cells does not have any moving parts; so, unlike normal generators they does not produce sound , requires very little maintenance and produces no gasses or fumes. Fuel cell's efficiency and cost per KW of power is independent of their size; so, they also offer design flexibility and a room for further research and development.

But, the initial design and manufacturing cost of fuel cell is very high. They produce small voltages and also, their service life is not much as compared to other cells.

12.6 HYDROGEN FUEL CELL

Hydrogen Fuel cell or Hydrogen-Oxygen Fuel cell is one of the most basic type of fuel cell. Hydrogen fuel cell uses Hydrogen (H) as the fuel and Oxygen (O) is the oxidizing agent.

The basic construction of a Hydrogen-Oxygen Fuel cell is:



The electrodes are made up of sintered Nickel plates having a coarse pores surface and a fine pores surface; the two surfaces for gas and electrolyte respectively. A solution of KOH is used as electrolyte. The water vapor formed during the reaction is passed back by condensation from the opening for passing hydrogen into the cell.

A continuous flow of Hydrogen and oxygen is maintained, the oxygen and hydrogen reacts with potassium hydroxide at the surface of electrodes to produce electricity.

CHECK YOUR PROGRESS

1. What are the methods of converting wave energy into electricity?
2. Define Tidal power.
3. State advantages and disadvantages of fuel cell.

LET US SUM UP

In this unit, we have learnt about

- Tidal energy
- Ocean thermal energy
- Wave energy
- Fuel cell

ANSWERS TO CHECK YOUR PROGRESS

There are three basic methods for converting wave energy to electricity.

1. **Float or buoy systems** that use the rise and fall of ocean swells to drive hydraulic pumps. The object can be mounted to a floating raft or to a device fixed on the ocean bed. A series of anchored buoys rise and fall with the wave. The movement is used to run an electrical generator to produce electricity which is then transmitted ashore by underwater power cables.
2. **Oscillating water column devices** in which the in-and-out motion of waves at the shore enters a column and force air to turn a turbine. The column fills with water as the wave rises and empties as it descends. In the process, air inside the column is compressed and heats up, creating energy. This energy is harnessed and sent to shore by electrical cable.
3. **Tapered channel** rely on a shore mounted structure to channel and concentrate the waves driving them into an elevated reservoir. Water flow out of this reservoir is used to generate electricity using standard hydropower technologies.

Tidal Power is the power of electricity generation achieved by capturing the energy contained in moving water mass due to tides. Two types of tidal energy can be extracted: kinetic energy of currents between ebbing and surging tides and potential energy from the difference in height between high and low tides.

The electrode materials in a Fuel Cell are not changed during chemical reaction so a Fuel Cell does not requires recharging; they can be used as a continuous generator as long as the fuel and oxidizing agent are supplied. Also, fuel cells does not have any moving parts; so, unlike normal generators they does not produce sound , requires very little maintenance and produces no gasses or fumes. Fuel cell's efficiency and cost per KW of power is independent of their size; so, they also offer design flexibility and a room for further research and development.

But, the initial design and manufacturing cost of fuel cell is very high. They produce small voltages and also, their service life is not much as compared to other cells.

UNIT END EXERCISE

1. Write a short note on wave energy and give its advantages.
2. Explain the construction and working of Fuel cell.

SUGGESTED READINGS

1. Solar Energy-principles of thermal collection and storage- S.P.SUKHAME-tata- McGraw-Hill publishing company ltd.
2. Solar Energy: The State of the Art, Jeffrey M. Gordon, Earthscan, 2013.

WEB REOURCE

1. Sources of Energy — Vikaspedia
2. Fuel Cell - Definition, Working, Types, and Applications of fuel cell. (byjus.com)