Manonmaniam Sundaranar University,

Directorate of Distance & Continuing Education,

Tirunelveli - 627 012 Tamilnadu, India

OPEN AND DISTANCE LEARNING (ODL) PROGRAMMES

(FOR THOSE WHO JOINED THE PROGRAMMES FROM THE ACADEMIC YEAR 2023–2024)

M.Sc. Physics

Course Material

ENERGY PHYSICS

Prepared

By

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Tirunelveli - 12

Elective - List 1 – 1. ENERGY PHYSICS	I/II YEAR - FIRST/THIRD SEMESTER

Subject Code	Subject Name	Category	L	T	P	Credits	Inst. Hours	Marks
	ENERGY PHYSICS	ELECTIVE	3	-	-	3	3	75

Pre-Requisites
Knowledge of conventional energy resources
Learning Objectives
➢ To learn about various renewable energy sources. ➢ To know the ways of effectively utilizing the oceanic energy. ➢ To study the method of harnessing wind energy and its advantages. ➢ To learn the techniques useful for the conversion of biomass into useful energy. ➢ To know about utilization of solar energy.

UNITS	Course Details
UNIT I: INTRODUCTION TO ENERGY SOURCES	Conventional and non-conventional energy sources and their availability–prospects of Renewable energy sources– Energy from other sources–chemical energy–Nuclear energy– Energy storage and distribution.
UNIT II: ENERGY FROM THE OCEANS	Energy utilization–Energy from tides–Basic principle of tidal power–utilization of tidal energy – Principle of ocean thermal energy conversion systems.
UNIT III: WIND ENERGY SOURCES	Basic principles of wind energy conversion–power in the wind–forces in the Blades– Wind energy conversion–Advantages and disadvantages of wind energy conversion systems (WECS) - Energy storage–Applications of wind energy.
UNIT IV: ENERGY FROM BIOMASS	Biomass conversion Technologies– wet and dry process– Photosynthesis Biogas Generation: Introduction–basic process: Aerobic and anaerobic digestion – Advantages of anaerobic digestion–factors affecting bio digestion and generation of gas- bio gas from waste fuel– properties of biogas-utilization of biogas.
UNIT V: SOLAR ENERGY SOURCES	Solar radiation and its measurements–solar cells: Solar cells for direct conversion of solar energy to electric powers–solar cell parameter–solar cell electrical characteristics– Efficiency–solar water Heater –solar distillation– solar cooking–solar greenhouse – Solar Pond and its applications.

TEXT BOOKS	1. G.D. Rai, 1996, Non – convention sources of, 4th edition, Khanna publishers, New Delhi. 2. S. Rao and Dr. ParuLekar, Energy technology. 3. M.P. Agarwal, Solar Energy, S. Chand and Co., New Delhi (1983). 4. Solar energy, principles of thermal collection and storage by S.P.Sukhatme, 2^{nd}edition, Tata McGraw-Hill Publishing Co. Lt., New Delhi (1997). 5. Energy Technology by S.Rao and Dr.Parulekar.
REFERENCE BOOKS	1. Renewable energy resources, John Twidell and Tonyweir, Taylor and Francis group, London and New York. 2. Applied solar energy, A.B.MeinelandA.P.Meinal 3. John Twidell and Tony Weir, Renewable energy resources, Taylor and Francis group, London and New York. 4. Renewal Energy Technologies: A Practical Guide for Beginners C.S. Solanki-PHI Learning 5. Introduction to Non-Conventional Energy Resources -Raja et. al., Sci. Tech Publications
WEB SOURCES	1.https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=2411&printable=1 2. https://www.nationalgeographic.org/encyclopedia/tidal-energy/ 3. https://www.ge.com/renewableenergy/wind-energy/what-is-wind-energy 4. https://www.reenergyholdings.com/renewable-energy/what-is-biomass/ 5. https://www.acciona.com/renewable-energy/solar-energy/

COURSE OUTCOMES:

At the end of the course, the student will be able to:

CO1	To identify various forms of renewable and non-renewable energy sources	**K1**
CO2	Understand the principle of utilizing the oceanic energy and apply it for practical applications.	**K2**
CO3	Discuss the working of a windmill and analyze the advantages of wind energy.	**K3**
CO4	Distinguish aerobic digestion process from anaerobic digestion.	**K3,K4**
CO5	Understand the components of solar radiation, their measurement and apply them to utilize solar energy.	**K2,K5**
K1 - Remember; K2 – Understand; K3 - Apply; K4 - Analyze; K5 - Evaluate;		

UNIT I:

INTRODUCTIONTO ENERGY SOURCES

CONVENTIONAL AND NON-CONVENTIONAL ENERGY SOURCES AND THEIR AVAILABILITY

Conventional energy sources

Conventional energy refers to energy sources that have been widely used for a long time and are typically derived from traditional sources such as fossil fuels (coal, oil, natural gas), as well as nuclear power. These sources have been the backbone of global energy production for decades, providing electricity, heat, and power for various industrial, commercial, and residential purposes. However, conventional energy sources are often associated with environmental concerns, including air and water pollution, greenhouse gas emissions, and resource depletion.

- Coal
- Oil
- Gas
- Nuclear power
- Hydro

are the commonly known Conventional energy sources.

Coal

Coal has been the most common source of energy in the last three decades the world switched over from cool to oil as a major source of energy because it is simple and cleaner to obtain useful energy from oil

Coal developed from vegetable matter which grew in past Geological ages.Trees and plants falling into water decayed and produced peat bogs. Gigantic Geological upheaval buried this box under layers of silt. Soil pressure, heat and movement of earth’s crust thrust distilled off some of the bog’s gashes matter to form brown coal or lignite. Continuing subterrane an activity reduces the coal’s gaseous content progressively to form different ranks; peat lignite, Bituminous and anthracite.

Estimates indicate that coal is plentiful. It's sufficient for 200 years. But its calorific value is minimal, and shipping costs are high. In addition to being polluting, burning coal releases CO and CO2. Since flora worldwide is unable to absorb the vast amounts of carbon dioxide created by burning significant amounts of coal, the widespread use of coal as a source of energy is likely to upset the ecological balance of CO2.

Oil

Oil, also known as petroleum, is a naturally occurring, flammable liquid found beneath the Earth's surface. It is composed of hydrocarbons, which are organic compounds made up primarily of carbon and hydrogen atoms. Oil is formed over millions of years from the remains of plants and animals that lived in ancient seas. These organic materials undergo a process of decomposition and transformation under high pressure and temperature, resulting in the formation of crude oil.

Crude oil is typically extracted from underground reservoirs through drilling. Once extracted, it can be refined into various petroleum products such as gasoline, diesel, jet fuel, heating oil, and various types of lubricants and waxes. These refined products are crucial sources of energy for transportation, heating, and electricity generation, making oil one of the most important natural resources in the world.

Oil provides the world with energy to the tune of about 40%. The international economy has been significantly strained by the rising price of oil, particularly in the case of developing nations whose oil supplies are insufficient for their own needs. Unless more oil is found, 250,000 million tonnes of oil would be sufficient for nearly 100 years based on current use. The concern is whether there would then be an oil substitute available; otherwise, the world would need to begin considering shifting away from an oil-based global economy.

Gas

Due to a lack of a ready market, gas is now underutilised and vast amounts are burned off during the oil production process. The high cost of gas for transportation could be the cause. Transporting gas is more expensive than oil transportation. It is thought that sizable reserves are situated in unreachable regions.

The following categories apply to gaseous fuels:

- Gases with set compositions, such as ethylene, methane, and acetylete.
- Composite industrial gases, which include blast furnace gas, water gas, coke oven gas, producer gas, and so forth.

Nuclear power

This energy source is very significant because of the massive energy release from a very modest number of nuclear fuels. The heat energy produced by burning 2200 tonnes of oil or 4500 tonnes of high-grade coal is equivalent to the energy released by the full fission of one kilogramme of U235. As in conventional power plants, the heat generated by the nuclear fission of fissionable material's atoms is used in specific heat exchangers to make steam, which powers turbogenerators.

There are currently very little uranium deposits in the globe. Although expensive, these reserves can be recovered. Furthermore, just 3% of the energy found in oil reservoirs is thought to be present in uranium reserves.

Hydro energy

Water can be made to descend against gravity to generate water power. It is mostly employed in the production of electric power.

Actually, it wasn't until the introduction of electrical power transmission at the turn of the 20th century that the large-scale generation of water power became feasible. Previous to that, hydroelectric plants, often known as water power plants, typically had modest capacities—less than 100 kW.

The availability of electricity to people living in remote locations may not be cost-effective due to long transmission lines with low load factors, and the establishment of isolated diesel production plants will result in significant losses when using the current electric tariff rates. In order to provide electricity to rural locations, this results in the creation of mini or micro hydroelectric facilities. When practical, these initiatives can be integrated into the main grid or run as standalone systems. The significance of micro hydroelectric projects has been noted in certain regions of the nation where year-round river flow has a medium-to higher-head development prospect.

Non-conventional energy sources

"Non-conventional energy," also referred to as "alternative energy" or "renewable energy," encompasses energy sources and technologies that are different from traditional fossil fuels such as coal, oil, and natural gas. These alternative sources are typically considered more sustainable and environmentally friendly.

Examples of non-conventional energy sources include:

- Solar power

- Wind power
- Hydrogen energy
- Geothermal energy
- Biomass
- Tidal energy

Solar power

Solar energy has the highest potential of all the renewable energy sources, and even if it is only partially utilized, it will still be one of the most significant energy sources, particularly once the nation's other sources have run out.

The solar power on Earth's surface is 1016 watts, but the solar power where the sun reaches the atmosphere is 1017 watts. The whole power consumption of civilization on Earth is 1013 watts. As a result, the sun provides 1000 times more energy than we require. This energy will be 50 times more than what the world needs if we can use even 5% of it. There have been attempts to harness the approximately 1 kW/m2 of energy that the sun radiates on a bright, sunny day in order to raise steam that could be used to power prime movers and produce electricity. However, because of the significant amount of area needed, the uncertainty around the steady supply of energy due to clouds, winds, haze.

Wind power

Wind mills are a cost-effective way to generate electricity from wind energy.

Convection currents are created by the heating and cooling of the atmosphere. The absorption of solar radiation in the atmosphere and on the surface of the earth causes heating the earth's rotation with respect to the atmosphere and its orbit around the sun.

Wind energy has a lot of potential as a power source. According to estimates, there is 1.6 x 107 MW of energy accessible in the winds over the surface of the world, which is equivalent to the planet's current energy usage.

Hydrogen energy

As long as the technological issues with its production, storage, and transportation are adequately overcome and the cost is frequently reduced through improved combustion efficiency, hydrogen energy has the potential to be a significant substitute for traditional fuels. It can be utilized in fuel cells to generate both usable heat and electricity through its non-polluting burning process.

The availability of catalyst for hydrogen generation consist of rare earth metals makes a concern in hydrogen energy.

Geothermal energy

This is the energy that the earth is made of. There are several hypotheses that claim the planet has a molten core. These theories are supported by the fact that there are several locations on Earth's surface where volcanic activity occurs. In certain parts of the planet, the steam and hot water are naturally occurring.

In order to release volcanic activity on a broad scale, bore holes are typically drilled to a depth of up to 1000 meters. Where the earth's molten inner mass erupts to the surface through fissures, temperatures there can reach as high as 500 degrees Celsius.

Currently, only steam generated from the earth is used to provide energy; hot water that contains up to 30% dissolved salts and minerals is thrown away because it seriously damages the turbine's corrosion. But more than one-third of the thermal energy that is available is present in the water. Research is being done to develop turbines resistant to the corrosive effects of hot water that emerges from wells.

Bio-mass

Biomass has a lot of potential for use as a substitute energy source. For the generation of biomass, our agricultural and forest resources are abundant. In nature, photosynthesis, which is powered by solar energy conversion, produces biomass. As the term unambiguously indicates, biomass is organic matter. The reaction, which is essentially the process of photosynthesis in the presence of solar radiation, is shown as follows.

$$H_2O + CO_2 \rightarrow CH_2O + O_2$$

Water and carbon dioxide are transformed into organic material (CH20), the building block of carbohydrates. While CH20 is stable at moderate temperatures, it breaks down at high ones, producing heat equivalent to 112,000 Cal/mole (469 kJ mole).

$$CH_2O + O_2 \rightarrow CO_2 + H_2O + 112\ Kcal/mole.$$

This is the minimum amount of energy that photons should absorb. Therefore, it is feasible to grow vast amounts of carbohydrates, such as algae, in ponds or plastic tubes under ideal growing circumstances. The algae could be gathered, dried, and burned to produce heat that could then be used to generate energy using more traditional techniques. Burning the biomass directly or processing it further to create more convenient liquid and gaseous fuels are two ways to use it.

Tidal energy

The universal gravitational pull of celestial entities like the sun and moon on Earth causes the tides in the sea. Because of the fluidity of the water mass, the force's effect can be seen in the motion of the water, which exhibits a cyclical rise and fall in levels that corresponds with the sun's and moon's daily cycles.

A few strategically located locations, where the topography of an inlet or bay encourages the installation of large-scale hydroelectric plants, make it feasible to use the tides to generate electricity. A dam would be constructed across the bay's mouth to control the tides. Large gates and hydraulic reversible turbines with low head will be installed in it. A tidal basin is created and dammed off from the ocean. The sea and basin's differences in water level are determined. Through the use of a sluice turbine, the built-in basin is filled during high tide and emptied during low tide.

These kinds of plants can only be built in specific locations where the tide is high enough to be economically viable.

In 1966, a 240-megawatt tidal power facility at Rance, France, was constructed. It uses a two-way pumping system with a single basin.

Three recommended locations for tidal power plants in India include the Sunderban area in West Bengal, the Gulf of Cambay, and the Gulf of Kutchh in Gujarat. Nevertheless, no such plant has been built in our nation as of yet.

PROSPECTS OF RENEWABLE ENERGY SOURCES

The one "new" energy source that has the potential to displace coal, gas, and oil is the sun, which is a distinct type of fusion reactor. 3.8 x 1024 J, the total amount of solar energy that the planet and its atmosphere absorb in a year, is 15–20 times more energy than is contained in all of the world's recoverable hydrocarbon reserves. In fact, more usable energy might be produced annually by capturing just 0.005% of this solar energy through the use of fuel crops, properly constructed buildings, wind and water turbines, solar collectors with energy converters, and similar devices than are currently produced by burning fossil fuels. Renewable energy sources never run out, in contrast to capital energy resources.

The rate at which they are used is the only restriction; no specific energy reservoir (such a column of flowing air or falling water) can be used up faster than it can be refilled.

A sizable portion of the world's energy needs are being met by renewables.

For instance, approximately one-seventh of all fuel consumed—and over 90% of the fuel used in some third-world countries—comes from biomass; hydropower produces one-quarter of the world's electricity and over two thirds of the electricity used in over 35 countries; and sunlight directly heats the interior of almost all buildings through windows and walls, though exact figures for this contribution are unknown. Nonetheless, during the past 20 years, more industrialized countries have shown an increasing interest in renewable energy, which has increased capital investment.

The majority of conventional energy technologies are not as appealing as renewable energy technologies in many aspects.

(i) They reduce the need to utilize expensive fuels or electricity to offer low-grade forms of energy like hot water (which may be supplied in many different ways) because they can be scaled to the need and deliver energy of the quality that is necessary for a specific purpose.

(ii) They can frequently be constructed on or near the location where the energy is needed, which reduces the cost of transmission.

(iii) They can be made in huge quantities and deployed fast, in contrast to major power plants that have lengthy lead times—often ten years or longer. Quick planning and building reduce unit costs and enables planners to react swiftly to shifting demand trends.

(iv) Increased supply security and flexibility are a result of the variety of solutions that are available. Conversely, an excessive reliance on imported fuels increases a nation's susceptibility to political pressures from multinational corporations and production nations.

The supply of electricity may be threatened by common power plant problems, significant malfunctions, industrial action, or just unfavourable weather conditions.Various renewable energy types prospects were,

Solar Energy

Solar energy is abundant and accessible. The total solar radiation absorbed by the Earth and its atmosphere annually is approximately 3.8 x 10^24 J. This energy is harnessed through various technologies, including solar water heaters, solar cookers, solar cells, and power towers. Millions of installations worldwide utilize solar energy, making it a key player in the renewable energy sector.

Prospects: With advancements in technology and decreasing costs, the prospects for solar energy are bright. Continued innovation in photovoltaic cells and concentrated solar power systems promises greater efficiency and affordability, driving widespread adoption and reducing dependence on fossil fuels.

Wind Energy

Wind energy utilizes the kinetic energy available in the atmosphere's circulation. The annual energy potential from wind is substantial, estimated at 7.5 x 10^20 J. Wind turbines, both large and small-scale, are deployed worldwide to harness this energy. Multi-megawatt turbines are increasingly common, contributing significantly to global electricity generation.

Prospects: The prospects for wind energy are promising, with ongoing developments in turbine technology, grid integration, and offshore wind farms. As governments and industries prioritize renewable energy, the growth of wind power is expected to accelerate, providing a clean and reliable source of electricity.

Biomass Energy

Biomass energy derives from organic materials such as plants and wood. The solar radiation absorbed by plants annually amounts to 1.3 x 10^21 J, with a substantial portion stored as energy in biomass. Biomass serves as a vital energy source, particularly in developing countries, where it accounts for a significant percentage of fuel consumption.

Prospects: The utilization of biomass for energy is expected to expand further, driven by advancements in biomass conversion technologies and increasing awareness of sustainable energy practices. Biogas plants, in particular, hold great potential for decentralized energy production, offering a renewable alternative to fossil fuels.

Tidal Energy

Tidal energy results from the gravitational interaction between the Earth, the moon, and the sun. The energy dissipated due to tidal action is substantial, around 10^26 J annually. Despite its immense potential, tidal energy remains underutilized, with only a few operational tidal power plants worldwide.

Prospects: Tidal energy presents significant opportunities for clean power generation, especially in coastal regions with strong tidal currents. Ongoing research and development efforts aim to enhance tidal energy technology and increase its contribution to the global energy mix.

Wave Energy

Wave energy harnesses the kinetic energy present in ocean waves. Although the energy stored in waves is considerable, the deployment of wave energy technology remains limited. Operational wave energy facilities, such as tidal barrages, are relatively few in number but hold promise for future expansion.

Prospects: Despite current challenges, wave energy holds immense potential as a reliable and predictable renewable energy source. Continued investments in research and infrastructure are needed to overcome technical barriers and scale up wave energy projects for commercial viability.

Hydro Energy

Hydroelectric power relies on the gravitational force of flowing or falling water. The annual precipitation on land provides a substantial energy resource, estimated at 9 x 10^20 J. Large hydropower schemes contribute significantly to global electricity generation, particularly in developing countries.

Prospects: Hydropower remains a cornerstone of renewable energy, with vast untapped potential for further development. Small-scale hydro projects, in particular, offer opportunities for decentralized energy production and rural electrification. Continued investment in hydropower infrastructure and environmental sustainability is essential to maximize its benefits while minimizing ecological impacts.

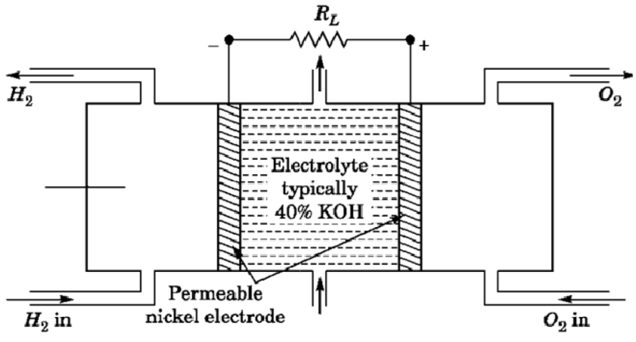
ENERGY FROM OTHER SOURCES

CHEMICAL ENERGY

A cell, or group of cells, having the ability to directly transform fuel's chemical energy into electrical energy in order to produce an electric current. In that it has an electrolyte sandwiched between positive and negative electrodes, the fuel cell is comparable to other electric cells. The positive electrode receives oxygen, frequently from air, while the negative electrode receives fuel in an appropriate form. The fuel is oxidized during cell operation, and the energy needed to convert the fuel into electricity is provided by a chemical reaction. In contrast to traditional electric cells, fuel cells obtain their active materials—fuel and oxygen—from outside sources rather than from within.

Pure—or at least relatively pure—hydrogen gas would be the ideal fuel for fuel cells, but it is more expensive. If impure hydrogen derived from hydrocarbon fuels proves to be effective, coal might potentially serve as the main energy source. Fuel cells are mostly used in automobiles, electricity generation, and specific military applications.

As mentioned, these are electrochemical devices, meaning that the fuel's chemical energy is immediately transformed into electrical energy. The free energy of the reactants used is the chemical energy. Both the temperature and the pressure are constant during this conversion. The fundamental characteristic of a fuel cell is the combination of ions, as opposed to neutral molecules, between the fuel and its oxidant.The majority of fuel cells use oxygen, either from air or oxygen, as the active material at the positive electrode and hydrogen, either pure or impure, as the active material at the negative electrode. A solid electrical conductor is needed in a fuel cell to act as a current collector and to supply a terminal at each electrode because hydrogen and oxygen are gasses. In most cases, the solid electrode material is porous.



Hydroxy H_2, O_2 cell

Platinum-like metal that is either integrated into or placed on top of the porous electrode material. When feasible, other catalysts like nickel (for hydrogen) and silver (for oxygen) are employed instead of the costly platinum metals. Numerous active sites are provided by the minuscule catalyst particles, enabling the electrochemical processes to proceed at a reasonably quick pace.

The schematic figure shows that while the design details of practical fuel cells vary, the fundamental ideas remain the same. One electrode receives hydrogen gas, whereas the other electrode receives oxygen gas (or air). There is an electrolyte layer in between the electrodes. The majority of fuel cells in use today operate at temperatures lower than 200^0C, where an aqueous solution of an acid or alkali typically serves as the electrolyte. In most cases, a porous membrane holds the liquid electrolyte in place, but in certain cells, it might flow freely. Connecting a load between the electrode terminals allows for the conventional extraction of a different electric current from the cell.

NUCLEAR ENERGY

Nuclear Fission.

Fission neutrons are released during the fission process in addition to energy being released; each fissioning nucleus typically releases two to three neutrons on average. The neutrons released have the potential to split further nuclei, which would release further neutrons that could split still more nuclei, and so on. However, a few conditions must be satisfied in order for a self-sustaining fission chain with continuous energy release to be achievable.

Neutron + Heavy nucleus →Fission fragments + Neutrons 2 to 3 + Energy

The heavy nuclei must, among other things, be such that neutrons of any energy can fission them; these materials are known as fissile species. Fission neutrons have a high kinetic energy at first, but as a result of collisions with different nuclei, this energy quickly drops. Low energy neutrons must still be able to produce from accessible materials in order for a fission chain to continue. These requirements are only met by three fissile species: plutonium-239, uranium-235, and uranium-233. Out of these three species, only uranium 235 is found in the natural world; the other two are man-made. One noteworthy feature of fission as a source of energy is its ability to function as a self-sufficient process.

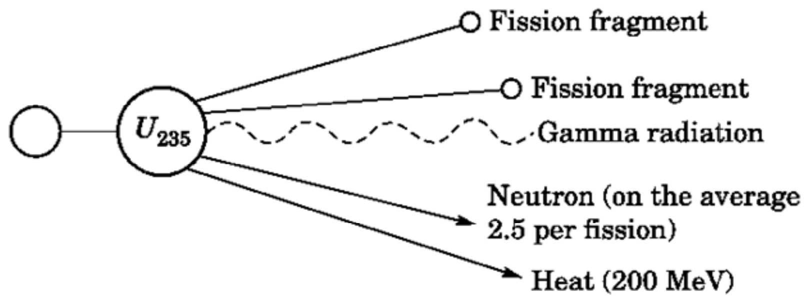
A neutron can initiate a fission, which releases more neutrons, which can then initiate other fissions, and so on. Then, a fission chain reaction with an ongoing energy release is feasible. Other particles can also trigger fission, but since two or three neutrons are typically released for every one absorbed by fission, neutrons are the only ones that can actually produce a prolonged reaction. These sustain the ongoing reactions.

The U-236 isotope is created when the nucleus of a U-235 atom absorbs a neutron. There may be only a millionth of a second that this isotopic, extremely unstable form of uranium is present. Approximately splitting into two equal parts, it releases 200 MeV of energy in total. Fission fragments, neutrons, and electromagnetic radiation, or gamma rays, are among the items that are produced. The majority of the energy generated by the fission is absorbed by the fission products as kinetic energy, which is then transformed into heat when the fragments collide. With some neutron particle emission and, in rare cases, alpha radiation, the particles decay primarily by beta and gamma radiation.

Near the fission site, the majority of the energy released is released as heat into the surrounding environment. With every fission, two or three neutrons are released on average.

$$U_{92}^{235} + N_0^1 \rightarrow Ba_{56}^{137} + kr_{56}^{97} + 2N_0^1 + \nu$$

A typical reaction resulting from the fission of uranium-235 by a neutron is the production of barium, krypton, two or three neutrons, and energy release from mass loss. Example presented schematically



The fission process

Fission fragments are the directly produced (immediate) byproducts of a fission event, as the previously mentioned Ba137 and Kr97. Fission products refer to both them and their byproducts.

ENERGY STORAGE AND DISTRIBUTION.

Energy storage may be classified according to the form in which the energy is stores. The following categories appears to be important. They are,

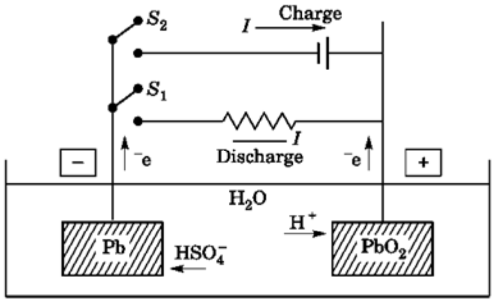
- Mechanical energy storage
- Electrical storage
- Chemical storage
- Electromagnetic storage
- Thermal energy storage
- Biological storage

Electrical storage batteries

A battery comprises individual cells, which are the elemental units containing materials and electrolytes forming the basic electrochemical energy storage mechanism. Conceptually, a battery can be likened to a black box where electrical energy is input, stored electrochemically, and later retrieved as electrical energy.

Each cell consists of two electrodes, namely the anode and cathode, immersed in an electrolyte. Upon connecting an electrical load between the electrodes, charge separation occurs at the interface of one electrode and the electrolyte, releasing both an electron and an ion. The electron traverses the external load while the ion moves through the electrolyte, recombining at the opposite electrode.

The polarity and magnitude of the cell's terminal voltage depend on factors such as electrode materials, electrolyte properties, cell temperature, and other variables. By combining cells in series and parallel configurations, batteries can generate the desired voltage and current output. Moreover, adjusting the number of cells enables the attainment of the desired power output.



Lead acid battery

One of the cells that make up the lead acid battery is schematically seen in Figure. There are two solid plates submerged in a conducting solution (electrolyte), much like in any other electrochemical cell. In this instance, the plates are shaped like grids and contain lead and lead dioxide pastes, respectively. Sulfuric acid, the electrolyte, ionizes in the manner described below.

$$H_2SO_4 \rightarrow H^+ + HSO_4^-$$

During discharge, the reaction at the negative electrode is

$$Pb + HSO_4^- \rightarrow PbSO_4 + H^+ + 2e^-$$

Energy storage via hydrogen

Energy can be both stored and transported through the utilization of hydrogen, which serves as a secondary fuel. The process involves decomposing water (H2O) through electrochemical or chemical reactions into its constituent elements, hydrogen and oxygen. These elements can subsequently be recombined to release stored energy as needed. Instead of utilizing the oxygen produced from water, commonly available oxygen from the air is employed, allowing for the sale of pure oxygen for industrial applications such as iron and steel fabrication.

Hydrogen, in various forms, can be transported for energy storage and distribution purposes. It can be transported as compressed hydrogen gas, liquid hydrogen at low temperatures, or in the form of solid compounds with specific metals or alloys. This versatility allows hydrogen to serve as a means of storing and transporting energy generated in remote locations far from traditional load centres.

Renewable energy sources, such as solar and wind, can be utilized to produce hydrogen through electrolysis. In a wind-electric or photovoltaic system with a direct current (DC) output, power can be fed directly into an electrolyzer tank, which generates hydrogen and oxygen from water. These gases can be stored either under pressure or at near-atmospheric pressure and then compressed to the desired pressure using external pumps, albeit requiring auxiliary energy. The stored hydrogen and oxygen can be converted back into electrical energy as needed through fuel cells, effectively storing the sun's energy in a usable form. This system allows for a smooth and reliable power output for a limited time determined by the hydrogen storage capacity.

Thermal Energy Storage:

The demand for thermal energy storage arises from various renewable energy applications such as solar and wind energy. This discussion delves into the general principles of heat storage, encompassing both sensible and latent heat storage methods.

Sensible Heat Storage

Sensible heat storage involves storing energy by raising the temperature of a material. This method is commonly employed in domestic water and space heating applications. Materials like water and rocks are utilized due to their ability to store energy as specific heat. However, their usage is restricted by their relatively low specific heats.

Latent Heat Storage

Latent heat storage involves storing energy through phase change, such as the transition from solid to liquid or from liquid to vapor. This method does not involve a change in temperature. Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) is a cost-effective and readily available salt hydrate used for latent heat storage. Other salts and inorganic oxides like MgO and CaO are utilized for high-temperature storage ranging from 200 to 300°C due to their significant heat of hydration.

ENERGY DISTRIBUTION

Energy distribution refers to the process of transporting energy from its source to the end-users or consumers. This process involves various methods and technologies depending on the type of energy being distributed and the distance it needs to travel. Some common distribution methods were:

Gas pipelines

The flow in the pipelines that are often used to transport fuel gasses is turbulent but not supersonic. Here, the pressure gradient (ignoring the gas's compressibility) throughout a brief section of pipe with diameter D is as follows:

$$\frac{dP}{dx} = -2f\frac{\rho u^2}{D}$$

Where;

f = friction of the fluid

p = density of the fluid

u = mean speed of the fluid

D = diameter of pipe.

The compressibility of the gas offers another benefit. The pipe itself can be used as a temporary store, simply by pumping gas faster then it is taken out so that compressed gas accumulates in the pipe, such storage is very substantial.

Electricity transmission

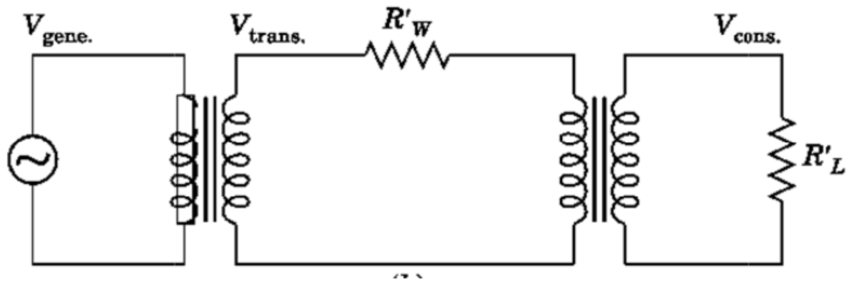
Consider two alternative systems transmitting the same useful power p toa load RL at different voltage V_1, V_2 in wire of the same resistance per unit length.

The corresponding currents are $I_1 = P/V_1$, $I_2 = P/V_2$, and therefore the ratio of power lost in the two systems is

$$\frac{P_1'}{P_2'} = \frac{I_1^2 R_w}{I_2^2 R_w}$$

$$= \left(\frac{P}{V_1}\right)^2 \left(\frac{V_2}{P}\right)^2$$

$$= \frac{V_2^2}{V_1^2}$$



Electrical transmission

At high voltage, the system dissipates a significantly less amount of electricity.

If the low voltage system were to have the same loss as the high voltage system, it would require thicker, more costly cable. For example, if energy is to be transmitted at 110 V or 220 V domestic main voltage, the cost of the cable becomes unaffordable for any distance longer than roughly 200 m. The challenge increases even further at 12 V, which is a relatively low voltage. All electrical power networks are designed with these considerations in mind. Standard rotating generators operate optimally at voltages of 10 kV. The fact that AC transmission systems are now the norm for all but the smallest networks can be attributed to the ease with which AC can be converted from one voltage to another. Power is produced at a low voltage, increased for transmission, and then decreased once again to a safer level for consumption, as seen in Figure. The dielectric breakdown of the air around the overhead wires and the insulation of the cables from the metal towers (at earth potential) limit the transmission voltage. Transmission voltages on long lines have increased from 6000 V in 1900 to over 200000 V now thanks to advancements in insulation.

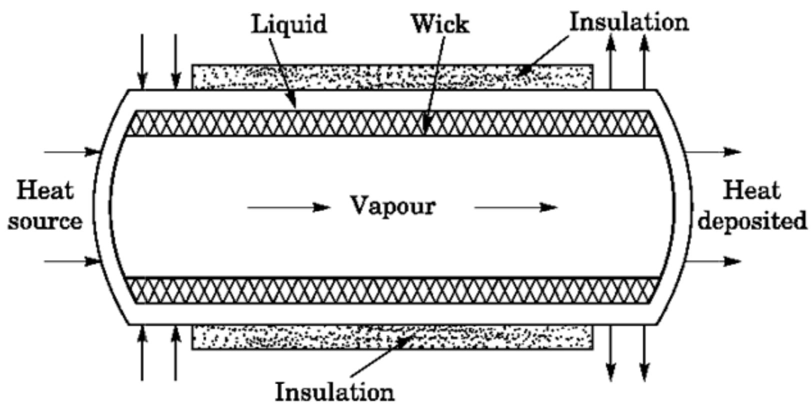
Batch Transport

Coal and biomass can be transported by road, rail, boat, or hand in appropriate containers. However, it is rarely cost-effective to spread biomass across long distances (> 1000 km) due to its low density and bulky nature. Distributing biomass purely for its energy worth is unlikely to be profitable, even over medium-sized distances (1–1000 km). Because of this, the economic and ecological usage of biomass energy sources rely on capturing energy from a biomass flow that is already occurring for another reason, such as the extraction of sugar from sugarcane, from which the leftover cane is frequently utilized to power the factory. In this instance, fuel transportation might be considered "free" or almost free. However, once they have been converted from raw biomass (for example, by pyrolysis), biofuels can be delivered over medium to large distances.

Alternatively, extremely near to its source, the biomass might be put to use. This is typically the case with firewood, which is still a vital fuel in the majority of underdeveloped nations.

Heat pipe

Another method for transferring a lot of heat over very small distances is the heat pipe. It is a tube that has a substantially higher effective conductivity than copper and holds vapor with condensate that is recycled by a wick. Typically, heat pipe uses the latent heat of a liquid's vaporization to efficiently transfer heat from a source to a cooler recipient. This section concludes with a description of an alternative type of heat pipe. A heat pipe is essentially a closed chamber that holds a suitable working liquid and its vapor. The colder substance to which the heat is to be transferred is in contact with one section of the space and the heat source is in contact with another. A porous substance known as wick lines the room's internal wall. The wick may be constructed from multiple layers of a woven metal wire mesh for high temperature functioning. Figure depicts a basic heat pipe configuration, although more intricate setups that meet the prerequisites mentioned above are conceivable as well.



Simple heat pipe

The working fluid vaporizes in the hotter (heat source) portion of the heat pipe, absorbing the latent heat of vaporization. Because of the decreased pressure, the vapour diffuses toward the colder area and condenses to liquid there. It transfers the heat of vaporization that it has absorbed from the source in this way. Through the wick's capillary action, the liquid is brought back to the area of the heat source.

Thus, heat is transferred continuously together with the movement of vapor from the heat source to the receiver and the condensed liquid back to the source.

The capacity of the heat pipe to transfer heat quickly even when the temperature differential between the source and the recipient is minimal is one of its unique characteristics. The pace of other heat transfer techniques, such as radiation, convection, and conduction, is largely influenced by the temperature differential; but, in a heat pipe, the heat of liquid vaporization is the most crucial factor to take into account.

A heat pipe also has the benefit of acting as a concentrator, allowing heat to be drawn from a broad area by vaporization and then deposited on a smaller area through condensation.

The working fluid or liquid for a heat pipe used to operate at high temperatures has been sodium, which melts at 97^0C. Because of its high heat of vaporization and excellent thermal conductivity, it is especially well suited for this use. Heat could be sent to a Stirling engine from a source—possibly stored heat—using a sodium heat pipe.

UNIT II:

ENERGY FROM THE OCEANS

ENERGY UTILIZATION

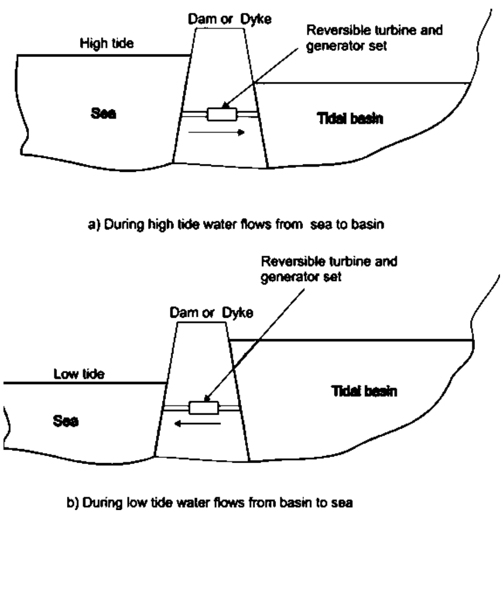
In the optimal design of Ocean Thermal Energy Conversion (OTEC) plants, proximity to shore plays a crucial role in minimizing transmission costs and maximizing efficiency. Ideally, an OTEC plant should be located within approximately 30 kilometres from the shoreline. This proximity allows for cost-effective transmission of electricity to land via submarine cables. While slightly greater distances may incur increased transmission costs, they could still remain within acceptable limits.

However, if the plant is situated too far from the shore, rendering transmission costs prohibitively high, alternative strategies can be explored. In such cases, the electricity generated at the plant site can be utilized to produce energy-intensive materials, thereby optimizing resource utilization.

One viable approach involves using direct electric current to electrolyze seawater. This process results in the decomposition of water into hydrogen and oxygen gases. The hydrogen produced can be liquefied and transported via tanker to suitable locations for use as fuel. Alternatively, it can be combined with atmospheric nitrogen to produce ammonia, a valuable compound used primarily as fertilizer. This approach offers the additional benefit of reducing reliance on natural gas, which is currently the primary source of hydrogen for ammonia production.

By considering factors such as proximity to shore, transmission costs, and alternative utilization strategies, OTEC plants can be designed and operated efficiently to harness the abundant energy potential of the ocean while minimizing environmental impact and maximizing economic viability.

ENERGY FROM TIDES



a) During high tide water flows from sea to basin

b) During low tide water flows from basin to sea

Tides, driven by the gravitational forces of the sun and moon on Earth's water, offer a vast potential for renewable energy. Estimates suggest that tidal power, derived from friction and eddies, rivals the exploitable power of all the world's rivers. Early efforts to harness ocean energy date back to the eleventh century with tidal "mills" in Great Britain, France, and Spain.The significant up-and-down movement of seawater presents an inexhaustible energy source. By utilizing the differential head between high and low tides, hydraulic turbines can convert tidal energy into electrical power. While conceptually simple, practical challenges abound. Tides are free but irregular, varying in timing and intensity and requiring substantial capital investment.

The energy crisis of the 1970s renewed interest in tidal energy. General De-Gaulle commissioned the world's first tidal power plant at La Rance in 1966, demonstrating the feasibility of large-scale tidal energy production. La Rance, with an average tidal range of 8.4 meters and a maximum of 13.5 meters, employs reversible propeller-type turbine generators. It boasts 24 turbo generator units of 10 MW each, with a capacity factor of 0.26.

Presently, France and the USSR host operational tidal power stations. The French project at Rance, utilizing a dam across the estuary, serves as a commercial station. In Canada, the Bay of Fundy boasts the world's highest tidal ranges, reaching up to 16 meters. Nova Scotia's Annapolis Royal project, commissioned in 1983, showcases innovative turbine designs, aiming to maximize efficiency and reliability.

Despite periods of stagnation, advancements continue, with ongoing efforts to overcome technical and logistical challenges. Tidal energy represents a promising avenue for sustainable electricity generation, offering a reliable and renewable resource for the future.

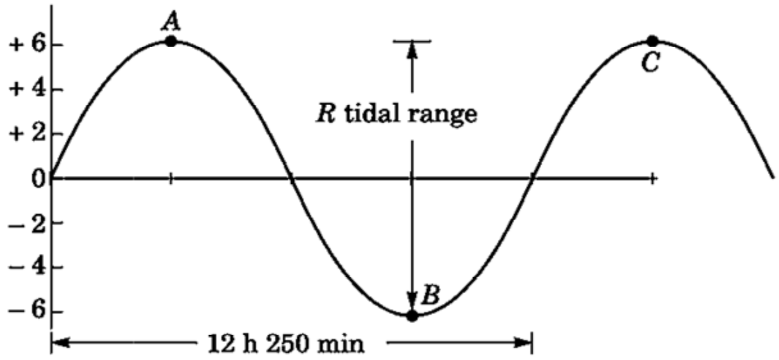
BASIC PRINCIPLE OF TIDAL POWER

Tides primarily result from the gravitational forces of the moon and the sun acting on the Earth's oceans and solid surface. Approximately 70% of tidal force is attributed to the moon, while the remaining 30% is due to the sun. The moon's gravitational pull causes water on the side of the Earth facing it to be drawn towards it, creating high tides. Simultaneously, water on the opposite side of the Earth is pulled away from the moon, also forming high tides in those areas. Consequently, low tides occur at intermediate points between the high tide zones.

As the Earth rotates, the relative position of any given area changes in relation to the moon, resulting in a periodic succession of high and low tides. Due to the interaction between the moon's gravitational force and the Earth's rotation, two high tides and two low tides are generated in a single day. Since the Earth completes one rotation every approximately 24 hours, any point on its surface passes through the tidal bulges created by the moon twice daily.

The gravitational force of the moon causes water closest to it to experience a stronger pull, resulting in a high tide bulge towards the moon. Conversely, on the opposite side of the Earth, where the gravitational force is weaker, water is pulled away from the moon, creating another high tide bulge. This phenomenon leads to semi-diurnal tides, with two high tides and two low tides occurring approximately every 24 hours and 50 minutes.

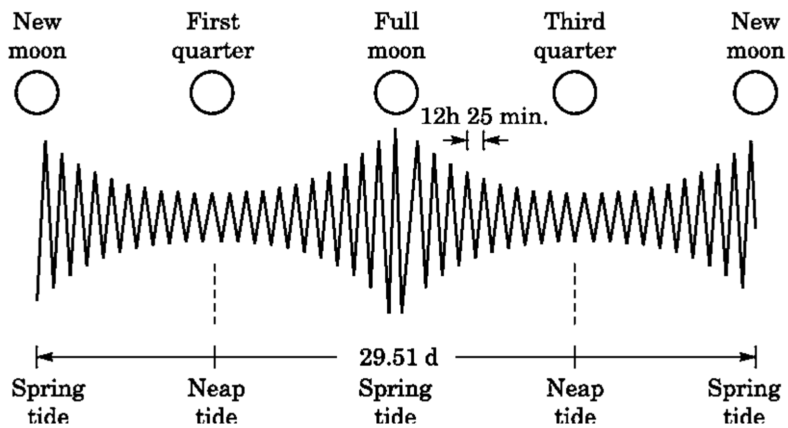
The rise and fall of water levels follow a sinusoidal curve, with high tide points denoted as point A and low tide points as point B. The time interval between high and low tides at any given location is slightly over 6 hours, forming a characteristic tidal pattern.



The tides of sea

The average duration for water to descend from point A to point B and then ascend to point C is approximately 6 hours and 12.5 minutes. The difference between the highest and lowest water levels during this cycle is termed the tidal range, calculated as the water elevation at high tide minus the water elevation at low tide (R = high tide elevation - low tide elevation). Due to the dynamic positions of the moon and sun relative to Earth, the tidal range undergoes continuous variation.

During periods near a full or new moon, when the sun, moon, and Earth align, their gravitational forces reinforce each other, resulting in exceptionally large tidal ranges. These heightened high tides and lowered low tides are termed spring tides. Conversely, during the first and third quarters of the moon, when the sun and moon form a right angle relative to Earth, neap tides occur. Neap tides are



characterized by exceptionally small tidal ranges, with lower high tides and higher low tides than the average.

It's essential to acknowledge that tidal range is not constant but subject to periodic fluctuations and variations. These variations, including monthly and seasonal ranges, must be considered when designing and operating tidal power plants. While tidal patterns are generally predictable, precise tide tables are often available to aid in planning and operations.

Tidal ranges differ from one location to another on Earth and are influenced by factors such as local shoreline profiles and water depths. The economic viability of constructing dams and associated hydroelectric power plants for harnessing tidal energy depends on the magnitude of tidal ranges. Consequently, locations with significant tidal ranges capable of justifying the considerable construction costs are limited worldwide.

UTILIZATION OF TIDAL ENERGY

The generation of electricity from water power requires that there should be a difference in levels (or heads) between which water flows. The power generation from tides involves flow between an artificially developed basin and the sea. Tidal energy generation typically involves building a dam or barrage across a tidal estuary or bay, which creates a reservoir on one side and a lower water level on the other side. As the tide rises and falls, water flows through turbines in the dam, generating electricity. The amount of electricity generated depends on the size of the dam or barrage, the speed of the tidal currents, and the tidal range (the difference in water level between high and low tide). However, in order to have a more or less continuous generation, this basic scheme can be elaborated by having two or more basins.

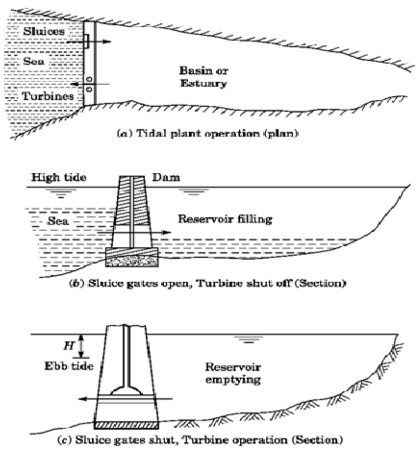
(1) Single basin arrangement
(2) Double basin arrangement.

Single basin arrangement

In a single tide cycle system, generation is influenced by the sea's flood tide. During this phase, water from the sea flows into the basin via turbines to generate power. Once the flood tide subsides and the sea level begins to decrease, generation ceases, and the basin is emptied back into the sea through sluice ways. This flood operation scheme typically requires larger plants that operate for shorter periods, making them less efficient compared to ebb tide operation.

Conversely, ebb operation plants are smaller in size but operate over longer periods. The goal is to maximize operational time while minimizing the operating head. Adjustable blade bulb turbines are ideal for such operations under low and variable heads.

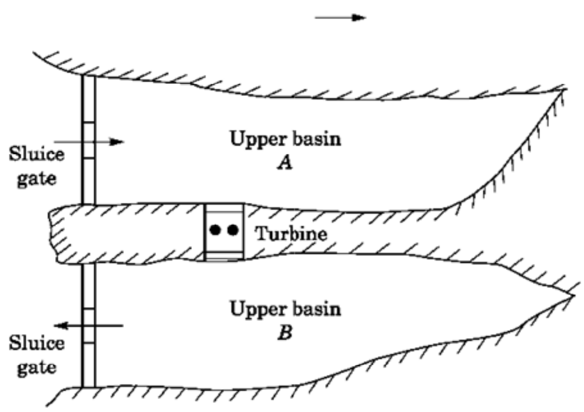
Tide cycle systems necessitate deeper reservoirs to accommodate the sluice gate sills, leading to higher construction costs. Studies suggest that energy production from an ebb cycle system can exceed that of a tide cycle system by up to 1.5 times. Understanding these operational dynamics is crucial for optimizing tidal energy generation.



Single basin

Double basin arrangement

In this dual-basin system, turbines are strategically positioned between adjacent basins, while sluice gates are integrated into the dam structure spanning the estuaries' mouths. At the onset of the flood tide, the turbines are inactive, and the gates of upper basin A are opened while those of lower basin B are shut. Basin A begins to fill while Basin B remains empty. Once the water level in A provides adequate head over B, the turbines are activated, and water flows from A to B through the turbines, facilitating power generation. This process continues concurrently with Basin A's filling.



Dual basin

As the flood tide reaches its peak and Basin A attains maximum capacity, its sluice gates are closed. Subsequently, when the ebb tide causes Basin B's water level to drop below A's, its sluice gates open, allowing water to flow from B to A, thus increasing the head for turbine operation. This cycle repeats with each tidal cycle, enabling a prolonged and uninterrupted period of power generation.

Despite the continuous water flow between the basins, variations in water head occur within each tidal cycle and from day to day, impacting power generation consistency. To mitigate this, off-peak power generated by tidal sources or alternative systems can be utilized to pump water from the low basin to the high basin during times of low demand. This process increases the head available for tidal power generation during peak demand, resembling the principles of pumped storage systems in hydroelectric power stations.

Understanding and optimizing the operation of such dual-basin schemes are vital for maximizing tidal energy generation efficiency and meeting fluctuating energy demands effectively.

PRINCIPLE OF OCEAN THERMAL ENERGY CONVERSION SYSTEMS

PRINCIPLE OF WORKING OF OTEC:

The water at the surface of the ocean is warmer than the water at deeper depths. This temperature difference can be used by Ocean Thermal Energy Conversion (OTEC) systems to generate electricity.

Construction:

Warm water intake:

OTEC requires a large amount of warm surface seawater to drive the heat engine. The temperature of this water should be around 20-25°C (68-77°F) or higher, depending on the specific OTEC design.

Cold water intake:

OTEC also requires a large amount of cold deep seawater to condense the working fluid of the heat engine. The temperature of this water should be around 5-10°C (41-50°F) or lower, depending on the specific OTEC design.

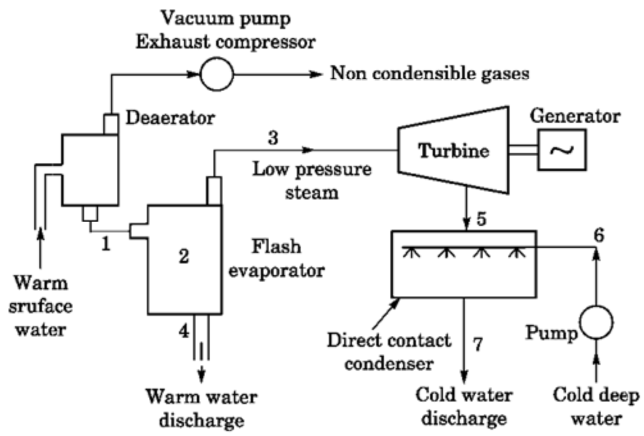
Heat exchanger: The heat exchanger is the component that transfers heat from the warm seawater to the working fluid, which is typically a low-boiling-point fluid such as ammonia.

Turbine: The working fluid vaporizes as it is heated and expands through a turbine, which generates electricity.

Condenser: The working fluid is then cooled and condensed back to a liquid state using cold seawater in the condenser, ready to be used again in the heat exchanger.

Working

In an Ocean Thermal Energy Conversion (OTEC) plant, warm surface water heats low boiling point liquid ammonia, converting it into a gas. This pressurized ammonia vapor drives turbines connected to generators, producing electricity from ocean thermal energy. After passing through the turbines, the used vapor is condensed back into a liquid state by cold water from deeper ocean layers in a condenser. This cycle repeats to ensure continuous electricity generation. Crucially, the OTEC system requires a temperature difference of at least 20°C between surface and deeper waters, extending up to 2 km deep, to function effectively.



OTEC

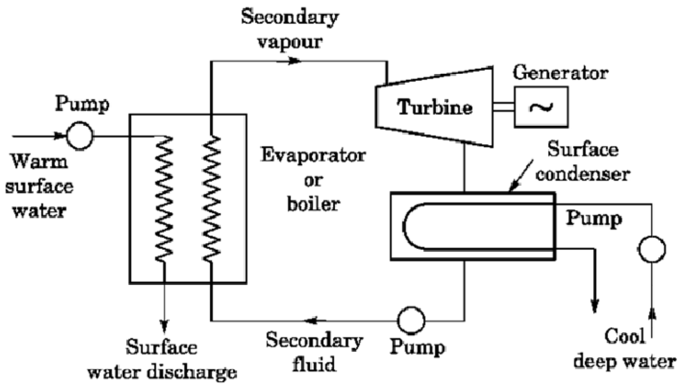
The Closed or Anderson, OTEC cycle

A schematic of a closed cycle OTEC power plant is shown in Figure. Evaporators and condensers, two types of heat exchangers, are essential components because they require large surface areas to transmit large amounts of low-quality heat from the low temperature differentials being used. Put differently, a lot of water needs to be pumped through the OTEC power plant.

fluid that uses heat exchangers (surface condenser, evaporator, or boiler) to accept and reject heat to the source and sink. Propane, ammonia, or Freon could be the working fluid. These fluids have substantially greater operational (saturation) pressures than water at the boiler and condenser temperatures roughly 10 kg/cm2 (10 bar) at the boiler—and significantly lower specific volumes. They are comparable to steam in traditional power plants.

Turbines that employ the low-pressure steam of the open cycle are substantially larger and hence more expensive than ones that use these pressures and specified volumes.

Additionally, the closed cycle eliminates the evaporator's issues. However, because the amounts of heat added and rejected are around 50 times the plant's output, it necessitates the use of very large heat exchangers (boiler and condenser), with an efficiency of about 2%. To enable the greatest temperature differential across the turbine, the boiler and condenser temperatures must also be



Closed OETC

maintained as low as feasible, which adds to the significant surfaces of these units.

Although Barjot first presented the closed cycle technique in 1926, Anderson and Anderson's version from the 1960s is the most current. The Anderson Cycle is another name for the closed cycle. Propane was selected as the working fluid in the cycle. There was a 200C temperature differential between the warm and cool surfaces. The depth of the chilly surface was roughly 600 m. Propane is vented in the condenser at around 5 bar after being vaporized at 10kg/cm2 (10 bar) or higher in the boiler or evaporator.

UNIT III:

WIND ENERGY SOURCES

BASIC PRINCIPLES OF WIND ENERGY CONVERSION

- **The Nature of the Wind**

The uneven heating over water is what causes the air to circulate in the atmosphere. This is shown as a strong onshore wind in coastal places. The process is reversed at night as the breeze blows off shore as a result of the air cooling down over the land more quickly.

Similar processes drive the primary planetary winds: warm air over the tropics rises as cool surface air from the poles flows down. However, the earth's rotation influences the direction of these enormous air movements, resulting in a significant country-clockwise air circulation around low-pressure zones in the northern hemisphere and a clockwise circulation in the southern hemisphere. As the solar input fluctuates with the seasons, so do the planetary winds' strengths and directions.

Even though the wind is sporadic, the patterns of the wind at any given location are astonishingly consistent from year to year. In coastal and hilly regions, average wind speeds are higher than those deep inlands. Where there is less surface drag, the winds also have a tendency to blow over the water's surface more steadily and strongly.

As one rises in elevation, wind speed increases. They are found to be 20–25% greater than near to the surface when they are measured at the typical height of ten meters. Because of the earth's surface's decreased drag, they may be 30–60% higher at 60 meters.

- **POWER IN THE WIND**

The motion of the wind gives it energy. Any apparatus, such as a sail or propeller, that can slow down the mass of moving air can collect some of the energy and use it to do work that is beneficial.

The output of a wind energy converter is determined by three factors:

(i) wind speed;
(ii) wind swept by the rotor cross-section; and
(iii) total conversion efficiency of the rotor, transmission system, generator, or pump.

The idea of kinetics can be used to calculate the power in the wind.

The wind mill operates on the tenet of transforming wind energy from kinetic to mechanical form. Power is equivalent to energy per unit of time, as we know. The wind's kinetic energy is the accessible energy. Any particle's kinetic energy is 1/2 mV2, or half its mass times the square of its velocity. The mass of air, m, is equal to its volume times its density, p, and the amount of air that moves across an area A at a velocity of V in a unit of time is A. V.

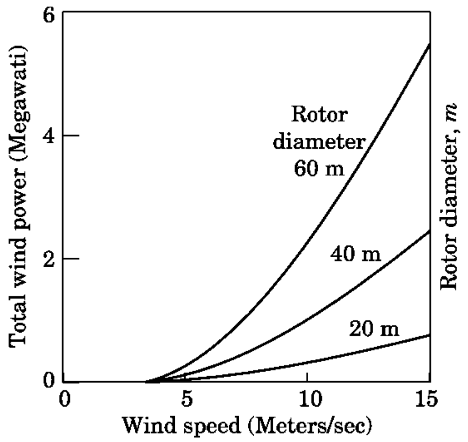
$$m = \rho\, AV$$

$$= \frac{1}{2}\rho A V^3 \text{watts}$$

According to the equation, the maximum wind that is actually accessible will be somewhat less because the energy that is available is proportional to the cube of the wind speed and cannot all be extracted. Thus, it is clear that even a slight increase in wind speed can have a significant impact on wind power.

Available wind power

$$P_a = \frac{P}{2}\frac{\pi}{4} D^2 V^3 \text{watts}$$



Plotting was done to show the combined impact of wind speed fluctuations and rotor diameter.

The power-coefficient is the percentage of free-flow wind power that a rotor can harvest; thus

Power coefficient is the product of wind rotor power and wind available power.

FORCES IN THE BLADES

Propeller-type wind turbine blades are taken into consideration here. The blades are under the influence of two different kinds of forces. The two forces that produce torque are the circumferential force operating in the direction of wheel rotation and the axial force acting in the direction of the wind stream, which produces an axial thrust that needs to be countered by appropriate mechanical design.

It is possible to determine the torque T, or circumferential force, from

$$T = \frac{P}{\omega} = \frac{P}{\pi DN}$$

The real efficiency $\eta = \frac{P}{P_{total}}$

Where;

T = torque in newton.

ω = angular velocity of turbine wheel in m/s.

D = diameter of the turbine wheel.

R = wheel revolution per unit time.

WIND ENERGY CONVERSION

During the Middle Ages, traditional windmills were widely employed for watering animals and draining land, as well as grinding grain. In certain regions of the world, wind energy converters are still utilized for these functions today, but producing electricity with them is currently the principal application for them. Although the market for wind-powered water and space heaters as well as glass houses is expanding, it is still far less than that of electricity production.

Though it is rarely used today, the term "wind mill" is still frequently used to refer to wind energy conversion systems. The terms "WECS," "aerogenerators," "wind turbine generators," or even just "wind turbines" are more appropriate when referring to modern wind energy conversion systems.

For certain uses, such as pumping water for land drainage, the wind's variable and intermittent nature is insignificant—that is, if there is a broad match between the energy required and the energy delivered over any important period. The work gets done if the wind blows; if not, it has to wait. However, the disruption of supply may be extremely inconvenient for numerous applications of energy. Wind turbine operators and users are required to make sure that there is a backup plan in place for times when there is either too little or too much wind. Backup options for small manufacturers include:

(i) storing batteries;
(ii) connecting to the neighbourhood's electrical grid;
(iii) utilizing a liquid or gaseous fuel-powered stand-by generator.

Large producers.

Large and medium-sized wind turbines are made to feed electricity directly into the grid and to provide a steady and consistent electrical production over a broad range of wind speeds. Their main function is to save fuel, which lowers the overall fuel consumption of the utility.

The size of the local distribution grid and the generating capacity that goes along with it determine the type of generator to use. Normally, an induction generator is employed in situations where a sizable quantity of additional generating capacity exists (which could supply the reactive power required for excitation). Induction generators require less control equipment and are strong and dependable. A synchronous generator is better suited for isolated networks with limited other local generating capacity and high levels of autonomous control requirements.

Compared to induction machines, synchronous generators are more costly due to their increased complexity.

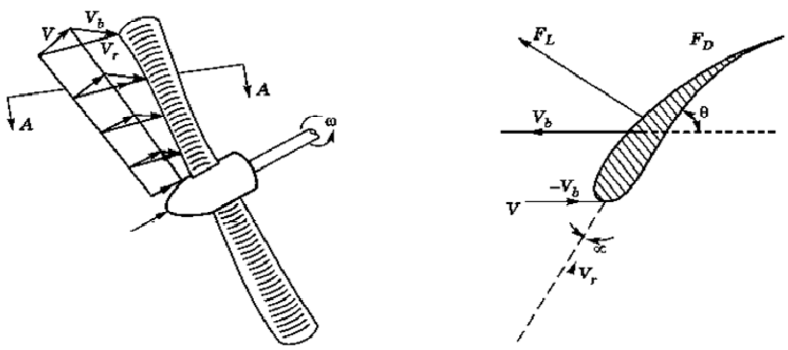
Lift and drag:

The foundation for converting wind energy. The process of producing specific forces and using them to rotate (or translate) a mechanism is necessary in order to extract power, and consequently energy, from the wind. The two main processes that harness the force of the wind are lift and drag.

Drag forces act in the direction of the flow, whereas lift forces act perpendicular to the air flow. Lift forces are generated by altering the air stream's velocity over either side of the lifting surface. A faster air flow results in a lower pressure, whereas a slower air stream generates a higher pressure. Stated differently, every variation in velocity causes a pressure differential across the lifting surface. A force known as an airfoil is created by this pressure differential, which starts to work on the high-pressure side of the lifting surface and travels toward the low-pressure side. An excellent airfoil has a high lift/drag ratio; under certain situations, it can produce lift forces that are 30 times greater than the drag force parallel to the flow when perpendicular to the direction of the air stream. Up until the point where the angle of the air flow on the low-pressure side becomes excessive, the lift increases as the angle produced at the junction of the airfoil and the air-stream (the angle of attack) gets less and less accurate. At this point, the air flow splits off from the low-pressure side.

There are two other methods for producing lift besides airfoils. One is the so-called Magnus effect, which results from rapidly rotating a cylinder in a stream of air. The spinning creates a similar effect to an airfoil by slowing down the air speed on the side of the cylinder moving into the wind and increasing it on the other. Although this idea isn't usually used, it has been applied practically in one or two instances. The second method involves forcing air through cylinder's tiny Thwaits holes, which allow the air to exit tangentially. Additionally, this causes the air flow to rotate, or circulate, which produces lift.

The latter techniques presumably have little practical value because the lift drag ratio of airfoils is often significantly better than that of revolving or slotted cylinders.



Windmill blade

V = Free wind velocity

V_b = Velocity of airfoil element

V_r = Resultant wind as seen by airfoil element

F_L = Lit force perpendicular to V_r

F_D = Drag force

θ = Angle of twist

α = Angle of incidence

ω = Angular speed of rotor

r = Distance of airfoil element from its axis of rotation.

ADVANTAGES AND DISADVANTAGES OF WIND ENERGY CONVERSION SYSTEMS (WECS)

Advantages

- It is a renewable source of energy.
- Like all forms of solar energy, wind power systems are non-polluting, so
- it has no adverse influence on the environment.
- Wind energy systems avoid fuel provision and transport.

- On small scale up to a few kilowatts system is less costly. Only a large-scale cost can be competitive with conventional electricity and lower cost.

Disadvantages

- Unlike water energy wind energy needs storage capacity because of its irregularity.
- Wind energy systems are noisy in operation; a large unit can be heard many kilometres away.
- Wind power systems have a relatively high overall weight, because they involve the construction of a high tower and include also a gearbox, a hub and pitch changer, a generator coupling shaft etc. For large systems a weight of 110 kg/kW (rated) has been estimated.
- Large areas are needed, typically, propellers 1 to 3 m in diameter, deliver power in the 30 to 300 W range.
- Present systems are neither maintenance free not-practically reliable. However, the fact that highly reliable propeller engines are built for aircraft suggest that the present troubles could be overcome by industrial development work.

ENERGY STORAGE

At very high or very low wind speeds, it is not practicable to operate a wind turbine. Consequently, energy storage of some kind is needed in case other sources—like electric utility power—are not available. The excess energy would be kept for use at a later time when the power generated exceeded the need. Battery storage is practical for WEC devices with low and intermediate electric power.

Storage increases the MTECS's usability by enabling peak shaving, capacity reduction, and fuel savings. It can be costly, though, so each utility will need to decide whether to install it or not. It is made feasible via storage.

Batteries can be directly charged by direct-current generators with wind turbines up to around 20 kW in power output. Generators are needed for greater power alternating current, and the current needs to be rectified in order to charge batteries. When a cell or battery is discharged, the chemical reaction that occurs within it while charging is reversed. As a result, when a charged cell is discharged, chemical energy that was previously stored as electrical energy can be recovered. The batteries can be used to provide direct current for lighting, small tools, and appliances, as well as for heating water for residential use and space heating.

Television sets and other large equipment may require conversion into alternating current using an inverter. There may be better storage options for agricultural businesses.

For instance, wind energy can be stored as hot water (Heat storage) and utilized to heat greenhouses or dry crops. Resistance heaters can then be utilized with either direct current or alternating current without the requirement for batteries.

Alternatively, frictional forces like churning water can directly transform the mechanical motion generated by the wind turbine into heat.

A favourable scenario would be the operation of many wind turbines in conjunction with a hydroelectric power plant for mechanical or water power storage, where high-power aerogenerators are integrated with an electric grid. The hydroelectric plant can partially shut down if the total amount of electricity generated—wind and hydroelectric—exceeds the demand. Alternatively, the extra power can be used to pump water back into the main reservoir from an auxiliary reservoir located at the bottom of the dam. The hydroelectric system's overall capacity would rise in this way.

Another option for potentially storing energy is to store it in a compressed air volume. For instance, it would be possible to build a wind turbine that would immediately pump air into an appropriate pressure storage tank. The air's stored energy might then be used to power an air turbine, whose shaft would then power a generator, providing the necessary electric power during windless periods. Wind energy can be immediately supplied into an electrolyzer, which uses regular water to create hydrogen and oxygen, since it has a d.c. output. The resulting hydrogen and oxygen gasses can be stored as liquids or gases, and when needed, they can be swiftly and simply transformed back into electric energy using the well-known fuel cell. Moreover, cars and other practical engines may run on hydrogen as a fuel.

APPLICATIONS OF WIND ENERGY

Direct Heat Applications.

Wind-powered machinery can be used to drive heat pumps, generate heat through the friction of solid objects, churn liquids, or in other situations, use centrifugal or other pumps in conjunction with restrictive orifices that allow the working fluid to pass through them and produce heat through turbulence and friction. The heat can then be used directly for things like air conditioning and heating in residential buildings, or it can be stored in materials with a high heat capacity like water, stones, eutectic salts, etc.

It has also been possible to create a home heating system that produces direct heat for a building without first producing energy by means of a wind-powered pump and a restrictive orifice.

Greenhouse applications, crop drying, milk processing, food processing, refrigeration, frost protection, ventilation, and waste processing are a few examples of potential uses for wind-powered agricultural process heat.

The following are some examples of common industrial processes that could be able to employ low temperature heat (i.e., heat produced by wind energy up to about 175^0C).

(1) Inorganic chemical production, such as sodium metal, potassium chloride, borax, bromine, and chlorine.

(2) The production of synthetic materials and plastics, including polyethylene, polyvinyl chloride, and polystyrene, requires around 45% of the process steam to be at a temperature between 100 and 1750 degrees Celsius.

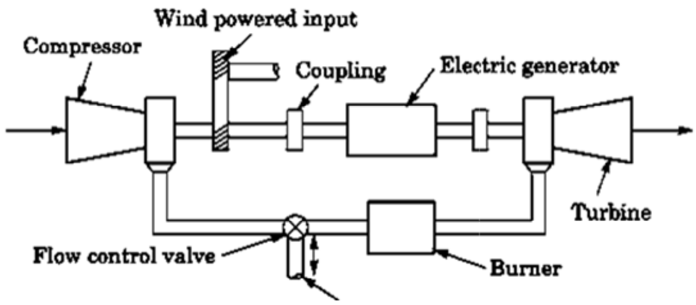
(3) Production of organic chemicals, including different kinds of alcohols and solvents, artificial fragrances, flooring materials, chemicals used in rubber processing, etc.

(4) Food processing, which uses around 80% of the process heat at temperatures lower than 1750C. This includes packing and preparing meat, dehydrating fruits and vegetables, wet grinding corn, milling soybean oil, etc. Roughly 25% of this is used for dehydration, 15% for cooking, and process heating.

(5) Textile processing, mostly using hot air or steam to dry, cure, and finish fabrics and threads.

Pumping application

When using pumped hydro, the wind units can provide the energy needed to pump water back into the main reservoir above the hydroelectric dam from an auxiliary reservoir below it. This increases the hydroelectric system's ability to provide base load electricity by allowing the water in the main reservoir to be refilled during windy conditions. Times when a public utility system is at its busiest. Conventional gas turbines can be adapted to separate the generator, compressor, and power stages using



Wind pump

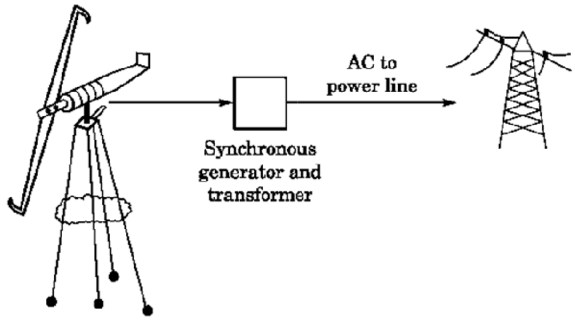
clutches for this kind of application. In one mode of operation, the air compressor is driven by the motor generator, which is powered by a wind machine and functions as a motor.

A storage tank, sizable cave, depleted natural gas well, or aquifer are some of the places where the compressed air is provided. In this mode, no fuel is used and the power turbine is not operational.

Electric Generation Applications.

In centralized utility applications, synchronous a.c. electrical generators can be powered by wind energy. Through voltage step-up transformers, the energy is directly delivered into power networks in these applications.

WECS units have the ability to be utilized in a "water-saver" mode of operation and connected with current hydroelectric networks. The hydroelectric plants in the network may decrease their electrical generation by the same amount as the "WECS units" when the wind is blowing. In order to enable the water saved in the reservoir to be used at a higher rate when the wind was not blowing, a portion of the network load generating facilities are installed at the hydro-plant. This results in a firm generating capacity that is equal to the firm generating capacity of the hydro-plant plus the average generating capacity of the wind-powered plant.



Electricity generation system via wind

Wind energy can be utilized in distributed applications to provide direct current electrical power. This electricity can then be used for dc applications or space heaters like resistance heaters, or it can be stored in batteries and turned on to power alternating current loads.

UNIT IV:

ENERGY FROM BIOMASS

BIOMASS CONVERSION TECHNOLOGIES

Biomass conversion technologies can take many form

- Direct combustion
- Thermochemical conversion
- Biochemical conversion

Direct combustion

The most popular technique for turning biomass into useable energy is direct burning. For most crops, drying may be necessary before combustion since direct combustion requires biomass with a moisture content of 15% or less. Any type of biomass can be burned directly to heat buildings and water, provide process heat for industry, and power steam turbines. A biomass-fired gasifier has a maximum temperature of 900 degrees Celsius. In order to avoid the creation of pollutants including particulate matter, nitrogen oxides, and unburned hydrocarbons, it is imperative to maintain the optimum temperature during combustion.

Thermochemical conversion

Thermochemical conversion takes two forms:

- Gasification
- Liquefaction

Gasification

Low heating value gas is produced during gasification by heating the biomass with little oxygen, or medium heating value gas is produced by reacting the biomass with steam and oxygen at high pressure and temperature. The latter can be immediately utilized as fuel or transformed into high heating value gas or methanol (methyl alcohol CH30H) or ethanol (ethyl alcohol CH3CH20H) through liquefaction.

Liquefaction

This thermal decomposition process involves heating organic materials, including wood, plastics, tires, and agricultural waste, in a sealed chamber without oxygen to create a syngas (synthesis gas), which is a mixture of carbon monoxide (CO), hydrogen (H_2), and methane (CH4). Next, liquid bio-oil is produced, and lastly solid biochar is formed.

Biochemical conversion

Fermentation is the breakdown of complex molecules in organic compound under the influence of a ferment such as yeast, bacteria, enzymes, etc. Fermentation is a well-established and widely used technology for the conversion of grains and sugar crops into ethanol. This process requires high cost and high energy required.

WET AND DRY PROCESS

Wet process

Biodegradation.

The biowaste is collected in the digester tank above the slurry throughout this operation and can be continually piped off. Complete animal or human faeces decompose in about ten days at the ideal temperature of 350C. The type of waste has a significant impact on gas output; for example, pig manure produces more gas than home trash or cow dung. In a modern batch or continuous feed unit, one kilogram of dry weight organic material should provide 450–500 liters of biogas (9–12 MJ) at atmospheric pressure; that is, one and a half to two digester volumes of gas each day. After digestion, the residue is useful fertilizer. It has a high protein content as well and can be dried and used to animal feed as a supplement.

Chemical reduction.

The least advanced method of wet biomass conversion is chemical reduction. It includes heating plant cellulose slurry or animal wastes under pressure at temperatures between 2500 and 4000 degrees Celsius while using an alkaline catalyst and carbon monoxide. The organic material is transformed into a mixture of oils under these circumstances, with a yield that is close to 50%. A high calorific value gas is produced when the temperature is raised and the pressure is decreased.

Dry process

Hydrogenation.

Carbon monoxide and steam react with cellulose under less extreme temperature and pressure settings (300–4000C and 100 atmospheres) to produce heavy oils that may be separated and processed into premium fuels.

Gasification and liquefaction of biomass are commercial technologies that are actively being developed in many countries.

Steam-gasification.

Direct production of methane from woody matter involves treating it with hydrogen gas at high pressures and temperatures. One can either add hydrogen or, more frequently, use steam and carbon monoxide inside the reactor vessel to create hydrogen. According to recent assessments, the most effective method for producing methanol is steam gasification. Although better yields are possible in the future as the technology is developed, net energy yields of 55% can be reached.

PHOTOSYNTHESIS

Photosynthesis is the biological process by which green plants, algae, and some bacteria convert light energy, typically from the sun, into chemical energy in the form of glucose and oxygen. It is a fundamental process for life on Earth, as it provides the primary source of energy for most organisms.

The overall chemical equation for photosynthesis is:

$$\mathbf{6CO_2 + 12H_2O + light\ energy + chlorophyll \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O}$$

The conditions necessary for photosynthesis are:

Light.

The intensity of solar radiation is one of the key inputs for the creation of biomass; however, only 40–45% of this energy is of the proper wavelength (400–700 Å) for photosynthesis. Only a portion of the energy that plants absorb from radiations between 400 and 700 Å is really used for photosynthesis.

Photosynthetically active radiation is the term for this spectrum of light (PAR). The effectiveness of photosynthesis has a maximum of approximately 5%.

CO_2 Concentration.

The main raw ingredient for photosynthesis is carbon dioxide. Approximately 0.03% of the atmosphere is made up of CO_2. On the other hand, there has been evidence of a limited but linear rise in the yield of several crops in the event that CO_2 availability is artificially raised. Therefore, feeding the plants more CO_2 is one way to increase biomass.

Temperature.

Photosynthesis is limited to the temperature range between 0^0 C and 60^0 C, which is the range that proteins can withstand. While the photochemical portion is unaffected by temperature, the biochemical portion, which is regulated by enzymes, is extremely susceptible to changes in temperature.

BIOGAS GENERATION:

INTRODUCTION

Through the breakdown of plant, animal, and human waste, biogas—a combination of 55–65% methane, 30–40% carbon dioxide, and the remaining impurities (H2, H2S, and some N 2—can be created. Its calorific value typically ranges from 5000 to 5500 kcal/kg (20935 to 23028 kJ/kg), or 38131 kJ/m3. It burns cleanly but slowly. It can replace firewood in cooking by being used directly. Furthermore, the material used to make the biogas may be recycled back into the soil and keeps its value as fertilizer. Up till now, biogas has been the raw material used in its manufacture. Not only may the excreta from cattle be utilized to generate biogas, but also the waste from piggeries and chicken droppings. Algae are among the additional resources that can be used to produce biogas. Biogas can also be produced through hydrogasification, pyrolysis, or digestion. Digestion is a biological process that takes place at ambient pressures and temperatures between 35 and 700 degrees Celsius, in the absence of oxygen and in the presence of anaerobic organisms. The digester is the container where this process of digesting occurs.

BASIC PROCESS

AEROBIC AND ANAEROBIC DIGESTION

Aerobic digestion

Aerobic digestion is a biological process used to treat organic waste, such as sewage sludge, agricultural waste, or organic solid waste, in the presence of oxygen. It involves the breakdown of organic matter by microorganisms into simpler, stable compounds like carbon dioxide, water, and energy-rich biomass.

In aerobic digestion, oxygen is provided to support the growth and activity of aerobic microorganisms like bacteria and fungi. These microorganisms consume the organic material as a source of energy and nutrients, breaking it down through biochemical reactions. The process typically occurs in tanks or reactors where the waste is mixed with air to ensure sufficient oxygen levels for microbial activity.

Aerobic digestion has several advantages over anaerobic digestion, another common waste treatment process. It operates at higher temperatures, usually between 40°C to 60°C, which helps to accelerate the microbial activity and reduce the retention time required for digestion. Additionally, aerobic digestion produces less odorous byproducts compared to anaerobic digestion and does not generate methane, a potent greenhouse gas.

Overall, aerobic digestion is an effective method for treating organic waste, producing stabilized material that can be safely used as fertilizer or soil conditioner, and reducing the volume of waste for disposal. However, it requires energy input for aeration and may not be suitable for all types of organic waste.

Anaerobic digestion

Microorganisms are the focus of biogas technology. These tiny, living things are undetectable to unassisted eyes and are minuscule in size. These microbes come in several varieties. They go by the names of viruses, fungus, bacteria, etc. Once more, bacteria are divided into two groups: good bacteria and bad bacteria. Beneficial bacteria, for example, produce vinegar, compost, and biogas. Dangerous bacteria include those that cause cholera, typhoid, and diphtheria. This class of bacteria is known as a pathogen because it may infect humans and animals and cause disease.

The two main categories of bacteria can be distinguished by their oxygen requirements. Anaerobic growth occurs when there is no gaseous oxygen present, whereas aerobic growth occurs when there is oxygen present. Gas is produced during the anaerobic digestion process of organic matter when it ferments—a chemical shift brought about by living organisms. We refer to this gas as bio-gas. A range of facultative and anaerobic microorganisms' ferment or bio digestion different wastes to produce biogas. It is possible for facultative bacteria to grow in the presence or absence of oxygen or air.

Organic matter can be broken down by fermentation, both anaerobic and aerobic. Aero bic fermentation often results in the production of C02, NH3, a degraded material, and a minor quantity of other gases in addition to heat evolution. Anaerobic fermentation yields a degraded material as well as C02, CH4, H2, and trace amounts of other gases.

When recovering plant nutrients for later use in the fields and hygienic material are the primary goals, aerobic fermentation is employed. Nutrients including C, N2, P, and K are abundant in the residue. The primary goal of anaerobic digestion is to produce methane in a biogas plant. Here, acid-producing bacteria break down the complex organic molecule into sugar, alcohols, insecticides, and amino acids. Another class of bacteria then uses these compounds to make methane.

ADVANTAGES OF ANAEROBIC DIGESTION

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

Calorific valve of gas.

The creation of biogas, a byproduct with a calorific value that can be used as an energy source to generate steam or hot water, is one of the primary advantages. Gas storage and supply are not an issue in the dairy industry since energy sources are crucial for the production of dairy products. However, gas has direct utility in the form of heat energy.

New sludge production.

Methane and carbon dioxide are produced when organic matter is converted, leaving less surplus sludge behind.

Stable sludge.

Municipal digestion systems were installed primarily to produce an inoffensive and non-putrescible sludge; in many cases, just a part of the gas generated was used.

Low running cost.

The anaerobic treatment does not involve any aeration. Operating costs in this digestion are naturally 25% of those in an analogous aerobic system.

Low odour.

The confined nature of the mechanism keeps the odors contained. Digestive processes break down the compounds that cause odor. Hydrogen sulfide typically emits a very faint odor in gas form. But the issue won't occur if the gas is burned.

Stability.

Anaerobic sludge that has been properly adjusted can be left unfed for a long time without showing any signs of degradation.

Pathogen reduction.

Research has demonstrated that the digester's transit of the effluent lowers the quantity of pathogens present, hence minimizing disposal issues later on.

Value of sludge.

When anaerobic treatment is applied to aerobic sludge, the resulting sludge contains more nitrogen. Additionally, the use of biogas in industry will reduce the amount of coal consumed. Air pollution will be reduced if boilers run on biogas rather than coal.

FACTORS AFFECTING BIO DIGESTION AND GENERATION OF GAS

The following are the factors that affect generation of biogas:

1. pH or Hydrogen-ion Concentration:

- Optimal pH range between 6.5 to 7.5 promotes efficient microbial activity for methane production.
- Acidic pH below 6 inhibits methanogenic organisms, reducing biogas yield.

2. Temperature:

- Elevated temperatures, typically between 35°C to 40°C, accelerate microbial activity and enhance biogas production.
- Low temperatures slow down digestion rates and can lead to process inhibition, especially below 20°C.

3. Total Solid Content of the Feed Material:

- Proper adjustment of total solid content, typically 8-10%, ensures optimal conditions for microbial digestion.
- Excessive solids can lead to poor mixing, reduced gas production, and potential digester blockages.

4. Loading Rate:

- Controlled loading rates maintain optimal conditions for microbial activity and prevent overloading, which can lead to process instability.
- High loading rates can cause acidification and inhibit methane production.

5. Uniform Feeding:

- Even distribution of feed material ensures consistent digestion and gas production throughout the digester.
- Irregular feeding patterns can lead to localized accumulation of solids, reducing overall efficiency.

6. Carbon to Nitrogen Ratio:

- Balanced C:N ratio (typically 20-30:1) supports microbial growth and ensures efficient decomposition of organic matter.
- Imbalanced ratios can lead to nitrogen limitation or excess, affecting microbial activity and biogas yield.

7. Seeding:

- Adding starter cultures or "seeds" containing active methanogenic bacteria jump-starts the digestion process.
- Insufficient or ineffective seeding can result in prolonged lag phases and reduced biogas production initially.

8. Diameter to Depth Ratio:

- Proper design with an appropriate diameter to depth ratio ensures efficient gas mixing and distribution within the digester.
- Improper ratios can lead to poor gas circulation, stratification, and reduced overall biogas yield.

9. Nutrients:

- Adequate supply of essential nutrients such as nitrogen, phosphorus, and trace elements support microbial growth and metabolism.
- Nutrient deficiencies can limit microbial activity and biogas production.

10. Mixing or Stirring or Agitation of the Content of the Digester:

- Regular mixing or agitation prevents solids from settling, maintains homogeneity, and enhances contact between microbes and substrate.

- Inadequate mixing can lead to stratification, decreased digestion efficiency, and reduced biogas production.

11. Retention Time or Rate of Feeding:

- Sufficient retention time allows for complete digestion of organic matter and maximizes biogas production.
- Overfeeding or short retention times can lead to incomplete digestion and reduced gas yield.

12. Type of Feedstocks:

- Different feedstocks vary in their composition and digestibility, affecting biogas yield and process stability.
- Certain feedstocks may contain inhibitors or compounds that require special processing to optimize biogas production.

13. Toxicity due to End Product:

- Accumulation of toxic compounds such as ammonia or volatile fatty acids can inhibit microbial activity and reduce biogas yield.
- Monitoring and managing end product toxicity are essential to maintain stable digestion conditions.

14. Pressure:

- Moderate pressure within the digester promotes gas dissolution and enhances biogas yield.
- Excessive pressure can impede gas production and compromise digester integrity.

15. Acid Accumulation Inside the Digester:

- Controlled acid accumulation within the digester helps maintain pH stability and supports microbial activity.
- Excessive acid buildup can disrupt digestion, inhibit methanogenesis, and reduce biogas production.

BIO GAS FROM WASTE FUEL

The subject of biogas production from fresh-plant wastes is not at all new. The process of bio digestion as already described is carried out generally in following two recognized systems:

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

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

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

Single stage process.

One chamber is used to finish the full process of turning complicated organic molecules into biogas. Raw materials are continuously delivered into this chamber, while the wasted residue continuously exits. In a single stage continuous process, serious issues arise. This topic is covered in another discussion.

Double stage process.

Two chambers physically divide the acidogenic and methanogenic phases. Only the diluted acids are supplied into the second chamber, which is where bio-methanation occurs and where the biogas can be collected, during the first step of acid synthesis, which is completed in a separate chamber. Given the challenges associated with fermenting fibrous plant waste materials, a two-stage procedure might have a better chance of success. However, based on a two-stage approach, appropriate technology for rural India needs to be developed.

PROPERTIES OF BIOGAS

Biogas is flammable and can be ignited in the presence of oxygen, making it suitable for combustion-based energy generation methods.

Biogas may have an odor due to the presence of hydrogen sulfide and other sulfur compounds, which can give it a characteristic "rotten egg" smell.

Biogas is colourless, odourless, and non-toxic in its natural state, making it safe to handle and use when properly managed.

Calorific value

60% methane	= 22.350 to 24.22 MJ/m3
without CO2	= 33.525 to 35.390 MJ/m
Octane rating without CO2	= 130
Octane rating with CO2	= 110
Ignition temperature	= 650^0C

Air to methane ratio for complete

combustion by volume = 10 to 1

Explosive limits to air by volume = 5 to 15

Property	Composition (%)	Volume (m^3/kg of feedstock)
Methane (CH4)	50 - 70	0.25 - 0.35
Carbon Dioxide (CO2)	30 - 50	0.15 - 0.25
Nitrogen (N2)	0.5 - 3	0.002 - 0.015
Hydrogen Sulfide (H2S)	< 1 (usually)	Varies
Oxygen (O2)	Traces	Varies
Water Vapor (H2O)	Variable depending on moisture content of feedstock	Variable depending on moisture content of feedstock

UTILIZATION OF BIOGAS

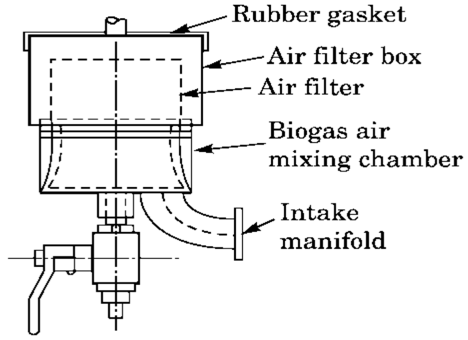
The main products of the bio-gas plant are fuel gas and organic manure.

Biogas is one gas that burns easily. Since methane makes up the only combustible portion of the gas, about 60% of its volume is only suitable for burning.

Biogas can be effectively used for home cooking, lighting, small engine operation, water pumping, chaffing feed, and flour grinding with current technology.

Modification of SI engine:

SI engines can run entirely on biogas; however, they must first be started on gasoline. To convert a SI engine to run on biogas, it is necessary to make arrangements for the entry of biogas, throttle intake air, and advance the ignition time.

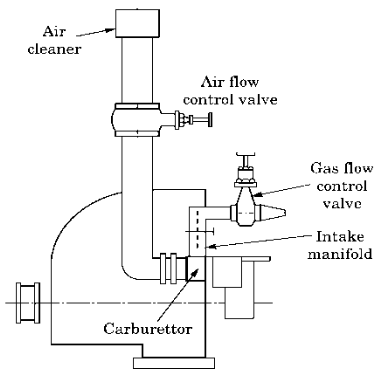


Details of mixing chamber

A stationary SI engine can accept biogas through the intake manifold, and as seen in Fig., an air flow control valve can be installed on the air cleaner pipe that connects the air cleaner and carburettor to limit the intake air. In this instance, the initial stage of the intake air must be manually throttled.

Modification of CI engine:

A CI engine may run on both fuels and biogas that has been mixed with air before entering the cylinder. The configuration seen in Figure is predominantly employed in stationary engines that are sold commercially in India. It is possible to maintain the mixing chamber's capacity at the engine displacement volume level. The engine must run smoothly and efficiently on dual fuel if the diesel pilot injection in the cycle is advanced. Because biogas admission into the engine during its initial stage raises engine speed, it is necessary to add an appropriate system that reduces the diesel supply by activating the control rack.



Modification of SI engine

UNIT V:

SOLAR ENERGY SOURCES

SOLAR RADIATION AND ITS MEASUREMENTS

Beam radiation: Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called "direct radiation" or Beam radiation. It is the radiation which produces a shadow when interrupted by an opaque object.

Diffuse radiation: It is solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere. Because the solar radiation is scattered in all directions in the atmosphere, diffuse radiation comes to the earth from all parts of the sky. The total solar radiation received at any point on the earth's surface is the sum of the direct and diffuse radiation.

Measurement of the heating effect of both diffuse and direct solar radiation was necessary in order to experimentally determine the amount of energy transmitted to a surface by solar radiation. Beam radiation is also measured, which reacts to solar radiation from a very narrow region of the circumsolar sky. By shielding the detecting element from the sun's beams, an instrument designed to measure total radiation can be used to measure diffuse radiation only.

Solar radiation data are measured mainly by the following instruments:

Pyranometer: A pyranometer is designed to measure global radiation, usually on a horizontal surface, but can also be used on an inclined surface. When shaded from beam radiation by using a shading ring, a pyranometer measures diffused radiation.

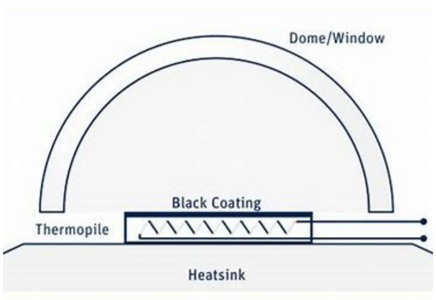
Pyrheliometer: An instrument that measures beam radiation by using a long narrow tube to collect only beam radiation from the sun at normal incidence.

Sunshine Recorder: It measures the sunshine hours in a day

Pyranometer:

A precision pyranometer is designed to respond to radiation of all wavelengths and hence accurately measures the total power in the incident spectrum.

Construction:



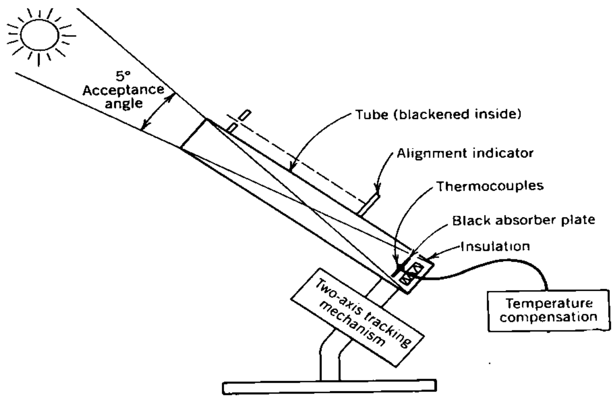
It contains a thermopile whose sensitive surface consists of circular, blackened, hot junctions, exposed to the sun, the cold junctions being completely shaded. The temperature difference between the hot and cold junctions is the function of radiation falling on the sensitive surface. The sensing element is covered by two concentric hemispherical glass domes to shield it from wind and rain which also reduces the convection currents. A radiation shield surrounding the outer dome and coplanar with the sensing element, prevents direct solar radiation from heating the base of the instrument

Pyrheliometer:

The normal incidence pyranometer uses a long collimator tube to collect beam radiation whose field of view is limited to a solid angle of 5.5 (generally) by appropriate diaphragms inside the tube.

Construction:

The inside of the tube is blackened to absorb any radiation incident at angles outside the collection solid angle. At the base of the tube a wire wound thermopile having an sensitivity of approximately 8 μV/W/m² and an output impedance of approximately 200 Ω is provided. The tube is sealed with dry air to eliminate absorption of beam radiation within the tube by water vapour. A tracker is needed if continuous readings are desired

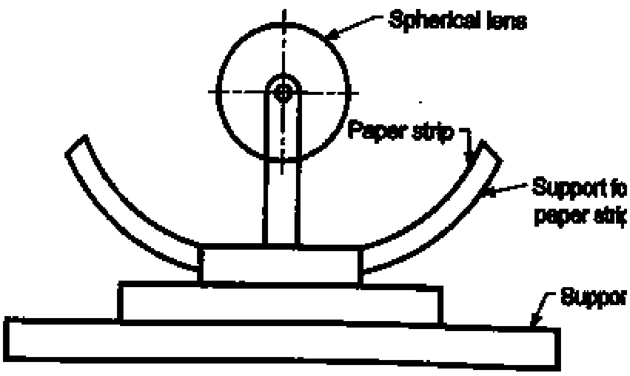


Sunshine recorder:

This instrument measures the duration in hours of bright sunshine during the course of a day.

construction:

It essentially consists of a glass sphere (about 10 cm in diameter) mounted on its axis parallel to that of the earth, within a spherical section (bowl). The bowl and glass sphere are arranged in such a way that the sun's rays are focused sharply at a spot on a card held in a groove in the bowl. The card is prepared from a special paper bearing a time scale. As the sun moves, the focused bright sunshine burns a path along this paper. The length of the trace thus obtained on the paper is the

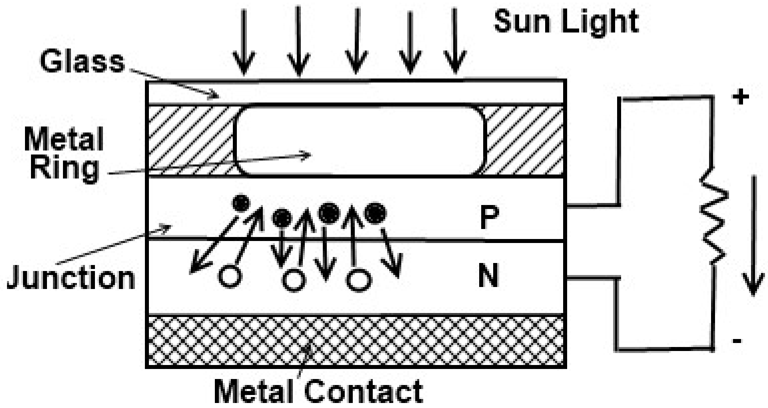


measure of the duration of the bright sunshine. Three overlapping pairs of grooves are provided in the spherical segment to take care of the different seasons of the year.

SOLAR CELL

Principle of conversion of Solar Energy into Electrical Energy

In an ordinary copper wire, the copper atoms have electrons that are free to move from atom to atom. Such a flow of electrons makes up an electric current. In an ideal state, the semiconductor materials are insulators as they have no free electrons. But if very small amounts of impurities such as antimony, arsenic, or phosphorus are present in semiconductor materials, a few free electrons are produced that can move and form an electric current. When photons from the sun are absorbed by a semiconductor, they create free electrons with higher energies than the electrons which provide the bonding in the base crystal. Once these electrons are created, there must be an electric field to induce these high energy electrons to flow out of the semiconductor. The actual conversion of solar energy directly into electrical energy in a semiconductor, for example a silicon cell. 10 Fig shows a typical silicon cell (solar cell). The silicon is neither a good conductor nor a good insulator. It has an outer electron shell of four valence electrons.



Formation of p-n junction:

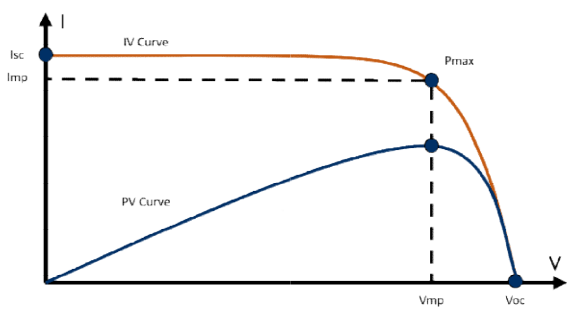
In its crystalline state, a silicon atom forms covalent bonds with four neighbouring atoms. Addition of traces of an element such as arsenic, or phosphorus, or antimony that contain one more electron than the silicon i.e., five valence electrons, renders the silicon conductive. Four of the five electrons complete covalent bonds with adjacent silicon atoms. The fifth, or the excess electron, at room temperature, has sufficient energy to become a free electron which will be negatively charged. The conduction in silicon which is added with materials such as arsenic or phosphorus is affected by such negative free electrons. The silicon with added materials such as arsenic or phosphorus is called n-type silicon. 11 The addition of elements such as boron or gallium to silicon reduces the number of valence electrons in the atom to three, i.e., one less than in the silicon. This type of atom has insufficient valence electrons to complete four valence bonds. The incomplete hole results in a vacancy or hole. The hole acts as positive charge and makes the silicon conductive. The silicon with added materials such as boron is called p-type silicon. A semiconductor device is made either from p-type or n-type base material into which one or more impurities of the positive polarity are introduced to form p-n-layers. The interface between the layers having opposite polarity is called p-n junction. In a p-n junction, free electrons from n-side tend to diffuse into p-side where they readily recombine because of the very large hole concentration. Similarly, all holes from the p-side of the junction tend to diffuse into n-side of the region and rapidly combine with numerous free electrons. Free electrons moving from n-side to p-side leave a net positive charge behind in the n-side of the junction, while migrating hole from p-side to n-side leave a negative charge on the p-side of the junction. This charge distribution near the junction gives rise to an electric field and hence a potential difference across the junction. This electric field originates mainly due to the chemical difference in the material on the two sides of the junction. This electric field built in the vicinity of the junction is permanent in nature.

Working:

When a p-n junction of a semiconductor is exposed to sunlight some of the solar photons are absorbed in the vicinity of the p-n junction. The photons absorbed at the p-n junction will have high energy to dislodge an electron from the fixed position in the material and give it enough energy to move freely in the material. The electron evicted from its customary bond can travel through the entire crystalline solid and is capable of responding to electric fields and other influences. The bond from which the electron was ejected is short of one electron creating a hole which is also mobile. Thus, the ejected free electron and the hole form an electron-hole pair. The electrons and the holes being of opposite charge will be pushed in different directions by the electric field which already exists in the vicinity of the junction if they come into the region near the p-n junction. The permanent electric field which was built-in near the p-n junction pushes the hole into the p-region and the electron into the n-region. Thus, the p-region becomes positively charged and the n-region becomes negatively charged. If an external load is applied, this charge difference will drive a current through it. The current will flow so long as the sunlight keeps generating the electron-hole pairs.

SOLAR CELL PARAMETER

Voltage and Current at Maximum Power Point



The current at which maximum power occurs. Current at Maximum Power Point is shown in the v-i characteristics of solar cell by I_m.

The voltage at which maximum power occurs. Voltage at Maximum Power Point is shown in the v-i characteristics of solar cell by V_m.

Open Circuit Voltage of Solar Cell

It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volt. It is normally denoted by Voc.

Short Circuit Current of Solar Cell

The maximum current that a solar cell can deliver without harming its own constriction. It is measured by short circuiting the terminals of the cell at most optimized condition of the cell for producing maximum output. The term optimized condition I used because for fixed exposed cell surface the rate of production of current in a solar cell also depends upon the intensity of light and the angle at which the light falls on the cell. As the current production also depends upon the surface area of the cell exposed to light, it is better to express maximum current density instead maximum current. Maximum current density or short circuit current density rating is nothing but ration of maximum or short circuit current to exposed surface area of the cell.

$$J_{sc} = \frac{I_{sc}}{A}$$

Where, I_{sc} is short circuit current, J_{sc} maximum current density and A is the area of solar cell.

Fill Factor of Solar Cell

The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell.

$$Fill\ Factor = \frac{p_m}{I_{SC} \times V_{oc}}$$

EFFICIENCY OF SOLAR CELL

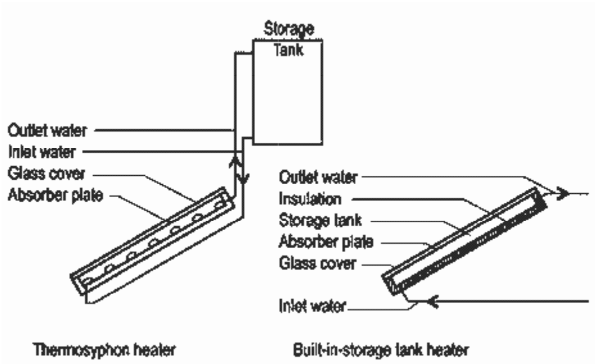
It is defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage. It is considered that the radiation power on the earth is about 500 watt/square metre hence if the exposed surface area of the cell is A then total radiation power on the cell will be 500 A watts. Hence the efficiency of a solar cell may be expressed as

$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{500A}$$

SOLAR WATER HEATER

Flat plate collector:

In the flat plate collectors as shown as a blackened sheet of metal is used to absorb all the sunlight, direct, diffuse and terrestrially reflected. A sheet of metal coated in black has the property of absorbing the sunlight falling on it and convert it into heat. The heat generated in the sheet of metal is subsequently transferred to the other fluids like, air, water, etc. The heat energy will be continuously transferred to the fluid after the blackened surface attains a temperature at which the equilibrium state is established between the rate at which the solar energy is absorbed and the rate at which the heat energy is transferred to the fluid. When the conduction, convection and radiation losses during absorption, generation and transfer are prevented, this method of solar energy conversion will have very high conversion efficiencies, even as high as 100%. In flat plate collectors, the conduction and convection losses can be minimised by placing the blackened sheet of metal in a closed thermally insulated box having its top covered by a transparent glass sheet so that the solar radiation can be allowed. The use of a glass cover serves as a diathermanous medium permitting the short wavelength solar radiation to be transmitted through it, while blocking the long wavelength radiation from the surface of the blackened sheet. By coating the absorbing surface with selective coating substances having high absorptiveness in the short wavelength region and low emissive in the long wavelength region the radiation losses from the absorbing surface may be reduced.



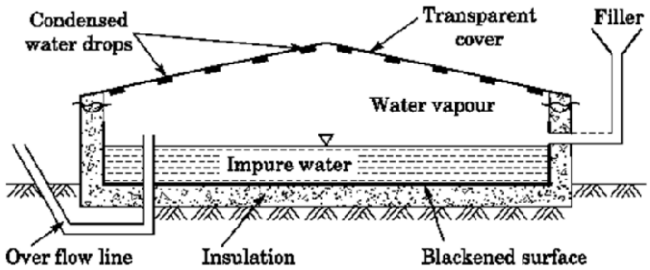
Flat plate collectors are used for a wide variety of low temperature applications such as cooking, water heating, drying of food grains and vegetables, seasoning of wood, desalination of water, etc.

solar distillation

SOLAR DISTILLATION

Even the most basic solar still—a basin—can be used to distill pure water. Its shape is similar to a roof. Often made of glass, the cover is slanted in the direction of a collection trough and may also be made of plastic. After passing through the cover, solar energy is absorbed by the black surface and transformed into heat. The heated impure water in the tray or basin condenses into purified water on the roof's colder interior through the production of vapour.

Since the transparent roof material, which is primarily glass, transmits almost all of the light that hits it and absorbs very little of it, the temperature stays low enough for the water vapor to condense. Condensed water runs off the roof's slope and gathers in troughs at the base. It is possible to replace the saline water in the process either continuously or in batches. Although basin type units come in a variety of configurations, their fundamental theory remains the same. The sole kind of solar still in use, the basin type, has produced distilled water at a cost per unit of product lower than other types of solar equipment. Practical units have managed to reach operating efficiency of between 35 and 50% per basin type, whereas the theoretical maximum is slightly over 60%.



Solar water still

Plotting the graph of the amount of fresh water generated per unit of basin area in a day against the intensity of solar radiation over the same length of time yields the performance rating and efficiency of the solar still. These curves are drawn for many stills. The definition of efficiency is

$$\eta = \frac{w\Delta h}{H}$$

Where;

w = weight of distillate per square meter per day.

Δh= enthalpy change from cold water to vapour.

H = Solar radiation intensity per square meter per day.

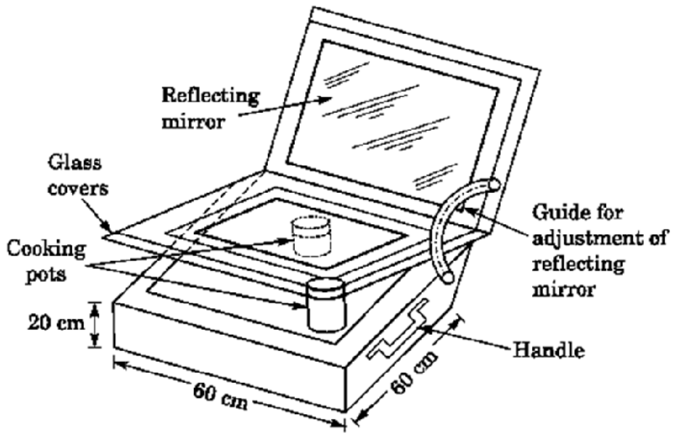
Here, the water's surface area needs to be taken into account. Ah takes into account the latent heat of vaporization, which is estimated to be 594.5 kcal/kg on average (2489 kJ/kg).

The amount of water generated by each unit of basin area in a day, or cubic meters of liters of water per square meter of basin area per day, is the standard way to represent a solar still's performance. This amount will change depending on the still's design, the amount of solar energy received, and the surrounding air quality. Although there are additional parameters that affect the production rate, such as ambient air temperature, wind speed, atmospheric humidity, sky conditions, etc., the primary determinant of the rate is the amount of solar radiation accessible.

SOLAR COOKING

Box Type Solar Cooker

The solar rays enter the solar box through the glass covers and are absorbed by a blackened metal tray stored inside. This is how the box-type solar cooker operates. The sun's short wavelengths are entering the box. The glass cover reduces reradiation from the absorber plate to the outside of



Solar box type cooker

the box by blocking the passage of higher wavelength radiation.

There are two glass coverings available to reduce heat loss even more. Making the box airtight reduces the loss from convection and conduction. When this kind of cooker is exposed to the sun, the temperature within the box rises as the blackened surface absorbs solar radiation.

Depending on the actual temperature reached within, food will cook in a specific amount of time when the cooking pots—which are also blackened—are filled with food material. The amount of insulation and solar radiation intensity determine the temperature attained.

A mirror or mirrors can be provided to increase the intensity of solar radiation. The solar cooker consists of an outside and inner wooden or metal box with two sheets of glass. Paint absorber trays (also known as blackened trays) in black using boiler interior paint or other appropriate black paint.

In order to endure the highest temperature reached within the cooker and the water vapor emitted by the cooking equipment, this paint should have a black colour.

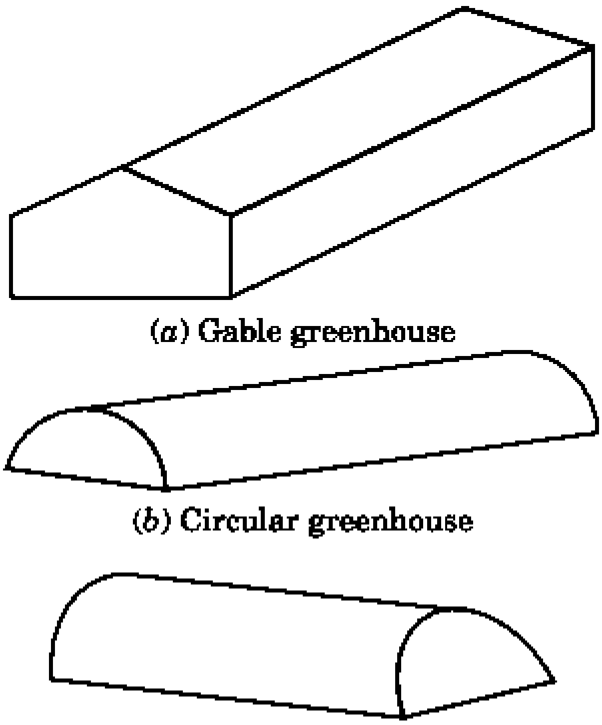
There are two simple glasses set in the wooden frame on top of the cover, each measuring 3 mm in thickness and spaced roughly 20 mm apart.

Use a padlock hasp to secure the top lid completely. Around the contact surfaces of the cooker box and glass cover, neoprene rubber sealing is present. In the sealing, there is a little valve allows vapour to escape. An equatorial plane reflecting mirror, hinged on one side of the glass frame, increases the collector area of the solar cooker by the same amount as the box. To adjust the reflector at different angles with the cooking box, a device (a mirror adjustment guide) is supplied.

Inside the box, the temperature rises from 150 to 250 degrees Celsius where the reflectors are located. A standard model's overall measurements are 60 x 60 x 20 cm in height. Because it can cook enough dry food ingredients for a family of five to seven people, this kind of cooker is known as a family solar cooker.

With just one reflector, the temperature inside the solar cooker may be controlled to be between 700 and 1100 degrees Celsius above room temperature. This temperature is sufficient to cook food slowly, gradually, and successfully while preserving its nutrients and flavour. Maximum air temperature reached within the cooker box in 11/2 to 2 hours (without cooking). Cooking times for rice range from 30 to 2 hours and 11 a.m. to 2 p.m. is the ideal time of day to cook. Summer cooking is quicker than winter cooking because of the higher outside temperature.

SOLAR GREENHOUSE



(a) Gable greenhouse

(b) Circular greenhouse

(c) Gothic arch greenhouse

A greenhouse is a type of growth chamber that allows plants to be produced all year round. These solar collectors work well. These can also be tailored to meet the demands of people living in suburbs, cities, and rural areas. When paired with a well-applied heat store, a greenhouse attached to a home can improve the physical and psychological well-being of its residents. This kind of solar collector, also known as a power house, can also supply a large portion of the necessary winter heat. Building solar greenhouses is comparatively straightforward, using only inexpensive materials and basic technologies. Since the earth is slightly closer to the sun in the winter than it is in the summer in the northern hemisphere, it is frequently possible to collect enough solar energy to support plant development both during the day and at night. Regretfully, in order to prevent overheating during the day, the typical green home is built in a way that allows it to lose the majority of the heat it generates, leaving no extra heat for use at night. In order to provide stored heat for use at night and on cloudy days, a solar greenhouse maximizes the amount of heat and sunlight it receives while minimizing heat losses.

Crop cultivation is possible in greenhouses in a regulated atmosphere. A green house is a transparent material-covered building that grows plants using solar radiation. It may also contain HVAC (heating, ventilation, and air conditioning) systems for temperature management.

Types of Greenhouses

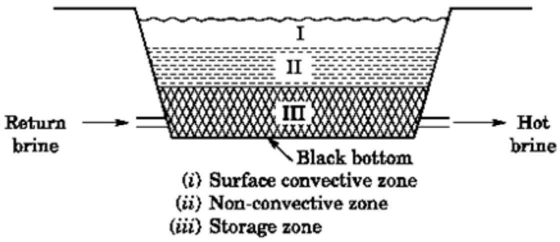
Several general categories of greenhouses comprise the following:

- **Anattached greenhouse** that can be fastened to practically any kind of building.
- **Porch-style greenhouses**, which can be made to resemble the front door of a home, business, or factory.
- **Free-standing greenhouses**, which can be placed on any handy plot of land or abandoned area.

- **Pit-style greenhouses**, which are typically used to retain heat and are situated on varying levels or sloping terrain.
- **Cold frame greenhouses**, which are essentially plant frames or hot beds with a slanted roof.

SOLAR POND AND ITS APPLICATIONS.

A natural and artificial body of water for collecting and absorbing radiation energy and storing it as heat is a solar pond.



Solar pond

A solar pond is a small body of water with a huge collection area that traps heat and is just one or two meters deep. To provide a steady density gradient, it comprises dissolved salts. A portion of the incident solar energy that reaches the pond's top is absorbed at the black bottom, while the remaining portion is absorbed throughout the depths. The bottom layers would warm up, expand, and rise to the surface if the pond had been filled with fresh water at first. The pond's temperature could only rise slightly due to convective mixing and heat loss near the surface.

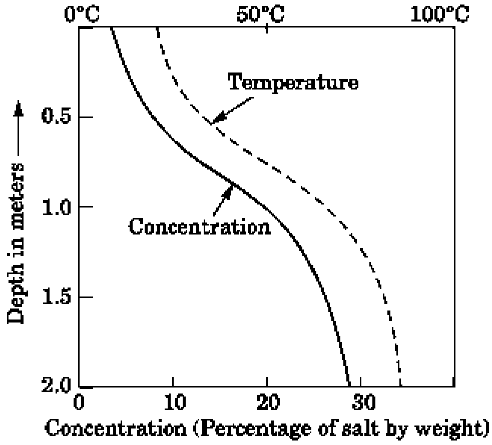
Conversely, convection can be avoided by first establishing a strong enough gradient in the concentration of salt. In this instance, the pond cannot become unstable due to thermal expansion in the hotter lower layers.

Only conduction is used to remove heat from the lower layers when convection is inhibited. The water acts as an insulator and allows high temperatures (over 900C) to form in the bottom layers due to its relatively low conductivity. The pond's bottom is lined with a thick, sturdy plastic sheet. components that make up the liner.

The salt content rises gradually with depth until it reaches the bottom, where it is quite high—roughly 20%. As a result, a solar pond contains three zones, each with a different salinity and depth:

i. Salinity less than 5%, surface convective zone or higher convective zone (0.3–0.5 m).
ii. 1 to 1.5 m is the non-convective zone; salinity rises with depth.

iii. Lower convective zone or storage zone, 1.5–2 m, 20% salinity.



Temperature and concentration profile of solar pond

APPLICATIONS OF SOLAR PONDS.

The solar ponds are used in thermal applications (heating and cooling), desalination, salt extraction and power generation

Some of the applications are

- Heating and Cooling of Buildings.
- Power generation
- Industrial process heat
- Desalination
- Salt production

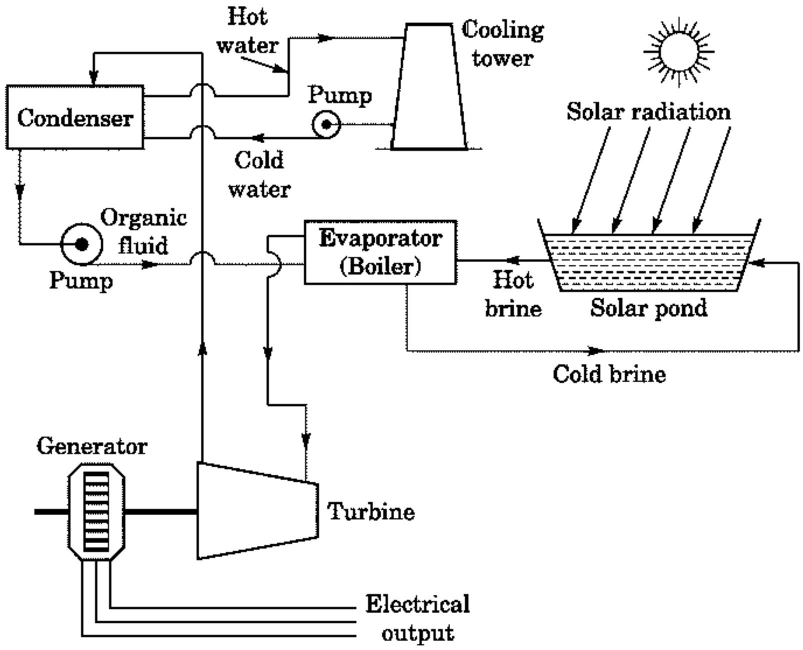
Heating and Cooling of Buildings.

The solar ponds are capable of storing large amount of heat energy in its lower convective zone. The operation of solar ponds is simple and is comparatively less expensive. Some researchers reported that solar pond technology offers heat at a cost of about $0.010 per kW-h. Researchers found solar pond house heating systems effective if that pond is used to supply thermal energy to many buildings.

Power generation

A thermo-electric device or an organic Rankine cycle engine—a turbine powered by the evaporation of an organic fluid with a low boiling point—can be powered by a solar pond to produce energy. In regions with enough insolation, topography, and soil properties to support the building and maintenance of large-scale solar ponds required to produce appreciable amounts of electrical energy, the idea of solar pond power generation has considerable potential.

Heat from a solar pond, even at low temperatures, can be transformed into electricity. Its modest



operating temperatures (70-1000C) limit the conversion efficiency. The Solar Pond Power Plant

(SPPP) needs organic fluids with low boiling points, like halo-carbons (like Freons) or hydrocarbons

(like propane), due to the low temperatures.

Solar pond electric power plant (SPPP)

Industrial process heat

The thermal energy required for different industrial process is directly utilized from the solar ponds. This facility was used in drying of crop products, vegetables, paper industry, etc. It is used mainly as a fuel saver in the IPH applications.

The thermal energy that is directly employed to prepare and treat materials and products produced by industry is known as industrial process heat. Numerous scientists have assessed the solar pond's viability as a source of process heat for industrial applications. They contend that the solar pond can save a substantial amount of coal, natural gas, electricity, and oil by providing process heat to businesses. The computations showed that the heat from solar ponds is quite competitive with oils and natural gas for crop drying and for the paper sector, for which economics have been established.

Desalination

Multi-flash desalination along with a solar pond is useful in the purification of saline water and making it potable for drinking purposes. The distilled water can be produced from multi-flash desalination plant operating below 1000C coupled with solar pond. It has been estimated that about700 m3/day-distilled water can be obtained from a pond of 0.31 km2 area with a multi-effort distillation unit. The water produced by this technology is five folds than conventional solar still.