RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA BHOPAL

New Scheme of Examination as per AICTE Flexible Curricula

Mechanical Engineering, VI-Semester

Open Elective ME- 604 (A) Robotics

Unit 1 Introduction:

Need and importance, basic concepts, structure and classification of industrial robots, terminology of robot motion, motion characteristics, resolution, accuracy, repeatability, robot applications.

Unit 2 End Effectors and Drive systems:

Drive systems for robots, salient features and comparison, different types of end effectors, design, applications.

Unit 3 Sensors:

Sensor evaluation and selection, Piezoelectric sensors , linear position and displacement sensing, revolvers, encoders, velocity measurement, proximity, tactile, compliance and range sensing. Image Processing and object recognition.

Unit IV Robot Programming:

Teaching of robots, manual, walk through, teach pendant, off line programming concepts and languages, applications.

Unit V Safety and Economy of Robots:

Work cycle time analysis, economics and effectiveness of robots, safety systems and devices, concepts of testing methods and acceptance rule for industrial robots.

References:

1. Mittal RK, Nagrath IJ; Robotics and Control; TMH
2. Groover M.P,Weiss M, Nagel,OdreyNG; Industrial Robotics-The Appl□; TMH
3. Groover M.P; CAM and Automation; PHI Learning
4. Spong Mark and Vidyasagar; Robot Modelling and control; Wiley India
5. Yoshikava ; Foundations of Robotics- analysis and Control; PHI Learning;
6. Murphy ; Introduction to AI Robotics; PHI Learning
7. FU KS, Gonzalez RC, Lee CSG; Robotics □Control, sensing□; TMH
8. Shimon, K; Handbook of Industrial Robots; John Wiley & Sons,.
9. Ghosal Ashitava; Robotics Fundamental concepts and analysis; Oxford
10. Saha S; Introduction to Robotics; TMH
11. Yu Kozyhev; Industrial Robots Handbook; MIR Pub.

RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA BHOPAL

New Scheme of Examination as per AICTE Flexible Curricula

Mechanical Engineering, VI-Semester

Open Elective ME- 604 (B) Optimization Techniques

Unit 1 Introduction to Optimization:

Engineering application of Optimization – Statement of an Optimization problem - Optimal Problem formulation - Classification of Optimization problem. Optimum design concepts, Definition of Global and Local optima – Optimality criteria - Review of basic calculus concepts – Global optimality

Unit 2 Linear programming methods for optimum design:

Review of Linear programming methods for optimum design – Post optimality analysis - Application of LPP models in design and manufacturing.

Unit 3 Optimization algorithms for solving unconstrained optimization problems:

Gradient based method: Cauchy's steepest descent method, Newton's method, Conjugate gradient method.

Unit-4 Optimization algorithms for solving constrained optimization problems:

Direct methods – penalty function methods – steepest descent method - Engineering applications of constrained and unconstrained algorithms.

Unit 5 Modern methods of Optimization:

Genetic Algorithms - Simulated Annealing - Ant colony optimization - Tabu search – Neural-Network based Optimization – Fuzzy optimization techniques – Applications. Use of Matlab to solve optimization problems.

References:

1. Rao S. S. - 'Engineering Optimization, Theory and Practice' - New Age International Publishers - 2012 - 4th Edition.
2. Deb K. - 'Optimization for Engineering Design Algorithms and Examples' – PHI - 2000
3. Arora J. - 'Introduction to Optimization Design' - Elsevier Academic Press, New Delhi - 2004
4. . Saravanan R. - 'Manufacturing Optimization through Intelligent Techniques' - Taylor & Francis (CRC Press) - 2006
5. Hardley G. -'Linear Programming' - Narosa Book Distributors Private Ltd. - 2002

RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA BHOPAL

New Scheme of Examination as per AICTE Flexible Curricula

Mechanical Engineering, VI-Semester

Open Elective ME- 604 (C) Renewable Energy Technology

UNIT-I Solar Radiation:

Extra-terrestrial and terrestrial, radiation measuring instrument, radiation measurement and predictions. Solar thermal conversion: Basics, Flat plate collectors-liquid and air type. Theory of flat plate collectors, selective coating, advanced collectors, Concentrators: optical design of concentrators, solar water heater, solar dryers, solar stills, solar cooling and refrigeration.
Solar photovoltaic: Principle of photovoltaic conversion of solar energy; Technology for fabrication of photovoltaic devices; Applications of solar cells in PV generation systems; Organic PV cells.

UNIT-II Wind Energy:

Characteristics and measurement: Metrology of wind speed distribution, wind speed statistics, Weibull, Rayleigh and Normal distribution, Measurement of wind data, Energy estimation of wind regimes; **Wind Energy Conversion**: Wind energy conversion principles; General introduction; Types and classification of WECS; Power, torque and speed characteristics; power curve of wind turbine, capacity factor, matching wind turbine with wind regimes; Application of wind energy.

UNIT-III Production of biomass:

Photosynthesis-C3 & C4 plants on biomass production; Biomass resources assessment; Co2 fixation potential of biomass; Classification of biomass; Physicochemical characteristics of biomass as fuel Biomass conversion routes: biochemical, chemical and thermo chemical Biochemical conversion of biomass to energy: anaerobic digestion, biogas production mechanism, technology, types of digesters, design of biogas plants, installation, operation and maintenance of biogas plants, biogas plant manure-utilization and manure values. Biomass Gasification: Different types, power generation from gasification, cost benefit analysis of power generation by gasification.

UNIT-IV Small Hydropower Systems:

Overview of micro, mini and small hydro system; hydrology; Elements of turbine; Assessment of hydro power; selection and design criteria of turbines; site selection and civil works; speed and voltage regulation; Investment issue load management and tariff collection; Distribution and marketing issues. Ocean Energy: Ocean energy resources, ocean energy routs; Principle of ocean thermal energy conversion system, ocean thermal power plants. Principles of ocean wave energy and Tidal energy conversion.

UNIT-V Geothermal Energy:

Origin of geothermal resources, type of geothermal energy deposits, site selection geothermal power plants; Hydrogen Energy: Hydrogen as a source of energy, Hydrogen production and storage. Fuel Cells: Types of fuel cell, fuel cell system and sub-system, Principle of working, basic thermodynamics

References:

1. Kothari, Singal & Rajan; Renewable Energy Sources and Emerging Technologies, PHI Learn
2. Khan, B H, Non Conventional Energy, TMH.
3. Sukhatme and Nayak, Solar Energy, Principles of Thermal Collection and Storage, TMH.
4. Tiwari and Ghosal, Renewable Energy Resources: basic principle & application, Narosa Publ

5. Koteswara Rao, Energy Resources, Conventional & Non-Conventional, BSP Publication.
6. Chetan Singh Solanki, Solar Photovoltaics: Fundamental, technologies and Application,PHI L
7. Abbasi Tanseem and Abbasi SA; Renewable Energy Sources; PHI Learning
8. Ravindranath NH and Hall DO, Biomass, Energy and Environment, Oxford University Press.
9. Duffie and Beckman, Solar Engineering of Thermal Process, Wiley
10. Nikolai, Khartchenko; Green Power; Tech Book International
11. Tester, Sustainable Energy-Choosing Among Options, PHI Learning.
12. Godfrey Boyle, Renewable Energy: Power for a sustainable future, Oxford OUP.

Renewable Energy Technology
(ME-604 C)

Unit 3: Biomass Energy

Introduction

Biomass energy or ‘‘bioenergy’’ includes any solid, liquid or gaseous fuel, or any electric power or useful chemical product derived from organic matter, whether directly from plants or indirectly from plant-derived industrial, commercial or urban wastes, or agricultural and forestry residues. Thus bio- energy can be derived from a wide range of raw materials and produced in a variety of ways. Because of the wide range of potential feedstocks and the variety of technologies to produce them and process them, bioenergy is usually considered as a series of many different feedstock/technology combinations. In practice, we tend to use different terms for different end uses—e.g., electric power or transportation.

The term ‘‘bio power’’ describe biomass power systems that use biomass feedstocks instead of the usual fossil fuels (natural gas or coal) to produce electricity, and the term ‘‘biofuel’’ is used mostly for liquid transportation fuels which substitute for petroleum products such as gasoline or diesel. ‘‘Biofuel’’ is short for biomass fuel.

The term ‘‘biomass’’ generally refers to renewable organic matter generated by plants through photosynthesis. During photosynthesis, plants combine carbon dioxide from the air and water from the ground to form carbohydrates, which form the biochemical ‘‘building blocks’’ of biomass. The solar energy that drives photosynthesis is stored in the chemical bonds of the carbohydrates and other molecules contained in the biomass. If biomass is cultivated and harvested in a way that allows further growth without depleting nutrient and water resources, it is a renewable resource that can be used to generate energy on demand, with little net additional contributions to global greenhouse gas emissions.

Materials having organic combustible matter are also referred under biomass. Biomass can be directly utilized as fuel or can be converted through different routes into useful forms of fuel. Biomass is a scientific term for living matter, but the word biomass is also used to denote products derived from living organisms— wood from trees, harvested grasses, plant parts and residues such as twigs, stems and leaves, as well as aquatic plants and animal wastes.

Burning biomass efficiently results in little or no net emission of carbon dioxide to the atmosphere, since the bioenergy crop plants actually took up an equal amount of carbon dioxide from the air when they grew. However, burning conventional fossil fuels such as gasoline, oil, coal or natural gas results in an increase in carbon dioxide in the atmosphere, the major greenhouse gas which is thought to be responsible for global climate change. Some nitrogen oxides inevitably result from biomass burning (as with all combustion processes) but these are comparable to emissions from natural wildfires, and generally lower than those from burning fossil fuels. Other greenhouse gas emissions are associated with the use of fossil fuels by farm equipment, and with the application of inorganic fertilizers to the bioenergy crop. However, these may be offset by the increase in carbon storage in soil organic matter compared with conventional crops. Utilization of biomass residues which would otherwise have been dumped in landfills (e.g. urban and industrial residues) greatly reduces greenhouse gas emissions by preventing the formation of methane.

All the Earth’s biomass exists in a thin surface layer called the biosphere. This represents only a tiny fraction of the total mass of the Earth, but in human terms it is an enormous store of energy—as fuel and as food. More importantly, it is a store which is being replenished continually. The source which supplies the energy is of course the Sun, and although only a tiny fraction of the solar energy reaching the Earth each year is converted into biomass, it is nevertheless equivalent to over five times the total world. The annual world of biomass is estimated at 146 billion metric tons, mostly from uncontrolled plant growth. The current world demand for oil and gas can be met with about 6% of the global production of biomass. Biomass is significant as heating fuel, and in some parts of the world the fuel is most widely used for cooking. An advantage of this source of energy is that use of biomass for fuel would not add any net carbon dioxide to the atmosphere.

The Earth's land-based production which is used by the human population worldwide ranges from a low figure of about 5% to a high of over 30% (including food, animal fodder, timber and other products, as well as bioenergy). The higher estimates include a lot of wasted material and inefficient activities such as forest clearance, as well as losses of productivity due to human activity. Globally bio- mass energy use has been independently estimated at about 55 exajoules per year, or about 2% of annual biomass production on land.

Biomass has the following advantages:

- It is widely available.
- Its technology for production and conversion is well understood.
- It is suitable for small or large applications.
- Its production and utilization requires only low light intensity and low temperature (535°C).
- It incorporates advantage of storage and transportation.
- Comparatively, it is associated with low or negligible pollution. Biomass can be classified as:

- *Agricultural and forestry residues.* They include silvicultural crops.
- *Herbaceous crops.* Include weeds, Napier grass.
- *Aquatic and marine biomass*. This category includes algae, water hyacinth, aquatic weeds, plants, sea grass beds, kelp and coral reap, etc.
- *Wastes*. Various wastes such as municipal solid waste, municipal sewage sludge, animal waste and industrial waste, etc.

Worldwide, biomass is the fourth largest energy resource after coal, oil and natural gas—estimated at about 14% of global primary energy (and much higher in many developing countries). In the US, biomass today provides about 3–4% of primary energy (depending on the method of calculation). Biomass is used for *heating* (such as wood stoves in homes and for process heat in bioprocess industries), *cooking* (especially in many parts of the developing world), *transportation* (fuels such as ethanol) and, increasingly, for *electric power production*. The installed capacity of biomass power generation worldwide is about 35,000 MW, with about 7,000 MW in the US derived from forest-product-industry and agricultural residues (plus an additional 2,500 MW of municipal solid waste-fired capacity, which is often not counted as part of biomass power, and 500 MW of landfill gas-fired and other capacity). Much of this 7,000 MW capacity is presently found in the pulp and paper industry, in combined heat and power (cogeneration) systems.

Energy Plantation

This term refers to an area that is used to grow biomass for energy purposes. The idea behind energy plantation program is to grow selected strains of tree and plant species on a short rotation system on waste or arable land. The sources of energy plantation depend on the availability of land and water and careful management of the plants. Energy crops, also called ''bioenergy crops'', are fast- growing crops that are grown for the specific purpose of producing energy (electricity or liquid fuels) from all or part of the resulting plant. They are selected for their advantageous environmental qualities such as erosion control, Soil organic matter build-up and reduced fertilizer and pesticide requirements. As far as suitability of land for energy plantation is concerned the following criterion is used: It should have a minimum of 60-cm annual precipitation and arable land having slope equal to or less than 30% is suitable for energy plantation.

The economics of energy plantation depends on the cost of planting and availability of market for fuel. Whereas these two factors are location specific, they vary from place to place. Further productivity of this program depends on the microclimate of the locality, the choice of the species, the planting spacing, the inputs available and the age of harvest. There are many suitable species for energy plantation, for example, *Acacia nilotica*. There are many other perennial plant species which could be used for energy crops. In addition, some parts of traditional agricultural crops such as the stems or stalks of alfalfa, corn or sorghum may be used for energy production.

Biomass Production Techniques

Careful planning is required for biomass production, which consists of integration of different techniques and improved methods. The general sequence for biomass production is the integration of different techniques and improved methods starting from site survey, nursery techniques, transplanting techniques and maintenance of the plantation. The production techniques include:

- Site survey
- Planting site selection
- Species selection
- Preparation of the planting site
- Preparation of the soil mixture
- Sowing of seed
- Method of sowing
- Transplanting of seedling into containers
- Transport of seedlings to the planting site
- Maintenance of the plantations

After successful plantation of biomass, it is harvested by various methods such as:

- *Coppicing*
It is one of the most widely used harvesting methods in which the tree is cut at the base, usually between 15 and 75 cm above the ground level. New shoots develop from the stamp or root. These shoots are sometimes referred to as sucker or sprouts. Management of sprouts should be carried out according to use. For fuel wood the number of sprouts allowed to grow, should depend on the desired sizes of fuel wood. If many sprouts are allowed to grow for a long period, the weight of the sprouts may cause the sprouts to tear away from the main trunk. Several rotations of coppicing are usually possible with many species. The length of the rotation period depends on the required tree products from the plantation. It is a suitable method for production of fuel wood. Most eucalyptus species and many species of the leguminous family, mainly naturally accessing shrubs can be harvested by coppicing.

- *Pollarding*
It is the harvesting system in which the branches including the top of the tree are cut, at a height of about 2 m above the ground and the main trunk is allowed to stand. The new shoots emerge from the main stem to develop a new crown. This results into a continuous increase in the diameter of the main stem although not in height. Finally, when the tree loses its sprouting vigor, the main stem is also cut for use as large diameter poles. An advantage of this method over coppicing is that the new shoots are high enough off the ground so that they are out of reach of most grazing animals. The neem tree (*Azadirachta indica*) is usually harvested in this manner. The branches may be used for poles and fuel wood.

- *Lopping*
  In this method most of the branches of the tree are cut. The fresh foliage starts sprouting from the bottom to the top of the denuded stem in spite of severe defoliation, surprisingly quickly. The crown also re-grows and after a few years, the tree is lopped again. The lopped trunk continues to grow and increases in height, unless this is deliberately prevented by pruning it at the top.

- *Pruning*
  It is a very common harvesting method. It involves the cutting of smaller branches and stems. The clipped materials constitute a major source of biomass for fuel and other purposes, such as fodder mulching between tree rows. It is also often required for the maintenance of fruit and forage trees, alley cropping and live fences. The process of pruning also increases the business of trees and shrubs for bio fencing. Root pruning at a required distance from the hole is effective to reduce border tree competition with crops for water and nutrients.

- *Thinning*
  It is a traditional forestry practice and in fuel wood plantation, it can also be of importance. The primary objectives of thinning are to enhance diametric growth of some specific trees through early removal of poor and diseased trees to improve the plantation by reducing the competition for light and nutrients. Depending on initial plant density, initial thinning can be used for fuel wood or pole production.

Biomass Conversion Processes

There are a number of technological options available to make use of a wide variety of biomass types as a renewable energy source. Conversion technologies may release the energy directly, in the form of heat or electricity, or may convert it into another form, such as liquid biofuel or combustible biogas. Various methods of conversion of biomass into useful energy gain can be explained as follows:

Direct Combustion Processes
Feedstocks used are often residues such as woodchips, sawdust, bark, bagasse, straw, municipal solid waste (MSW) and wastes from the food industry. Direct combustion furnaces can be divided into two broad categories and are used for producing either direct heat or steam. Dutch ovens, spreader-stoker and fuel cell furnaces employ two stages. The first stage is for drying and possible partial gasification, and the second is for complete combustion. More advanced versions of these systems use rotating or vibrating grates to facilitate ash removal, with some requiring water cooling.

1 Co-Firing

A modern practice which has allowed biomass feedstocks an early and cheap entry point into the energy market is the practice of co-firing a fossil fuel (usually coal) with a biomass feedstock. It refers to the blending of biomass with coal in the furnace of a conventional coal-fired steam cycle electric power plant. This is currently one of the simplest ways of utilizing biomass to displace fossil fuels, requiring no new investment or specialized technology. Between 5 and 15% biomass (by heat content) may be used in such facilities at an additional cost estimated at \0.5 cents/kWh (compared with coal-firing alone). Co-firing is known to reduce carbon dioxide emissions, sulfur dioxide (SO_X) emissions, and potentially some emissions of nitrogen oxides (NO_X) as well. Many electric utilities around the US have experimented successfully with co-firing, using wood chips, urban waste wood and forestry residues.

Co-firing has a number of advantages, especially where electricity production is an output. First, where the conversion facility is situated near an agro-industrial or forestry product processing plant, large quantities of low-cost biomass residues are available. These residues can represent a low-cost fuel feedstock although there may be other opportunity costs. Second, it is now widely accepted that fossil-fuel power plants are usually highly polluting in terms of sulfur, CO_2 and other GHGs. Using the existing equipment, perhaps with some modifications, and co-firing with biomass may represent a cost-effective means for meeting more stringent emissions targets. Biomass fuel's low sulfur and nitrogen (relative to coal) content and nearly zero net CO_2 emission levels allows biomass to offset the higher sulfur and carbon contents of the fossil fuel. Third, if an agro-industrial or forestry processing plant wishes to make more efficient use of the residues generated by co-producing electricity, but has a highly seasonal component to its operating schedule, co-firing with a fossil fuel may allow the economic generation of electricity all the year round.

Agro-industrial processors such as the sugarcane sugar industry can produce large amounts of electricity during the harvesting and processing season; however, during the off-season the plant will remain idle. This has two drawbacks, first, it is an inefficient use of equipment which has a limited lifetime, and second, electrical distribution utilities will not pay the full premium for electrical supplies which cannot be relied on for year-round production. In other words, the distribution utility needs to guarantee year-round supply and may therefore have to invest in its own production capacity to cover the off-season gap in supply with associated costs in equipment and fuel. If, however, the agro-processor can guarantee electrical supply year-round through the burning of alternative fuel supplies, then it will make efficient use of its equipment and will receive premium payments for its electricity by the distribution facility.

Thermochemical Process

1 Pyrolysis

Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above 430°C (800°F). In general, pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content. Extreme pyrolysis, which leaves mostly carbon as the residue, is called carbonization.

The biomass feedstock is subjected to high temperatures at low oxygen levels, thus inhibiting complete combustion, and may be carried out under pressure. Biomass is degraded to single carbon molecules (CH_4 and CO) and H_2 producing a gaseous mixture called ''producer gas''. Carbon dioxide may be produced as well, but under the pyrolytic conditions of the reactor it is reduced back to CO and H_2O; this water further aids the reaction. Liquid-phase products result from temperatures which are too low to crack all the long chain carbon molecules thus resulting in the production of tars, oils, methanol, acetone, etc. Once all the volatiles have been driven off, the residual biomass is in the form of char which is virtually pure carbon. Pyrolysis has received attention recently for the production of liquid fuels from cellulosic feedstocks by ''fast'' and ''flash'' pyrolysis in which the biomass has a short residence time in the reactor. A more detailed understanding of the physical and chemical properties governing the pyrolytic reactions has allowed the optimization of reactor conditions necessary for these types of pyrolysis. Further work is now concentrating on the use of high-pressure reactor conditions to pro- duce hydrogen and on low-pressure catalytic techniques (requiring zeolites) for alcohol production from the pyrolytic oil.

The pyrolysis process is used heavily in the chemical industry, for example, to produce charcoal, activated carbon, methanol and other chemicals from wood, to convert ethylene dichloride into vinyl chloride to make PVC, to produce coke from coal, to convert biomass into syngas, to turn waste into safely disposable substances, and for transforming medium-weight hydrocarbons from oil into lighter ones like gasoline. These specialized uses of pyrolysis are called by various names, such as dry distillation, destructive distillation or cracking.

Pyrolysis differs from other high-temperature processes like combustion and hydrolysis in that it does not involve reactions with oxygen, water or any other reagents. In practice, it is not possible to achieve a completely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. The term has also been applied to the decomposition of organic material in the presence of superheated water or steam (hydrous pyrolysis), for example, in the steam cracking of oil. Pyrolysis is the basis of several methods that are being developed for producing fuel from biomass, which may include either crops grown for the purpose or biological waste products from other industries. Fuel bio-oil resembling light crude oil can also be produced by hydrous pyrolysis from many kinds of feedstock by a process called thermal depolymerization (which may however include other reactions besides pyrolysis).

2 Torrefaction

Biomass can be an important energy source to create a more sustainable society. However, nature has created a large diversity of biomass with varying specifications. In order to create highly efficient biomass-to-energy chains, Torrefaction of biomass in combination with densification (palletization/briquetting), is a promising step to overcome logistic economics in large scale green energy solutions. Torrefaction of biomass can be described as a mild form of pyrolysis at temperatures typically ranging between 200 and 320°C. During Torrefaction the biomass properties are changed to obtain a much better fuel quality for combustion and gasification applications. Torrefaction combined with densification leads to a very energy dense fuel carrier of 20–25 GJ/ton.

Torrefaction is a thermochemical treatment of biomass at 200–320°C. It is carried out under atmospheric conditions and in the absence of oxygen. During the process, the water contained in the biomass as well as superfluous volatiles are removed, and the biopolymers (cellulose, hemicellulose and lignin) partly decompose giving off various types of volatiles. The final product is the remaining solid, dry, blackened material which is referred to as ‘‘torrefied biomass’’ or ‘‘bio-coal’’.

During the process, the biomass loses typically 20% of its mass (dry bone basis), while only 10% of the energy content in the biomass is lost. This energy (the volatiles) can be used as a heating fuel for the Torrefaction process. After the biomass is torrefied it can be densified, usually into briquettes or pellets using conventional densification equipment, to further increase the density of the material and to improve its hydrophobic properties. With regard to brewing and food products, Torrefaction occurs when a cereal (barley, maize, oats, wheat, etc.) is cooked at high temperature to gelatinize the starch endosperm creating the expansion of the grain and creating a puffed appearance. The cereal can then be used whole or flaked. In brewing, the use of small quantities of torrefied wheat or barley in the mashing process aids in head retention and clings to the glass. Additionally, torrefied cereals are generally less expensive than equal amounts of malted products.

Torrefied and densified biomass has several advantages which makes it a competitive option compared to conventional biomass (wood) pellets:

- Higher energy density.
- Energy density of 18–20 GJ/m^3 compared to 10–11 GJ/m^3 driving a 40–50% reduction in transportation costs.
- More homogeneous composition.

3 Carbonization

This is an age old pyrolytic process optimized for the production of charcoal. Traditional methods of charcoal production have centered on the use of earth mounds or covered pits into which the wood is piled. Control of the reaction conditions are often crude and relies heavily on experience. During carbonization most of the volatile components of the wood are eliminated; this process is also called ‘‘dry wood distillation’’. Carbon accumulates mainly due to a reduction in the levels of hydrogen and oxygen in the wood. The wood undergoes a number of physico-chemical changes as the temperature rises. Between 100 and 170°C most of the water is evaporated; between 170 and 270°C gases develop containing condensable vapors, CO and CO_2. These condensable vapors (long chain carbon molecules) form pyrolysis oil, which can then be used for the production of chemicals or as a fuel after cooling and scrubbing. Between 270 and 280°C an exothermic reaction develops which can be detected by the spontaneous generation of heat.

There are three basic types of charcoal-making: (a) internally heated (by con- trolled combustion of the raw material), (b) externally heated (using fuelwood or fossil fuels) and (c) hot circulating gas (retort or converter gas, used for the production of chemicals). Internally heated charcoal kilns are the most common form of charcoal kiln. It is estimated that 10–20% of the wood (by weight) is sacrificed; a further 60% (by weight) is lost through the conversion to, and release of, gases to the atmosphere from these kilns. Externally heated reactors allow oxygen to be completely excluded, and thus provide better quality charcoal on a larger scale. They do, however, require the use of an external fuel source, which may be provided from the ‘‘producer gas’’ once pyrolysis is initiated. Recirculating heated gas systems offer the potential to generate large quantities of charcoal and associated by-products, but are presently limited by high investment costs for large-scale plants.

4 Gasification

High temperatures and a controlled environment lead to virtually all the raw material being converted into gas. This takes place in two stages. In the first stage, the biomass is partially combusted to form producer gas and charcoal. In the second stage, the CO_2 and H_2O produced in the first stage are chemically reduced by the charcoal, forming CO and H_2. The composition of the gas is 18–20% H_2, an equal portion of CO, 2–3% CH_4, 8–10% CO_2 and the rest nitrogen. These stages are spatially separated in the gasifier, with gasifier design very much dependent on the feedstock characteristics. Gasification requires temperatures of about 800°C and is carried out in closed top or open top gasifiers. These gasifiers can be operated at atmospheric pressure or higher. The energy density of the gas is generally, 5.6 MJ/m^3, which is low in comparison to natural gas at 38 MJ/m^3, providing only 60% of the power rating of diesel when used in a modified diesel engine. Gasification technology has existed since the turn of the century when coal was extensively gasified in the UK and elsewhere for use in power generation and in houses for cooking and lighting. Gasifiers were used extensively for transport in Europe during World War II due to shortages of oil, with a closed top design predominating.

A major future role is envisaged for electricity production from biomass plantations and agricultural residues using large-scale gasifiers with direct coupling to gas turbines. The potential gains in efficiency using such hybrid gasifier/ gas turbine systems make them extremely attractive for electricity generation once commercial viability has been demonstrated. Such systems take advantage of low grade and cheap feedstocks (residues and wood produced using short rotation techniques) and the high efficiencies of modern gas turbines to produce electricity at comparable or less cost than fossil fuel-derived electricity. Net atmospheric CO_2 emissions are avoided if growth of the biomass is managed to match consumption. The use of BIG/STIG (biomass integrated gasifier steams injected gas turbine) initially and BIG/GTCC (biomass integrated gasifier gas turbine combined cycle) as the technology matures, is predicted to allow energy conversion efficiencies of 40–55%. Modern coal electrical plants have efficiencies of about 35% or less. Combined heat and power systems could eventually provide energy at efficiencies of from 50 to 80%. The use of low-grade feedstocks combined with high conversion efficiencies makes these systems economically competitive with cheap coal-based plants and energetically competitive with natural gas-based plants. It has been observed that it takes a little under 1,000 acres (400 ha) of poplar (grown as a short-rotation crop at a usable yield of 5 dry U.S. tons/acre, or 11 metric tons/ha) to supply an electric power plant with a capacity of one megawatt (1 MW). A typical small biomass-fired power plant (25 MW) with 80% availability (i.e., actually operating 80% of the time) would produce about 175 million kWh per year, or approximately the electricity needs of 25,000 people. The required 25,000 acres of land (about 10,000 ha) would occupy about 2% of the total land area within a radius of 25 miles (40 km). These calculations are based on a 30% conversion efficiency from heat to electricity, and an energy content for dry poplar wood of 17 Btu/U.S. ton (19.7 GJ/metric ton).

5 Catalytic Liquefaction

This technology has the potential to produce higher quality products of greater energy density. These products should also require less processing to produce marketable products. Catalytic liquefaction is a low temperature, high pressure thermochemical conversion process carried out in the liquid phase. It requires either a catalyst or a high hydrogen partial pressure. Technical problems have so far limited the opportunities of this technology.

Types of Gasifiers

1 Updraught or Counter Current Gasifier

The oldest and simplest type of gasifier is the counter current or updraught gasifier where the air intake is at the bottom and the gas leaves at the top. The combustion reactions occur near the grate at the bottom, which are followed by reduction reactions somewhat higher up in the gasifier. In the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones. The tars and volatiles produced during this process are carried in the gas stream. Ashes are removed from the bottom of the gasifier. The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency, as well as the possibility of operation with many types of feedstock (sawdust, cereal hulls, etc.).

Major drawbacks result from the possibility of ‘‘channeling’’ in the equipment, which can lead to oxygen breakthrough and dangerous, explosive situations and the necessity to install automatic moving grates, as well as from the problems associated with disposal of the tar-containing condensates that result from the gas cleaning operations. The latter is of minor importance if the gas is used for direct heat applications, in which case the tars are simply burnt.

2 Downdraught or Co-Current Gasifiers

A solution to the problem of tar entrainment in the gas stream has been found by designing co-current or downdraught gasifiers, in which primary gasification air is introduced at or above the oxidation zone in the gasifier. The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction.

On their way down the acid and tarry distillation products from the fuel must pass through a glowing bed of charcoal and therefore are converted into permanent gases hydrogen, carbon dioxide, carbon monoxide and methane. Depending on the temperature of the hot zone and the residence time of the tarry vapors, a more or less complete breakdown of the tars is achieved. The main advantage of down- draught gasifiers lies in the possibility of producing a tar-free gas suitable for engine applications. In practice, however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment: tar-free operating turn-down ratios of a factor 3 are considered standard; a factor 5–6 is considered excellent. Because of the lower level of organic components in the condensate, downdraught gasifiers suffer less from environmental objections than updraught gasifiers.

A major drawback of downdraught equipment lies in its inability to operate on a number of unprocessed fuels. In particular, fluffy, low density materials give rise to flow problems and excessive pressure drop, and the solid fuel must be pelletized or briquetted before use. Downdraught gasifiers also suffer from the problems associated with high ash content fuels to a larger extent than updraught gasifiers. Minor drawbacks of the downdraught system, as compared to updraught, are somewhat of lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas. Besides this, the necessity to maintain uniform high temperatures over a given cross-sectional area makes impractical the use of downdraught gasifiers in a power range above about 350 kW (shaft power).

3 Cross-Draught Gasifier

Cross-draught gasifiers are an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500 °C and higher) in the oxidation zone which can lead to material problems. In cross-draught gasifiers insulation against these high temperatures is provided by the fuel (charcoal) itself. Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. The reason is the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of a gasifier in conjunction with small engines.

A disadvantage of cross-draught gasifiers is their minimal tar-converting capabilities and the consequent need for high quality (low volatile content) charcoal. It is because of the uncertainty of charcoal quality that a number of charcoal gasifiers employ the downdraught principle, in order to maintain at least a minimal tar-cracking capability.

4 Fluidized Bed Gasifier

The operation of both up- and downdraught gasifiers is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are: lack of bunker flow, slagging and extreme pressure drop over the gasifier. Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor, very quickly mixed with the bed material and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolyzed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar- conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blow-out as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications.

5 Other Types of Gasifiers

A number of other biomass gasifier systems (double fired, entrained bed, molten bath), which are partly spin-offs from the coal gasification technology, are currently under development. In some cases these systems incorporate unnecessary refinements and complications, in others both the size and sophistication of the equipment make near-term application in developing countries unlikely.

Anaerobic Digestion

Anaerobic reactors are generally used for the production of methane-rich biogas from manure (human and animal) and crop residues. Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy.

They utilize mixed methanogenic bacterial cultures which are characterized by defined optimal temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide temperature range, i.e., above 0°C up to 60°C. When functioning well, the bacteria convert about 90% of the feedstock energy content into biogas (containing about 55% methane), which is a readily useable energy source for cooking and lighting. The sludge produced after the manure has passed through the digester is non-toxic and odorless. Also, it has lost relatively little of its nitrogen or other nutrients during the digestion process thus, making a good fertilizer. In fact, compared to cattle manure left to dry in the field the digester sludge has higher nitrogen content; many of the nitrogen compounds in fresh manure become volatized while drying in the sun. On the other hand, in the digested sludge little of the nitrogen is volatized, and the nitrogen is more readily accessible by plants than many of the nitrogen compounds found in dung, and thus the fertilizer value of the sludge may actually be higher than that of fresh dung.

Pressure from environmentally related legislation on solid waste disposal methods in developed countries has increased the application of anaerobic digestion as a process for reducing waste volumes and generating useful by-products. Anaerobic digestion may either be used to process the source separated fraction of municipal waste, or alternatively combined with mechanical sorting systems, to process residual mixed municipal waste. These facilities are called mechanical biological treatment plants. Utilizing anaerobic digestion technologies can help to reduce the emission of greenhouse gases in a number of key ways:

- Replacement of fossil fuels.
- Reducing or eliminating the energy footprint of waste treatment plants.
- Reducing methane emission from landfills.
- Displacing industrially produced chemical fertilizers.
- Reducing vehicle movements.
- Reducing electric grid transportation losses.

If the putrescible waste processed in anaerobic digesters was disposed of in a landfill, it would break down naturally and often anaerobically. In this case the gas will eventually escape into the atmosphere. As methane is about 20 times more potent as a greenhouse gas than carbon dioxide this has significant negative environmental effects.

The most common and popular on-farm use of biogas is to fuel an engine- generator (generator-set or genset) to produce electricity for on-farm use, or, less commonly, for off-farm sale or under a net-metered arrangement with the utility. Heat recovered from combustion of the biogas (whether in boilers or internal combustion engines) can be used to maintain the operating temperature of the anaerobic digester or for other on-farm uses. Burners and boilers used to produce heat and steam can be fueled by biogas. The direct substitution of biogas for natural gas or LPG, however, will not work for most standard commercially available burners. At the given fuel gas feed pressures, gas must flow into combustion in the right stoichiometric ratio with air. Because of its high CO_2 content, if biogas flows through the burner orifice at the pressure intended for feeding methane or propane, the fuel-to-air ratio is insufficient to ensure flame stability.

A relatively simple option is to provide the combustion equipment with a second ‘‘as is’’ biogas burner that operates in parallel with the first. In this case, regardless of the fuel used, air flow is kept constant. Burner orifices for the respective burners can be set such that each burner meters the proper amount of gas to meet combustion stoichiometry. This could require other control measures such as (for simplest control) complete switchovers from pure biogas fuel to the fossil alternative, and modest (a few hours' worth) backup biogas storage, but is otherwise straightforward.

Digester liquor can be used as a fertilizer supplying vital nutrients to soils. The solid, fibrous component of the digested material can be used as a soil conditioner to increase the organic content of soils. The liquor can be used instead of chemical fertilizers which require large amounts of energy to produce and transport. The use of manufactured fertilizers is therefore more carbon intensive than the use of anaerobic digester liquor fertilizer.

In countries that collect household waste, the utilization of local anaerobic digestion facilities can help to reduce the amount of waste that requires transportation to centralized landfill sites or incineration facilities. This reduced burden on transportation reduces carbon emissions from the collection vehicles. If localized anaerobic digestion facilities are embedded within an electrical distribution network, they can help in reducing the electrical losses that are associated with transporting electricity over a national grid.
There are four key biological and chemical stages of anaerobic digestion:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

In most cases biomass is made up of large organic polymers. In order for the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts or monomers such as sugars are readily available by other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high molecular weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids and fatty acids.

Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules such as volatile fatty acids (VFAs) with a chain length that is greater than acetate must first be catabolized into compounds that can be directly utilized by methanogens. The biological process of acidogenesis is where there is further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here, VFAs are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products. The process of acidogenesis is similar to the way that milk sours. The third stage of anaerobic digestion is aceto- genesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen.

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens utilize the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. It is these components that make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and 8. The remaining, non-digestible material which the microbes cannot feed upon, along with any dead bacterial remains constitutes the digestate.
The end products of biological treatment are:

- *Biogas* (methane not less than 55%, carbon dioxide not more than 45%, hydrogen sulfide not more than 2%, hydrogen not more than 1%);
- *fermented substrate as fermentation residue*, consisting of water, cellulose residues, small quantity of bacteria and organic nutrients (nitrogen, phosphorus, potassium, etc.).

Anaerobic digesters can be designed and engineered to operate using a number of different process configurations:

- Batch or continuous.
- Temperature: mesophilic or thermophilic.
- Solids content: high solids or low solids.
- Complexity: single stage or multistage.

1 Batch or Continuous

A batch system is the simplest form of digestion. Biomass is added to the reactor at the start of the process in a batch and is sealed for the duration of the process. Batch reactors suffer from odor issues that can be a severe problem when they are emptied. Typically, biogas production will be formed with a normal distribution pattern over time. The operator can use this fact to determine when they believe the process of digestion of the organic matter has completed. As the batch digestion is simple and requires less equipment and lower levels of design work it is typically a cheaper form of digestion.

In continuous digestion processes organic matter is constantly added (continuous complete mixed) or added in stages to the reactor (continuous plug flow; first in–first out). Here the end products are constantly or periodically removed, resulting in constant production of biogas. Single or multiple digesters in sequence may be used. Examples of this form of anaerobic digestion include continuous stirred-tank reactors (CSTRs), up flow anaerobic sludge blanket (UASB), expanded granular sludge bed (EGSB) and internal circulation reactors (IC).

2 Temperature

There are two conventional operational temperature levels for anaerobic digesters, which are determined by the species of methanogens in the digesters:

- Mesophilic which takes place optimally around 30–38°C or at ambient temperature between 20 and 45°C where mesophiles are the primary microorganism present.
- Thermophilic which takes place optimally around 49–57°C at elevated temperatures up to 70°C where thermophiles are the primary microorganisms present.

There are a greater number of species of mesophiles than thermophiles. These bacteria are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are therefore considered to be more stable than thermophilic digestion systems.

As mentioned above, thermophilic digestion systems are considered to be less stable, the energy input is higher and more energy is removed from the organic matter. However, the increased temperatures facilitate faster reaction rates and hence faster gas yields. Operation at higher temperatures facilitates greater sterilization of the end digestate.

3 Solids

Typically, there are three different operational parameters associated with the solids content of the feedstock to the digesters:

- High-solids (dry—stackable substrate)
- High-solids (wet—pumpable substrate)
- Low-solids (wet—pumpable substrate)

High-solids (dry) digesters are designed to process materials with high-solids content between 25 and 40%. Unlike wet digesters that process pumpable slurries, high solids (dry—stackable substrate) digesters are designed to process solid substrates deposited in tunnel-like chambers with a gas-tight door. They typically have few moving parts, require minimal or no pre-grinding or shredding, and do not use water addition. Solid state digestion of cattle dung is a suitable technology in which fresh cattle dung is anaerobically digested. Solid degradation of about 40–48% is observed in the effluent slurry that provides easy flowability to the outlet slurry.

Low-solids (wet) digesters can transport material through the system using standard pumps that require significantly lower energy input. Low-solids digesters require a larger amount of land than high-solids due to the increase volumes associated with the increased liquid-to-feedstock ratio of the digesters. There are benefits associated with operation in a liquid environment as it enables more thorough circulation of materials and contact between the bacteria and their food. This enables the bacteria to more readily access the substances they are feeding off and increases the speed of gas yields.

4 Number of Stages

Digestion systems can be configured with different levels of complexity:

- One-stage or single-stage
- Two-stage or multistage

A single-stage digestion system is one in which all of the biological reactions occur within a single sealed reactor or holding tank. Utilizing a single stage reduces construction costs; however, it facilitates less control of the reactions occurring within the system. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, as outlined earlier, operate in a strictly defined pH range. Therefore, the biological reactions of the different species in a single stage reactor can be in direct competition with each other. Another one-stage reaction system is an anaerobic lagoon. These lagoons are pond-like earthen basins used for the treatment and long-term storage of manures. Here, the anaerobic reactions are contained within the natural anaerobic sludge contained in the pool.

In a two-stage or multistage digestion system different digestion vessels are optimized to bring maximum control over the bacterial communities living within the digesters. Acidogenic bacteria produce organic acids and grow and reproduce more quickly than methanogenic bacteria. Methanogenic bacteria require stable pH and temperature in order to optimize their performance. Typically, hydrolysis, acetogenesis and acidogenesis occur within the first reaction vessel. The organic material is then heated to the required operational temperature (either mesophilic or thermophilic) prior to being pumped into a methanogenic reactor. The initial hydrolysis or acidogenesis tanks prior to the methanogenic reactor can provide a buffer to the rate at which feedstock is added. It should be noted that it is not possible to completely isolate the different reaction phases and often there is some biogas that is produced in the hydrolysis or acidogenesis tanks.

5 Residence

The residence time in a digester varies with the amount and type of feed material, the configuration of the digestion system and whether it be one-stage or two-stage. In the case of single-stage thermophilic digestion residence times may be in the region of 14 days, which compared to mesophilic digestion is relatively fast. The plug-flow nature of some of these systems will mean that the full degradation of the material may not have been realized in this timescale. In two-stage mesophilic digestion, residence time may vary between 15 and 40 days. In the case of mesophilic UASB digestion hydraulic residence times can be (1 h–1 day) and solid retention times can be up to 90 days. In this manner the UASB system is able to separate solid and hydraulic retention times with the utilization of a sludge blanket. Continuous digesters have mechanical or hydraulic devices, depending on the level of solids in the material, to mix the contents enabling the bacteria and the food to be in contact. They also allow excess material to be continuously extracted to maintain a reasonably constant volume within the digestion tanks.

6 Feedstocks

The most important initial issue when considering the application of anaerobic digestion systems is the feedstock to the process. Digesters typically can accept any biodegradable material; however, if biogas production is the aim, the level of putrescibility is the key factor in its successful application. The more putrescible the material the higher the gas yields possible from the system. Substrate com- position is a major factor in determining the methane yield and methane pro- duction rates from the digestion of biomass. Techniques are available to determine the compositional characteristics of the feedstock, while parameters such as solids, elemental and organic analyses are important for digester design and operation.

Anaerobes can break down material to varying degrees of success from readily in the case of short chain hydrocarbons such as sugars, to over longer periods of time in the case of cellulose and hemicellulose. Anaerobic microorganisms are unable to break down long chain woody molecules such as lignin. Anaerobic digesters were originally designed for operation using sewage sludge and manures. Sewage and manure are not, however, the material with the most potential for anaerobic digestion as the biodegradable material has already had much of the energy content taken out by the animal that produced it. Therefore, many digesters operate with *co-digestion* of two or more types of feedstock. For example, in a farm-based digester that uses dairy manure as the primary feedstock the gas production may be significantly increased by adding a second feedstock; e.g. *grass* and *corn* (typical on-site feedstock), or various organic by-products, such as *slaughterhouse waste*, *fats oils and grease* from restaurants, *organic household waste*, etc. (typical off-site feedstock).

A second consideration related to the feedstock is moisture content. Dryer, stackable substrates, such as food and yard wastes, are suitable for digestion in tunnel-like chambers. Tunnel style systems typically have near-zero wastewater discharge as well so this style system has advantages where the discharge of digester liquids is a liability. The wetter the material the more suitable it will be for handling with standard pumps instead of energy intensive concrete pumps and physical means of movement. Also, the wetter the material, the more volume and area it takes up relative to the levels of gas that are produced. The moisture content of the target feedstock will also affect what type of system is applied to its treatment. In order to use a high solids anaerobic digester for dilute feedstocks, bulking agents such as compost should be applied to increase the solid content of the input material. Another key consideration is the carbon: nitrogen ratio of the input material. This ratio is the balance of food a microbe requires in order to grow. The optimal C: N ratio for the 'food' of a microbe is 20–30:1. Excess N can lead to ammonia inhibition of digestion. The level of contamination of the feedstock material is a key consideration. If the feedstock to the digesters has significant levels of physical contaminants such as plastic, glass or metals, then pre-processing will be required in order for the material to be used. If it is not removed then the digesters can be blocked and will not function efficiently. It is with this that mechanical biological treatment plants are designed. The higher the level of pre-treatment a feedstock requires, the more processing machinery will be required and hence the project will have higher capital costs.

Ethanol Fermentation

Ethanol is mainly used as a substitute for imported oil in order to reduce their dependence on imported energy supplies. The substantial gains made in fermentation technologies now make the production of ethanol for use as a petroleum substitute and fuel enhancer, both economically competitive (given certain assumptions) and environmentally beneficial. The most commonly used feedstock in developing countries is sugarcane, due to its high productivity when supplied with sufficient water. Where water availability is limited, sweet sorghum or cassava may become the preferred feedstocks. Other advantages of sugarcane feedstock include the high residue energy potential and modern management practices which make sustainable and environmentally benign production possible while at the same time allowing continued production of sugar. Other feedstocks include saccharide-rich sugar beet, and carbohydrate-rich potatoes, wheat and maize.

Ethanol fermentation, also referred to as alcoholic fermentation, is a biological process in which sugars such as glucose, fructose and sucrose are converted into cellular energy and thereby produce ethanol and carbon dioxide as metabolic waste products. Because yeasts perform this process in the absence of oxygen, ethanol fermentation is classified as anaerobic. Ethanol fermentation occurs in the production of alcoholic beverages and ethanol fuel, and in the rising of bread dough. Typically, sugars are extracted from the biomass feedstock by crushing and washing (or in the case of starchy feedstocks like corn, by breakdown of starch to sugars). The sugar syrup is then mixed with yeast and kept warm, so that the yeast breaks down the sugars into ethanol. However, the fermented product is only about 10% ethanol, so a further stage of distillation is required to concentrate the ethanol to 95%. If the ethanol is intended for blending with gasoline, a ‘‘dehydration’’ phase may be required to make 100% pure ethanol. In the near future, ethanol may be made from cellulose, again by breakdown into sugars for fermentation. Cellulose is widely and cheaply available from many other biomass feedstocks, energy crops, agricultural and forestry residues.

A great number of bacteria are capable of ethanol formation. Many of these microorganisms, however, generate multiple end products in addition to ethyl alcohol. These include other alcohols (butanol, isopropylalcohol, 2, 3-butanediol), organic acid (acetic acid, formic acid, and lactic acids), polyols (arabitol, glycerol and xylitol), ketones (acetone) or various gases (methane, carbon dioxide, hydrogen). Many bacteria (i.e. *Enterobacteriaceas, Spirochaeta, Bacteroides*, etc.) metabolize glucose by the Embden-Meyerhof pathway. Briefly, this path utilizes 1 mol of glucose to yield 2 mol of pyruvate which are then decarboxylated to acetaldehyde and reduced to ethanol. Besides that, the Entner–Doudoroff pathway is an additional means of glucose consumption in many bacteria.

Biodiesel

Another form of liquid fuel from biomass is ‘‘biodiesel’’, which is derived from the vegetable oils extracted by crushing oilseeds, although waste cooking oil or animal fats (tallow) can also be used. The oil is strained and usually ‘‘esterified’’, by combining the fatty acid molecules in the oil with methanol or ethanol. Vegetable oil esters have been shown to make good-quality clean-burning diesel fuel.

The use of vegetable oils for combustion in diesel engines has occurred for over 100 years. In fact, Rudolf Diesel tested his first prototype on vegetable oils, which can be used, ‘‘raw’’, in an emergency. While it is feasible to run diesel engines on raw vegetable oils, in general the oils must first be chemically transformed to resemble petroleum-based diesel more closely. The raw oil can be obtained from a variety of annual and perennial plant species. Perennials include oil palms, coconut palms, physica nut and Chinese tallow tree. Annuals include sunflower, groundnut, soybean and rapeseed. Many of these plants can produce high yields of oil, with positive energy and carbon balances. Transformation of the raw oil is necessary to avoid problems associated with variations in feedstock. The oil can undergo thermal or catalytic cracking, Kolbe electrolysis, or transesterification processes in order to obtain better characteristics. Untreated oil causes problems through incomplete combustion, resulting in the buildup of sooty residues, waxes, gums, etc.

Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, propyl or ethyl) esters. Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat (tallow)) with an alcohol. Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel *converted* diesel engines. Biodiesel can be used alone, or blended with petrol and diesel. Blends of biodiesel and conventional hydrocarbon-based diesel products are most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the ‘‘B’’ factor to state the amount of biodiesel in any fuel mix:

- 100% biodiesel is referred to as B100, while
- 20% biodiesel is labeled B20
- 5% biodiesel is labeled B5
- 2% biodiesel is labeled B2.

Obviously, the higher the percentage of biodiesel, the more ecology-friendly the fuel is. Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines. Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems. Blending B100 with petroleum diesel may be accomplished by:

- Mixing in tanks at manufacturing point prior to delivery to tanker truck.
- Splash mixing in the tanker truck (adding specific percentages of biodiesel and petroleum diesel).
- In-line mixing, two components arrive at tanker truck simultaneously.
- Metered pump mixing, petroleum diesel and biodiesel meters are set to X total volume, transfer pump pulls from two points and mix is complete on leaving pump.

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Unit 4 Small Hydro Power Systems

1.1 Renewable Energy in the World and in India

Renewable energy is energy generated from natural resources—such as sunlight, wind, rain, tides, and geothermal heat—which are renewable (naturally replenished). In 2006, about 18 percent of the global final energy consumption came from renewable sources, with 13 percent coming from traditional biomass, such as wood-burning. Hydroelectricity was the next largest renewable source, providing 3 percent of global energy consumption and 15 percent of global electricity generation.

Wind power is growing at the rate of 30 percent annually, with a worldwide installed capacity of 1,21,000 megawatts (MW) in 2008. It is widely used in European countries and the United States. The annual manufacturing output of the photovoltaic industry reached 6,900 MW in 2008, and photovoltaic (PV) power stations are popular in Germany and Spain. Solar thermal power stations operate in the U.S.A and Spain, and the largest of these is the 354 MW SEGS power plant in the Mojave Desert. The world's largest geothermal power installation is The Geysers in California, with a rated capacity of 750 MW. Brazil has one of the largest renewable energy program in the world, involving production of ethanol fuel from sugar cane, and ethanol now provides 18 percent of the country's automotive fuel. Ethanol fuel is also widely available in the USA. While most renewable energy projects and production are large-scale, renewable technologies are also suited to small off-grid applications, sometimes in rural and remote areas, where energy is often crucial for human development. Kenya has the world's highest household solar ownership rate with roughly 30,000 small (20–100 watt) solar power systems sold per year.

Some renewable-energy technologies are criticized for being intermittent or unsightly, yet the renewable-energy market continues to grow. Climate-change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable-energy legislation, incentives and commercialization. New government spending, regulation and policies should help the industry weather the 2009 economic crisis better than many other sectors. With India's power needs projected to reach over 240,000 MW by 2012 – an increase of about 20,000 MW per year – it has become critically important to exploit other energy sources. As much as 18 percent of the additional grid interactive renewable power capacity that was commissioned during the first three years of the Tenth plan came from renewables.

The estimated potential in India for generation of power from wind, small hydro, and biomass is around 80,000 MW. Renewable power capacity is likely to double every five years or so in the future. By 2012 around 20,000 MW, which is 10 percent of the then installed capacity would be contributed by renewables. Sources estimate that about 7.5 billion dollars have so far been invested in the renewable power sector in India. About 90 percent of the investment has come from the private sector.

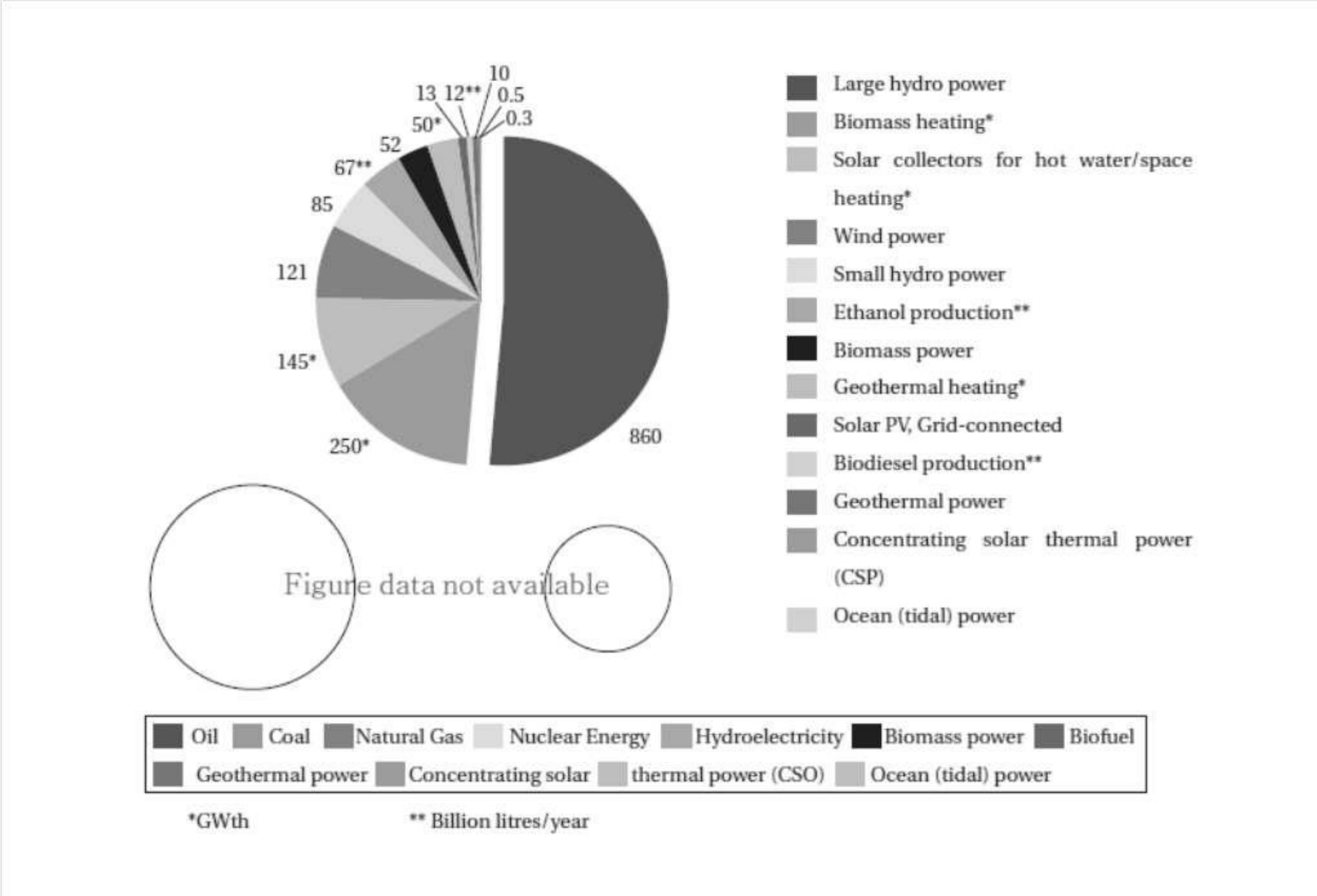


Figure 1.1 Renewable energy, end of 2008 (GW)

1.2 Hydro Power Generates Electricity

Of the renewable energy sources that generate electricity, hydro power is the one used most often. It is one of the oldest sources of energy and was used thousands of years ago, to turn a paddle wheel for the purpose of grinding grain.

How Hydro Power Works

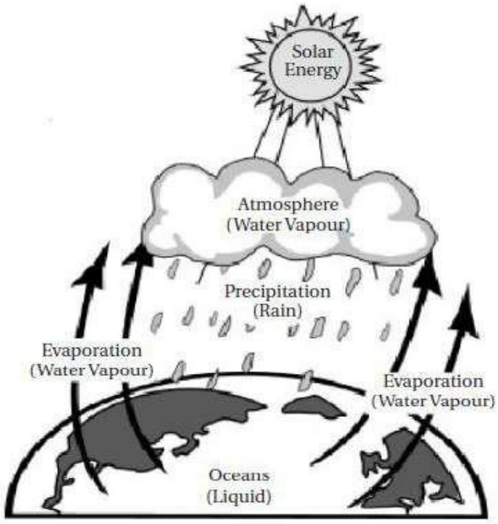
It is important to understand the water cycle to understand hydro power. In the water cycle:

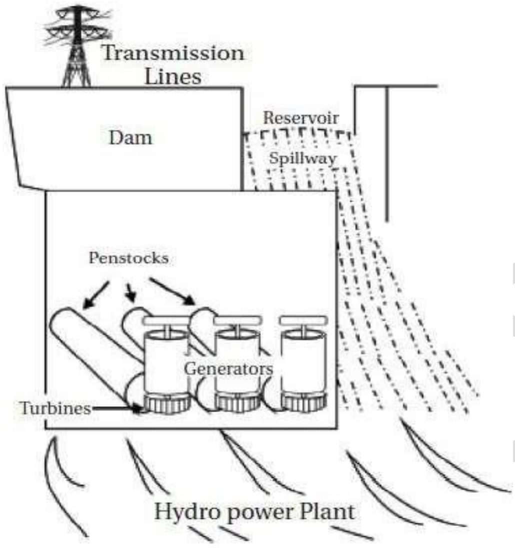
- Solar energy heats water on the surface, causing it to evaporate
- This water vapor condenses into clouds and falls back onto the surface

as precipitation

- The water flows through rivers back into the oceans, where it can evaporate and begin the cycle all over again.

Mechanical energy is derived by directing, harnessing, or channeling moving water. The amount of available energy in moving water is determined by its flow or fall. Swiftly flowing water in a big river, like the Narmada or the Ganges, carries a great deal of energy in its flow. The same is the case with water descending rapidly from a very high point. In either instance, the water flows through a pipe, or penstock, then pushes against and turns the blades in a turbine, to spin a generator to produce electricity. In a runoff-the-river system, the force of the current applies the needed pressure, while in a storage system, water is accumulated in reservoirs created by dams, then released when the demand for electricity is high. Meanwhile, the reservoirs or lakes are used for boating and fishing, and often the rivers beyond the dams provide opportunities for whitewater rafting and kayaking.





1.3 Hydro Power and the Environment

Some people regard hydro power as the ideal fuel for electricity generation because unlike the nonrenewable fuels used to generate electricity, it is almost free, there are no waste products and hydro power
does not pollute the water or the air. However, it is criticized because it does change the environment by affecting natural habitats. For instance, the recent Narmada Valley Project created a mass movement that pressurized the Government of India to lower the height of the dam so that a smaller area would be submerged. However, in this part of our syllabus we are talking of Small Hydro Power projects that have minimum impact on the environment and the people around it.

Over 40 percent of India's population does not have access to electricity and providing electricity for 24 hours in rural areas is a major challenge. For this, the Indian government has envisioned several paths for its energy requirements, from nuclear to renewable Overby Despite greening its energy requirements, the government has taken various paths, from bidding for foreign oil wells through diplomatic maneuvering, to establishing fossil fuel thermal plants.

The National Electricity Policy envisages that the per capita availability of electricity will be increased to over 1,000 KW, by 2012. To achieve this, the government is expecting a total capacity addition of about 78,577 MW at the end of 2012, of which:

- 16,553 MW is expected from hydro
- 58,644 MW from thermal and
- 3,380 MW from nuclear.

Although India has significant potential for generation of power from non-conventional energy sources (1,83,000 MW) such as wind, small hydro, biomass and solar energy, the emphasis is still on thermal energy sources. India has at present a 7.5 percent overall electrical energy shortage and 11 percent shortage during peak hours.

1.4 Options for Hydro power

In the 2005 National Electricity Policy the objectives have been set as follows:

- Provision for access to electricity for all households
- Demand to be met by 2012, with no energy and peaking shortages
- Adequate reserves to be made available and
- Reliable and quality power supplies, at reasonable rates.

The Indian government considers hydro power as a renewable, economic, non-polluting and environmentally benign source of energy. The exploitable hydro-electric potential in terms of installed capacity, is estimated to be about 1,48,700 MW (See Table 1), out of which, a capacity of 30,164 MW (20.3 percent) has been developed so far and 13,616 MW (9.2 percent) of capacity is under construction. In addition, 6,782 MW in terms of installed capacity from small, mini and micro hydro schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. The government expects to harness its full potential of hydro power by 2027, with a whopping investment of 5,000 billion rupees.

Table 1: India's Hydro power potential

River Basin	Potential at 60 percent load factor (MW)	Probable capacity (MW)
Indus Basin	19,988	33,832
Brahmaputra Basin	34,920	66,065
Ganga Basin	10,715	20,710
Centrall India Basin	2,740	4,152
System	6,149	9,430
East Flowing River System	9,532	14,511
Total	84,044	1,48,700

1.5 Small Hydro-Power: A Viable Option

Small and mini hydel projects have the potential to provide energy in remote and hilly areas where extension of an electrical transmission grid system is uneconomical. Realizing this fact, the Indian government is encouraging development of small hydro power (SHP) projects in the country. Since 1994 the role of the private sector for setting up of commercial SHP projects has been encouraged. So far, 14 States in India have announced policies for setting up commercial SHP projects through private sector participation. Over 760 sites of about 2,000 MW capacity have already been offered/allotted.

An estimated potential of about 15,000 MW of SHP projects exist in India. 4,233 potential sites with an aggregate capacity of 10,071 MW for projects up to 25 MW capacities have been identified. In the last 10-12 years, the capacity of Small Hydro projects up to 3 MW has increased 4-fold from 63 MW to 240 MW. 420 Small Hydro power projects up to 25 MW station capacity with an aggregate capacity, of an over 1,423 MW have been set up in the country and over 187 projects in this range with an aggregate capacity of 521 MW are under construction.

The Ministry of New and Renewable Energy Source (MNRES) provides various incentives like soft loans for setting up of SHP projects up to 25 MW capacity in the commercial sector, renovation and modernization of SHP projects, setting up of portable micro hydel sets, development/upgradation of water mills, detailed survey and investigation, detailed project report preparation, interest subsidy for commercial projects, capital subsidy for SHP projects in the North-Eastern region, and implementation of UNDP/GEF Hilly Hydro project. India has a reasonably well-established manufacturing base for the full range and type of small hydro equipment. There are currently eight manufacturers within India in the field of small hydro manufacturing,
supplying various types of turbines, generators, control equipment, etc.

Asian Development Bank(ADB) has begun its engagement in producing hydro-power in Uttarakhand in India with 4 SHPs (4-10 MW). However, the Manila based regional development bank believes that India's vast hydro power potential can contribute to the country's energy security in an environmentally sustainable and socially responsible manner. The report of ADB (Hydro power Development in India, 2007) provides an assessment of the hydro power development potential in India and highlights how hydro power can meet the country's goal of providing power for all by 2012. Probably, the World Bank would like to assist in the construction of hydro power structures and the ADB will lay the transmission lines from the projects to the grid. As major rivers transcend international boundaries in South Asia, India has taken up regional (mostly bilateral) co-operation on harnessing the hydro-power potential of international river systems. At present, India has the co-operation of Bhutan, Nepal and Myanmar on hydro-power. commercial SHP projects has been encouraged.

2. Small Hydro Power – Basic Working Principles

2.1 What is Micro Hydro power?
Micro Hydro power (from hydro meaning water and micro meaning small scale) refers to electrical energy that comes from the force of moving water used to power a household or a small village.
The fall and flow of water is part of a continuous natural cycle. The sun draws up moisture from the oceans and rivers and the moisture then condenses into clouds in the atmosphere. This moisture falls as rain or snow, replenishing the oceans and rivers. Gravity moves the water from high ground to low ground. The force of moving water can be extremely powerful, as anyone who has experienced whitewater rafting knows! Micro Hydro power harnesses some of this power to create electricity. Hydro power is a renewable energy source because it is replenished by snow and rainfall. If the rain falls, we won't run out of this energy source.

Small Hydro Power Site
The site that is chosen for SHP is usually rivers or streams. It is called a run-of-the river system. For a SHP site, two types of information are needed. First, the flood flow or the expected maximum water level is needed to size a spillway (if any), to locate turbines and generators above the highest expected water level and to design diversion structures or canals. Second, the statistical distribution of monthly stream flow volumes (flow duration curve) is needed to estimate the reliability of the site to produce a given amount of electrical power and to size a turbine.

2.2 How Does Micro Hydro Power Work?
Hydro power plants capture the energy of falling water to generate electricity. A turbine converts the energy of falling water into mechanical energy. Then an alternator converts the mechanical energy from the turbine into electrical energy. The amount of electricity a hydro power plant produces is a combination of two factors:
1. How far the water falls (Head): Generally, the distance the water falls depends on the steepness of the terrain the water is moving across, or the height of the dam the water is stored behind. The farther the water falls, the more power it has. In fact, the power of falling water is 'directly proportional' to the distance it falls. In other words, water falling twice as far has twice as much energy. It is important to note we are only talking about the vertical distance the water falls – the distance the water travels horizontally are consequential only in calculating the expense of the system and friction losses. 'Head' is usually measured in 'feet'.
2. Volume of water falling (Flow): More water falling through the turbine will produce more power. The amount of water available depends on the volume of water at the source. Power is also 'directly proportional' to river flow or flow volume. A river, with twice the amount of flowing water as another river, can produce twice as much energy. Flow volume is usually measured in 'gallons per minute', or GPM.

For Micro Hydro systems, this translates into two categories of turbines:
For high head and low flow volume sites, impulse turbines are the most efficient choice. The power produced by an impulse turbine comes entirely from the momentum of the water hitting the turbine

runners. This water creates a direct push or 'impulse' on the blades, and thus such turbines are called 'impulse turbines'.

For low head and high flow volume sites, a reaction turbine is the best choice. The reaction turbine, as the name implies, is turned by reactive force rather than a direct push or impulse. The turbine blades turn in reaction to the pressure of the water falling on them. Reaction turbines can operate on heads as low as 2 feet, but require much higher flow rates than an impulse turbine.

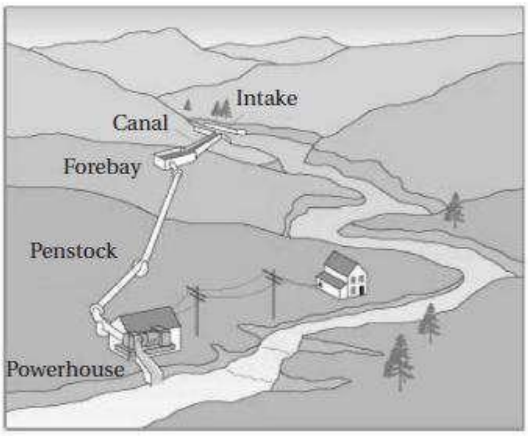
3. Working of an SHP

3.1 Main parts of an SHP

An SHP plant generates electricity or mechanical power by converting the power available in the flowing water of rivers, canals and streams. The objective of a hydro power scheme is to convert the potential energy of a mass of water flowing in a stream with a certain fall, called 'head', into electric energy at the lower end of the scheme, where the powerhouse is located. The power of the scheme is proportional to the flow and to the head. A well-designed SHP system can blend in with its surroundings and have minimal negative environmental impacts. SHP schemes are mainly run-of-the river, with little or no reservoir impoundment.

Figure 3.1: Small Hydro power model

Figure 3.2: Cross-section of an SHP



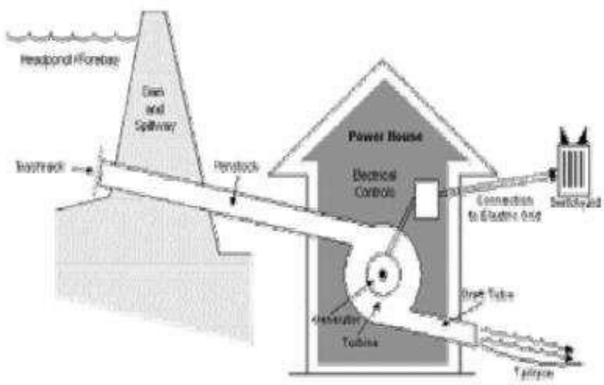


Figure 3.1: Small Hydro power model

Figure 3.2: Cross-section of an SHP

For run-of-the river systems, a portion of river water is diverted to a water conveyance which delivers the water to a turbine. The moving water rotates the turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes such as pumping water or it can be used to power an alternator or generator to generate electricity.

Small hydro power is not simply a reduced version of a large hydro plant. Specific equipment is necessary to meet fundamental requirements about simplicity.

3.2 Weir and Intake

An SHP must extract water from the river in a reliable and controllable way. A weir can be used to raise the water level and ensure a constant supply to the intake. Sometimes, a weir is not built because the natural features of the river are used. The following are required for an intake:

- The desired flow must be diverted,
- The peak flow of the river must be able to pass the weir and intake without causing damage to them,

- Minimum maintenance and repairs as for as possible,
- It must prevent large quantities of loose material from entering the canal,
- It should have the possibility for more piled up sediments.

3.3 Canal

The canal conducts water from the intake to the forebay tank. The length of the canal depends on the local conditions. In one case, a long canal combined with a short penstock can be cheaper or necessary while in other cases, the combination of a short canal with a long penstock is better suited. The canals are sealed with cement, clay or polythene sheets to reduce friction and prevent leakages. The size and shape of a canal is a compromise between cost and reduced head. The following are incorporated in a canal:

- Settling basin – these are basins which allow particles and sediments, which have come from the river

flow, and which will settle on the basin floor. The deposits are periodically flushed.

- Spillways – these divert excess flow at certain points along the canal. The excess flow can be due to floods.

3.4 Forebay tank

The forebay tank forms the connection between the canal and the penstock. The main purpose is to allow the particles to settle down, before the water enters the penstock.

3.5 Penstock

In front of the penstock, a trash rack (Figure 3.2) is installed to prevent large particles from entering the penstock. Penstock is a pipe which conveys water under pressure from the forebay tank to the turbine. Usually unplastified polyvinyl chloride (uPVC) is used to make penstock pipes. uPVC can reduce a lot of friction in the pipe, it is cheap, and it can withstand pressure when compared to other materials that can be
used to make penstock pipes. Pipes are generally made and supplied in standard lengths and must be joined together on site. There are several ways to join the pipe; flanged, spigot and socket, mechanical and welded. Expansion joints are used to compensate for maximum possible change in length.

Penstock pipes can be either buried or surface mounted. This depends on the nature of the terrain and environment considerations. Buried pipelines should be 0.75 m below the surface so that vehicles do not damage it. However, one disadvantage can be, that if leaks occur in the pipes, it would be difficult to detect and rectify. When pipes are run above ground, anchors or thrust blocks are needed to counteract the forces which can cause undesired pipeline movement. The pressure rating of the penstock is critical because the pipe wall must be thick enough to withstand the maximum water pressure. This pressure depends on the head; the higher the head the greater will be the pressure.

3.6 Powerhouse and tailrace

Powerhouse is a building that contains the turbine generator and the control units. Although the powerhouse can be a simple structure; its foundation must be solid. The tailrace is a channel that allows the water to flow back to the stream, after it has passed through the turbine. (Figure 3.2)

4. Electrical and Mechanical Equipment in a Small Hydro Power Plant

The Powerhouse:

In a small hydro power scheme, the role of the powerhouse is to protect the electromechanical equipment that converts the potential energy of water into electricity from the weather. The number, type and power of the turbo-generators, their configuration, the scheme head and the geomorphology of the site determine the shape and size of the building. As shown in figures 4.1 and 4.2, the following equipment will be displayed in the powerhouse:

- Inlet gate or valve
- Turbine
- Speed increaser (if needed)
- Generator
- Control system
- Condenser, switchgear
- Protection systems
- DC emergency supply
- Power and current transformers etc.,

Fig. 4.1 is a schematic view of an integral intake indoor powerhouse suitable for low 'head' schemes. The substructure is part of the weir and embodies the power intake with its trash rack, the vertical axis Kaplan turbine coupled to the generator, the draft tube and the tailrace. The control equipment and the outlet transformers are in the generator forebay.

4.1 Turbines

A turbine unit consists of a runner connected to a shaft that converts the potential energy in falling water into mechanical or shaft power. The turbine is connected either directly to the generator or is connected by means of gears or belts and pulleys, depending on the speed required for the generator. The choice of turbines depends mainly on the head and the design flow for the SHP installation. All turbines have power-speed characteristics.

Figure 4.1: Schematic view of a powerhouse - low head

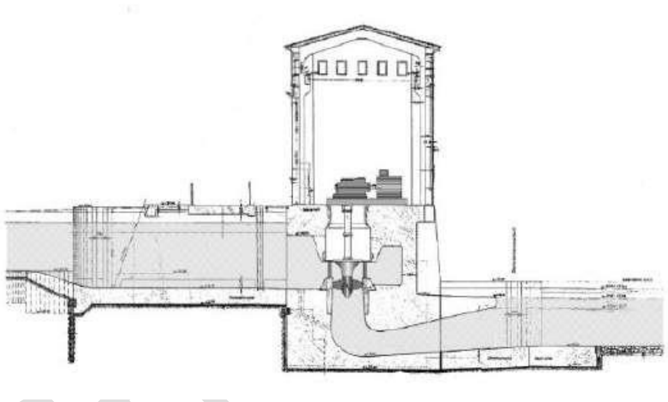
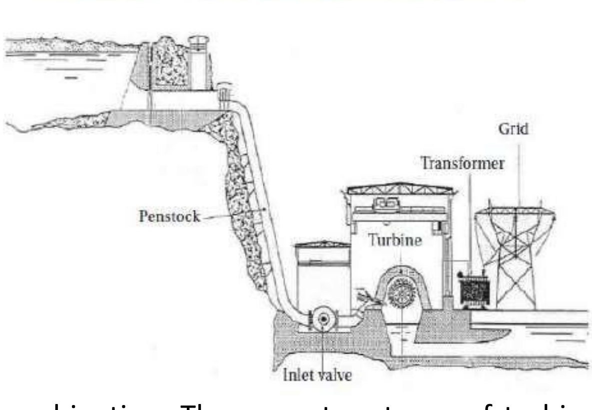


Figure 4.2: Schematic view of a powerhouse - high and medium heads



They perform most efficiently at a speed, head and flow combination. There are two types of turbines impulse and reaction. Table 2 shows which turbine is used for what kind of head.

4.1.1 Impulse turbines (high head, low flow)

Do you remember playing with toy pinwheels as a child? They are a good illustration of the principles behind an impulse turbine. When you blow on the rim of the pinwheel, it spins rapidly. The harder you blow, the faster it turns. The impulse turbine operates on the same principle, except that it uses the kinetic energy from the water as it leaves the nozzle rather than the kinetic energy of air. In a system using an impulse turbine, water is diverted upstream from the turbine into a pipeline. The water travels through this pipeline to a nozzle, which constricts the flow to a narrow jet of water. The energy to rotate an impulse turbine is derived from the kinetic energy of the water flowing through the nozzles. The term 'impulse' means that the force that turns the turbine comes from the impact of the water on the turbine runner. This causes the attached alternator to turn, and thus the mechanical work of the water is changed into electrical power.

Table 2: Groups of water turbines

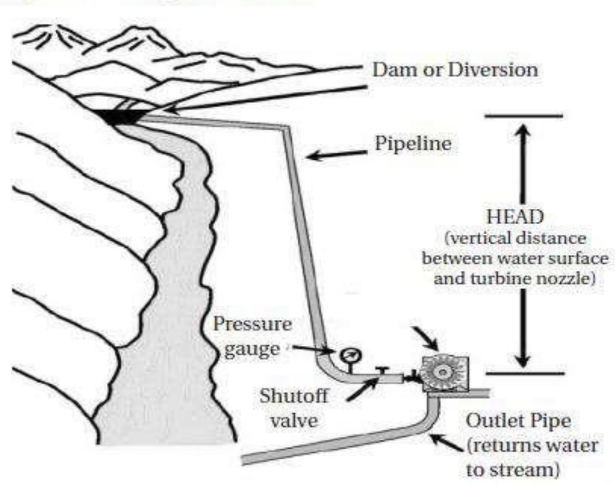
Turbine	High head (more than 100 m)	Medium head (20-100 m)	Low head
(5-20 m)	Ultra low 'head' (less than 5 m)		
Impulse	Pelton		
Turgo	Cross-flow		
Turgo			
Multi-jet pelton	Cross-flow		
Multi-jet pelton	Waterwheel		
Reaction	-	Francis	
Pump-as-turbine	Propeller		
Kaplan	Propeller		
Kaplan			

Most sites with a head of at least 25 feet now use impulse turbines. These turbines are very simple and relatively inexpensive. As the stream flow varies, water flow to the turbine can be easily controlled by changing nozzle sizes or by using adjustable nozzles. Common impulse turbines are the Pelton, Turgo, Cross flow and waterwheel or Chain turbines.

I. *Pelton Turbine*

This has a set of buckets on the periphery of a circular disc. It is turned by jets of water that are discharged from one or more nozzles. The bucket is split into two halves so that the central area does not act as a dead spot incapable of defecting water away from the oncoming jet. (Figure 4.4) The cutaway on the lower lip allows the following bucket to move further before cutting off the jet, propelling the bucket ahead of it and a permitting smoother entrance of the bucket into the jet.

Figure 4.3: Impulse Turbine



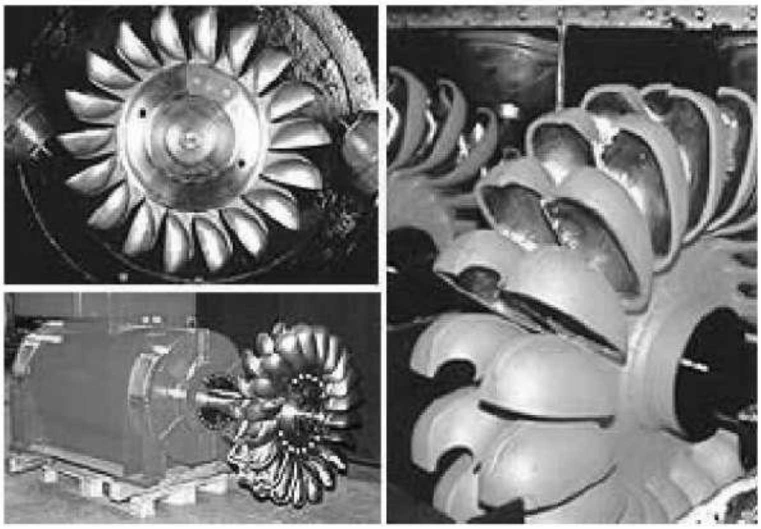


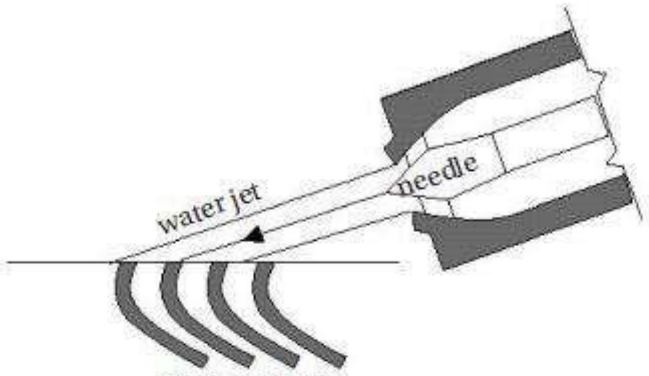
Figure 4.4 Pelton Turbine

The Pelton turbine can be used efficiently if the number of jets are increased. This ensures that the rotational speed is increased, for a given flow.

II. *Turgo Turbine*

These are designed to have higher specific speed. The jets are aimed to strike the plane of the runner on one side and exit on the other. (Figure 4.5) With smaller faster spinning runners, it is more likely and to convert Turgo turbines directly to the generator.

Figure 4.5: Turgo Turbine



III. *Cross-flow Turbine*

This has a drum-shaped runner consisting of two parallel discs connected near their rims by a series of curved blades. (Figure 4.6)

IV. *Waterwheel (Chain Turbine)*

These are traditional means of converting useful energy from flowing and falling water into mechanical power. (Figure: 4.7)

Figure 4.6: Cross-flow Turbine

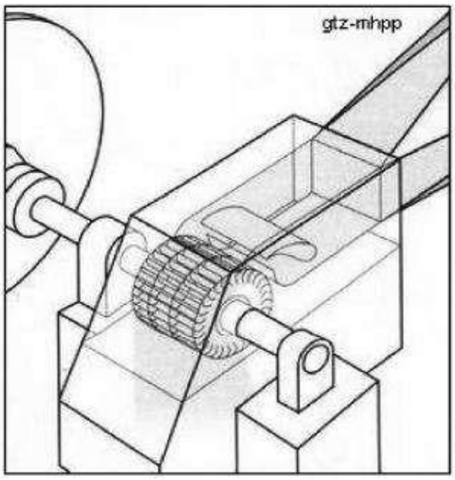
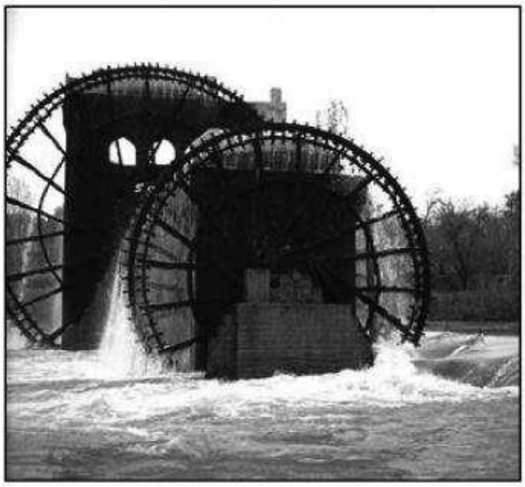
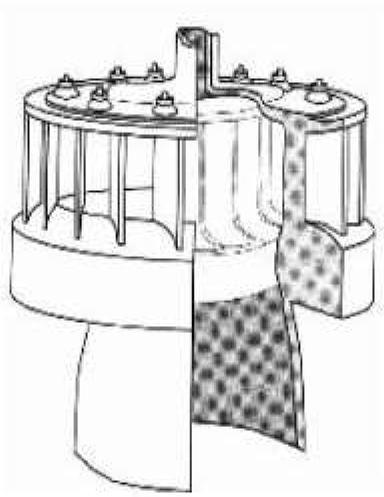


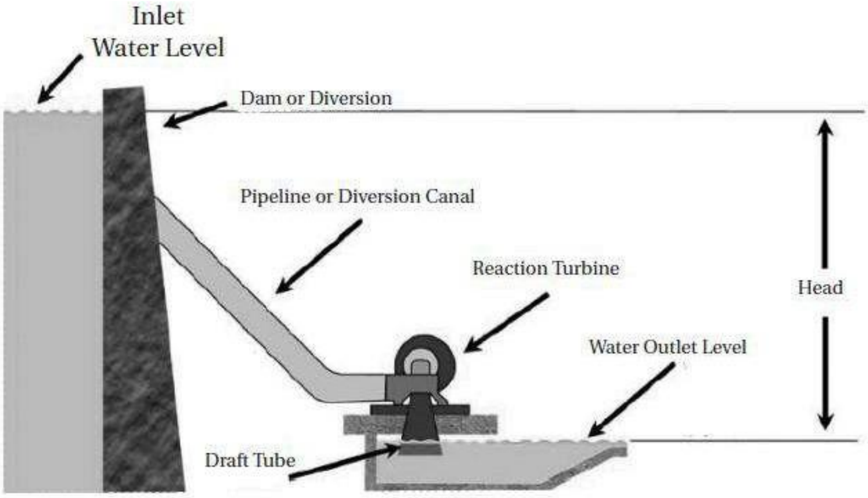
Figure 4.7 : Waterwheel



4.1.2 Reaction turbines (low head, high flow)

The reaction turbine, as the name implies, is turned by reactive force rather than by a direct push or impulse. In reaction turbines, there are no nozzles as such. Instead, the blades that project radially from the periphery of the runner are formed and mounted so that the space between the blades have in cross section, the shape of nozzles. You can use a balloon to demonstrate the kickback or reaction force generated by the nozzle blades. Blow up the balloon and release it. The air will rush out through the opening and the balloon will shoot off in the opposite direction. When the balloon is filled with air, you have potential energy stored in the increased air pressure inside. When you let the air escape, it passes through the small opening. This represents a transformation from potential energy to kinetic energy. The force applied to the air to speed up the balloon is acted upon by a reaction in the opposite direction. This reactive force propels the balloon forward through the air. You may think that the force that makes the balloon move forward comes from the jet of air blowing against the air in the room, but it is not so. It is the reaction of the force of the air as it passes through the opening that causes the balloon to move forward. The reaction turbine has all the advantages of the impulse-type turbine, plus a slower operating speed and greater efficiency. However, the reaction turbine requires a much higher flow rate than the impulse turbine. A reaction turbine runner, with the outer guide vanes guiding the water flow into the runner blades, which act as nozzles, Figure 4.8. Diagram showing the components of a reaction turbine system with a combination diversion system in figure 4.9





There are four types of Reaction turbines:

I. Francis Turbine

This is either volute cased or an open flume machine. The runner blades are profiled in a complex manner and direct the water so that it exits axially from the center of the runner. In doing so, the water imparts most of its pressure energy to the runner before leaving the turbine via a draft tube.

II. Propeller Turbine

This consists of a propeller fitted inside a continuation of the penstock pipe. The turbine shaft passes out of the pipe at the point where the pipe changes direction. A propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor cannot be changed.

III. Kaplan Turbine

This is a propeller type turbine with adjustable blades.

Figure 4.10 : Francis Turbine

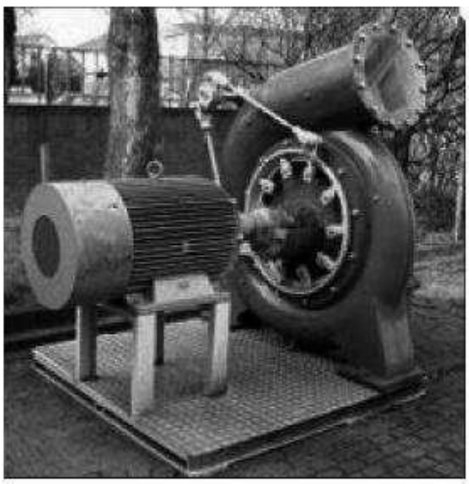
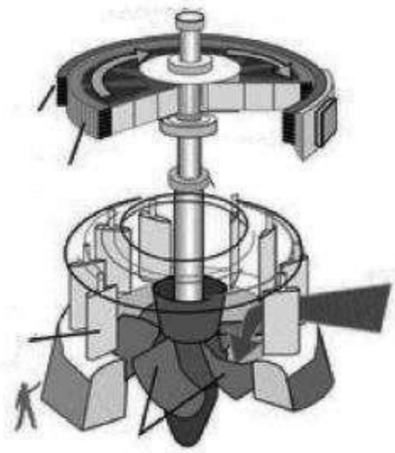


Figure 4.11 : Kaplan Turbine



IV. Reverse Pump Turbine

Centrifugal pumps can be used as turbines by passing water through them in reverse. Research is currently being done to enable the performance of pumps as turbines. The advantage is that it is low cost and spare parts are readily available. Impulse turbines are usually cheaper than reaction turbines because there is no need for specialist pressure casing. Impulse turbines are generally more suitable for SHP applications as compared with reaction turbines because they have:

- Greater tolerance of sand and other particles in water
- Better access to working parts
- Easier to fabricate and maintain
- Better part-flow efficiency

One major disadvantage of impulse turbines is that they are mostly unsuitable for low head sites.

4.3 Drive Systems

The drive system transmits power from the turbine shaft to the generator shaft. It also has the function of changing the rotational speed from one shaft to the other, when the turbine speed is different to the required speed of the generator. The following can be considered for the SHP drive system:

- Direct drive
- Flat belt and pulley
- V or wedge belt and pulleys
- Chain and sprocket
- Gearbox

4.4 Generators

These convert the mechanical (rotational) energy produced by the turbine to electrical energy. The basic principle of generator operation is that voltage is induced in a coil of wire when the coil is moved in a magnetic field. Although most early hydroelectric systems were of the direct current (DC) variety to match early commercial electrical systems, nowadays, only three-phase alternating current (AC) generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between:

- Synchronous generators: They are equipped with a DC electric or permanent magnet excitation system (rotating or static) associated with a voltage regulator to control the output voltage before the generator is connected to the grid. They supply the reactive energy required by the power system when the generator is connected to the grid. Synchronous generators can run isolated from the grid and produce power since excitation is not grid-dependent
- Asynchronous generators: They are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive energy by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive energy. They cannot generate when disconnected from the grid because are incapable of providing their own excitation current. However, they are used in very small stand-alone applications as a cheap solution when the required quality of the electricity supply is not very high.

Below 1 MW synchronous generators are more expensive than asynchronous generators and are used in power systems where the output of the generator represents a substantial proportion of the power system load. Asynchronous generators are cheaper and are used in stable grids where their output is an insignificant proportion of the power system load. The efficiency should be 95 percent for a 100 KW machine and can increase to 97 percent towards an output power of 1MW. Efficiencies of synchronous generators are slightly higher. In general, when the power exceeds some MVA, a synchronous generator is installed.

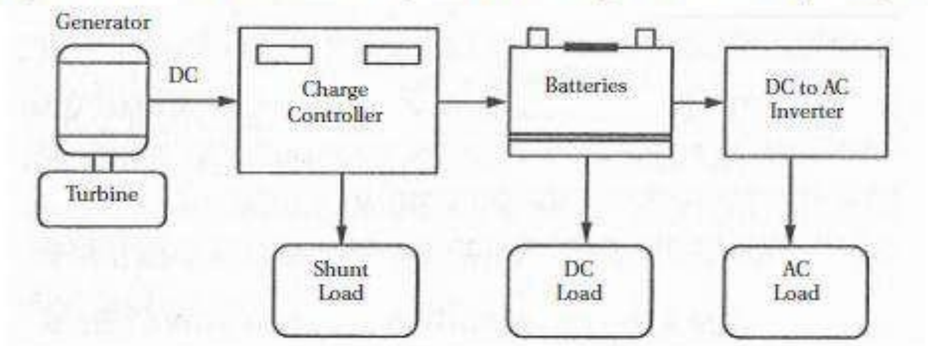
Recently, variable-speed constant-frequency systems (VSG), in which turbine speed is permitted to fluctuate widely, while the voltage and frequency are kept constant and undistorted, have become available. The frequency converter, which is used to connect the generator via a DC link to the grid, can even be “synchronized” to the grid before the generator starts rotating. This approach is often proposed as a means of improving performance and reducing cost. However, no cost reduction can be achieved using propeller turbines, if only the runner regulation is replaced. It is also not possible to improve the energy

production as compared to a double-regulated Kaplan turbine. There are, nevertheless, many cases, where variable speed operation seems to be a suitable solution, e.g. when the head varies significantly.
The operating voltage of the generator increases with power. The standard generation voltages of 400 V or 690 V allow for the use of standard distributor transformers as outlet transformers and the use of the generated current to feed into the plant power system. Generators of some MVA are usually designed for higher operating voltages up to some KV and connected to the grid using a customized transformer. In this case, an independent transformer HT/LT is necessary for the auxiliary power supply of the power plant.
Electrical power can be generated in either AC or DC. AC can be connected directly to household appliances and AC is much more economical for transmitting power to homes. DC can be used in two ways, either directly as DC or converted to AC using an inverter. The main advantage of DC is ease of battery storage. Lead acid deep cycle batteries are usually used in SHP plants.

4.5 Controllers

SHP systems with lead acid batteries require protection from overcharge and over discharge. Overcharge controllers redirect the power to an auxiliary or shunt load when the battery reaches a certain level. (Figure 4.12). This protects the generator from overspeed and overvoltage conditions. Over discharge control involves disconnecting the load from the batteries when the voltage drops below a certain level.

Figure 4.12 : Electrical block diagram of a battery-based small hydro system.



Over the last two decades, electronic load controllers (ELCs) have been developed that have increased the simplicity and reliability of the modern SHP system. An ELC is a solid state electronic device designed to regulate output power of SHP systems. Maintaining a near-constant load on the turbine generates stable voltage and frequency. The controller compensates for variation in the main load by automatically varying the amount of power dissipated in a resistive load, generally known as the ballast or dump load, to keep the total load on the generator and turbine constant. Water heaters are generally used as ballast loads. An ELC constantly senses and regulates the generated frequency. The frequency is directly proportional to the speed of the turbine. The major benefit of ELCs is that they have no moving parts, are reliable and virtually maintenance free.

4.6 Automatic Control

Small hydro schemes are normally unattended and operated through an automatic control system. Not all power plants are alike therefor it is almost impossible to determine the extent of automation that should be included in each system, though some requirements are of general application:
a) The system must include the necessary relays and devices to detect malfunctioning of a serious nature and then act to bring the unit or the entire plant to a safe de-energized condition.
b) Relevant operational data of the plant should be collected and made readily available so that operating decisions can be taken and stored in a database, for later evaluation of plant performance.
c) An intelligent control system should be included to allow for full plant operation in an unattended environment.
d) It should be possible to access the control system from a remote location and override any automatic decisions.

e) The system should be able to communicate with similar units, up and downstream, for optimizing operating procedures.
f) Fault anticipation constitutes an enhancement to the control system. Using an expert system fed with baseline operational data, it is possible to anticipate faults before they occur and take corrective action so that the fault does not occur.

The system must be configured by modules. They are an analogue-to-digital conversion module for measurement of etc., water level, wicket-gate position, blade angles, instantaneous power output, temperatures, etc., a digital-to-analogue converter module to drive hydraulic valves, chart recorders, etc. A counter module to count generated KWh pulses, rain gauge pulses, flow pulses, etc., and a “smart” telemetry module providing the interface for offsite communications via dial-up telephone lines, radio link or other communication technologies. This modular system approach is well suited to the widely varying requirements encountered in hydro power control, and permits both hardware and software to be standardized. Cost reduction can be realized using a standard system and modular software allows for easy maintenance. Automatic control systems can significantly reduce the cost of energy production by reducing maintenance and increasing reliability, while running the turbines more efficiently and producing more energy from the available water.

5. Generating Power

5.1 Developing Head Pressure

In the following section, we will discuss how head is developed at a hydro site and how it is transferred into power. Have you ever swum down to the bottom of a deep swimming pool and felt your ears pop? That’s caused by water pressure which is created by the weight of the water above you. We measure water pressure in pounds per square inch (PSI). That to the weight in pounds of the water on a one-square-inch area. A reaction turbine uses “pressure head” in the same way to produce electricity. If you substitute the diver in the picture for a submerged reaction turbine, you can imagine how the pressure of all that water falling through the turbine blades, creates the force to turn the blades and produce electricity.

This ‘pressure head’ accounts for most of the power output of a reaction turbine. In addition, many reaction turbines also have a water discharge tube called a ‘draft tube’, which can increase the head by producing a vacuum between the turbine runner blades and the level of the exit water. This is called the ‘suction head’ and can increase power output of the turbine by up to 20 percent, if it is set up properly. It is important that it is completely submerged in the tail water with no air leaks, maintaining a closed system and thus, the vacuum suction. With this system, the total head is a combination of the pressure head and the suction head.

Figure 5.1: Water Pressure exerts force on a diver

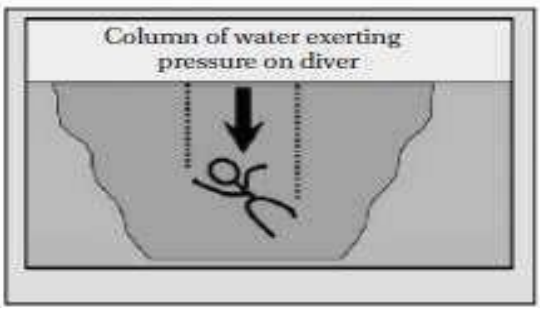
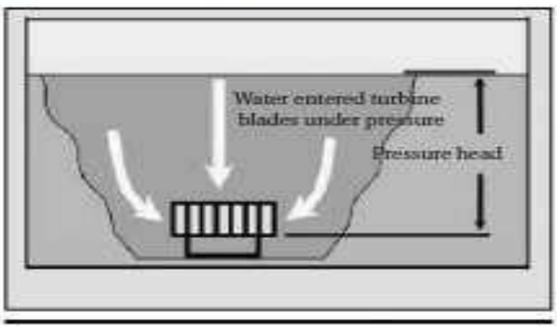


Figure 5.2: Pressure Head for a ReactionTurbine



Another important characteristic of water is that it is essentially a non-compressible liquid. This means it exhibits the unique trait of transferring pressure horizontally when in a confined space (what we define as a closed system). This becomes very important in hydro systems where a pipeline is involved, which is always the case with impulse turbines and is occasionally used with reaction turbines as well. Water that enters a pipe exhibits the same pressure at the bottom as it would if the pipe were perfectly vertical, even if the pipe itself isn't. The best way to demonstrate this is with a picture. If the water is not flowing through the pipeline, the pressure of the water at the lower end of the pipe is the same as the water pressure at an equivalent level directly below the inlet. This is true no matter how long the pipe is. Since water is a non-compressible liquid it transfers the pressure horizontally along the pipe route for any distance without any loss of pressure.

This is called the "static pressure" (or "static head") of the water. If this system were completely frictionless, the pressure would remain the same when the water was flowing as well. However, there is friction between the water and the inner surface of the pipeline, causing the pressure to drop once the water is moving (called "friction loss"). The usable force of the water when it reaches the turbine is called the "dynamic pressure" (or "dynamic head"), and is calculated by subtracting the friction loss caused by the pipeline from the amount of static head. The total length and diameter of the pipe you use becomes important in planning your system because you always want to minimize your friction losses. Impulse turbines are not submerged in the water,
and thus, the water exits the closed system when it exits the pipeline at the turbine nozzle. Hence there is no suction head and in an impulse turbine the total head is equal to the pressure head. What we are beginning to see is that in a hydro system, it's not just important how much head and how much flow you have available in a theoretical sense, it's also important to consider how you can get that water to your turbine location with as little loss as possible.

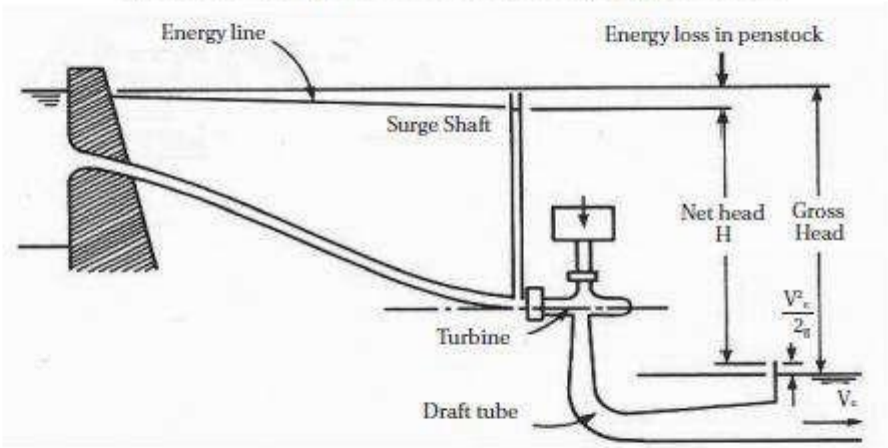
An analogy could be made with driving your car. Your car has a certain potential amount of power it can produce. But the amount of power you use at any given time has a lot to do with the road you are travelling on. A twisting, winding road will not allow you to move as fast as a straight one. A muddy road will not let you move as fast as nice smooth pavement. In the same way, it's not just the amount of power (from head) that you can theoretically get from your water source, it's also the 'road' you build to get your water to the turbine. We call this road a 'diversion system', and just as with a road, water prefers nice straight diversion systems without abrupt turns and smooth walls.

5.2 'Pressure Head' for an Impulse Turbine System

Hydro power is obtained from the potential and kinetic energy of water flowing from a height. The energy contained in the water is converted into electricity by using a turbine coupled to a generator. The hydro power potential of a site is dependent on the discharge and head of water. It is estimated by the following equation

P (power in KW) = Q x H x 9.81 x η, where
Q = discharge (rate of flow) in m^3 */s;*
H = Head (height) in meters; and
η= overall power generating system efficiency.

Figure 5.3: Components of a Small Hydropower Unit



A hydro power resource can be measured according to the amount of available power or energy per unit time. The power of a given situation is a function of head and rate of flow. (Figure 5.4) The energy in a SHP starts out as potential energy by its height above the powerhouse. Water under pressure in the penstock can do work when released so there is energy associated with the pressure as well. The transformation of energy is from potential to pressure to kinetic energy. The total energy is the sum of the potential, pressure and kinetic in a run-of-the river system.

Net head is the gross head minus the head losses that occur when water flows from the intake to the turbines through canals and penstock. Water loses energy (head loss) as it flows through a pipe, fundamentally due to:

1. Friction against the wall.

The friction against the pipe wall depends on the wall material roughness and the velocity gradient which by near the wall. The friction in the pipe walls can be reduced by increasing the pipe diameter. However, increasing the diameter increases the cost, so a compromise should be reached between the cost and diameter.

2. Flow turbulence

Water flowing through a pipe system with bends, sudden contractions and enlargement of pipes, racks, valves and other accessories experiences in addition to the friction loss, a loss due to inner viscosity. This loss depends on the velocity and is expressed by an experimental K multiplied with the kinetic energy. Water flown in a pipe bend, experiences an increase of pressure along the outer wall and a decrease of pressure along the inner wall. This pressure imbalance causes a secondary current. Both movements together (the longitudinal flow and the secondary current), produces a spiral flow at a length of around 100 meters is dissipated by viscous friction. The head loss produced depends on the radius of the bend and the diameter of the pipe. The loss of head produced by water flowing through an open valve depends on the type and manufacture of the valve.

6. Economics of using an SHP

6.1 Advantages of an SHP

Some of the key advantages of SHP are:

- Environmental protection through CO_2 emission reduction – CO_2 emission is reduced because electricity production from SHP does not release CO_2 in the process
- Proven and reliable technology
- Improves the diversity of energy supplies – this is the one of many alternatives of producing electricity
- Grid stability

- Reduced land requirements – unlike in wind energy, where a fair bit of land is required to install a wind turbine
- Local and regional development – leads the community to be independent of fossil fuel
- Assists in the maintenance of river basins
- Technology suitable for rural electrification in developing countries
- High energy payback ratio

6.2 Shortcomings of an SHP

Some of the shortcomings are:

- SHP is a site-specific technology and usually the site is far away from the place where the electricity is required
- Run-of-the river plants experience significant fluctuations in output power

6.3 Environmental Impact of an SHP

Firstly, 1GWh of electricity produced by SHP allows to:

- Supply electricity for one year to 250 households in a developed country
- Save 220 tons of petrol
- Save 335 tons of coal
- Avoid the emission of 480 tons of carbon dioxide
- Supply electricity for one year to 450 households in a developing country

Secondly, because SHP is produced from run-of-the river systems, it doesn't disturb aquatic life. A general rule of thumb is to not divert more than 20 percent of the water flow of the river through the turbine and to return any diverted water back to the river just below the turbine.

6.4 SHP Economics and Costs

The capital required for small hydro plants depends on the effective head, the flow rate, geographical and geological features, the equipment (turbines, generators and others) and civil engineering works and continuity of water flow.

Sites with low heads and high flow require a greater capital outlay, as large turbine machinery are needed to handle larger flow of water. If, however, the system can have a dual purpose- such as power generation and flood control, power generation and irrigation, power generating and drinking water production-the payback period can be lowered. The operation and maintenance cost including repairs and insurance can range from 1.5 to 5 percent of investment costs.

OCEAN ENERGY

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters. A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 283°C. Deep, cold water, meanwhile, forms at higher latitudes and descends to flow along the sea floor toward the equator. The warm surface layer, which extends to depths of about 100-200m, is separated from the deep cold water by a thermocline. The temperature difference, *T*, between the surface and thousand-meter depth ranges from 10 to 253°C, with larger differences occurring in equatorial and tropical waters, as depicted in Figure 1. *T* establishes the limits of the performance of OTEC power cycles; the rule-of thumb is that a differential of about 203°C is necessary

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

State of the Technology

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

The low energy conversion efficiency of OTEC means that more than 90% of the thermal energy extracted from the ocean's surface is 'wasted' and must be rejected to the cold, deep sea water. This necessitates large heat exchangers and seawater flow rates to produce relatively small amounts of electricity. Despite its inherent inefficiency, OTEC, unlike conventional fossil energy systems, utilizes a renewable resource and poses minimal threat to the environment. In fact, it has been suggested that widespread adoption of OTEC could yield tangible environmental benefits through avenues such as reduction of greenhouse gas CO_2 emissions; enhanced uptake of atmospheric CO_2 by marine organism populations sustained by the nutrient-rich, deep OTEC sea water; and preservation of corals and hurricane amelioration by limiting temperature rise in the surface ocean through energy extraction and artificial upwelling of deep water.

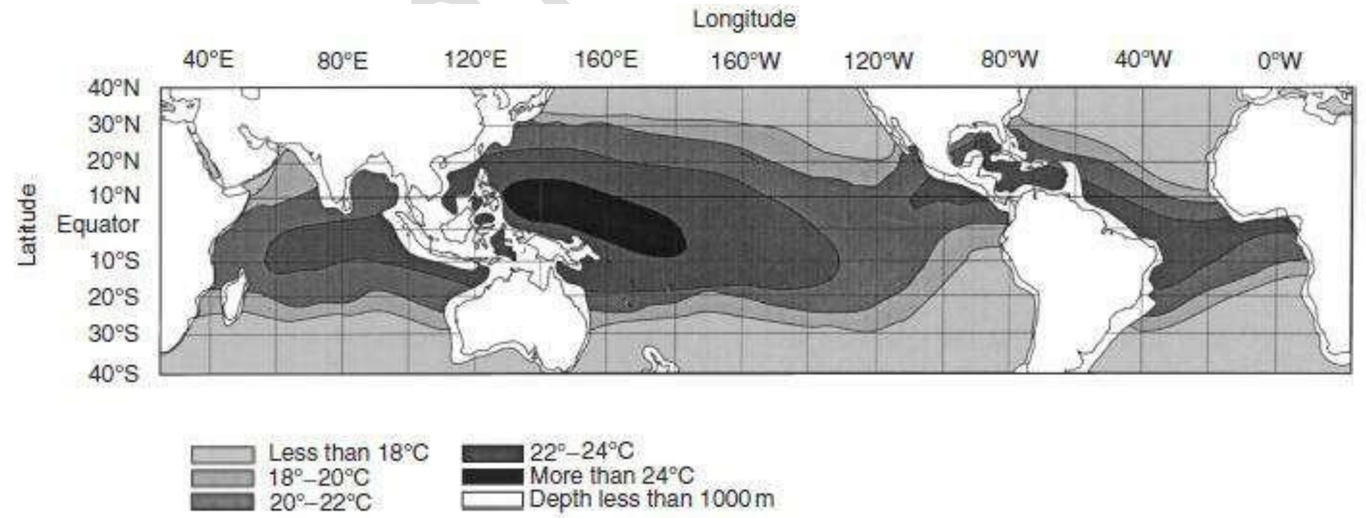


Figure 1 Temperature difference between surface and deep sea water in regions of the world. The darkest areas have the greatest temperature difference and are the best locations for OTEC systems.

Carnot efficiency applies only to an ideal heat engine. In real power generation systems, irreversibility will further degrade performance. Given its low theoretical efficiency, successful implementation of OTEC power generation demands careful engineering to minimize irreversibility. Although OTEC consumes what is essentially a free resource, poor thermodynamic performance will reduce the quantity of electricity available for sale and, hence, negatively affect the economic feasibility of an OTEC facility.

An OTEC heat engine may be configured following designs by J.A. D'Arsonval, the French engineer who first proposed the OTEC concept in 1881, or G. Claude, D'Arsonval's former student. Their designs are known, respectively, as closed cycle and open cycle OTEC.

Closed Cycle OTEC

D'Arsonval's original concept employed a pure working fluid that would evaporate at the temperature of warm sea water. The vapor would subsequently expand and do work before being condensed by the cold sea water. This series of steps would be repeated continuously with the same working fluid, whose flash path and thermodynamic process representation constituted closed loops hence, the name 'closed cycle.' The specific process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. Figure 2 is a simplified schematic diagram of a closed cycle OTEC system. The principal components are the heat exchangers, turbo generator, and seawater supply system, which, although not shown, accounts for most of the parasitic power consumption and a significant fraction of the capital expense. Also, not included are ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working fluid lost through leaks or contamination.

In this system, heat transfer from warm surface sea water occurs in the evaporator, producing a saturated vapor from the working fluid. Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle.

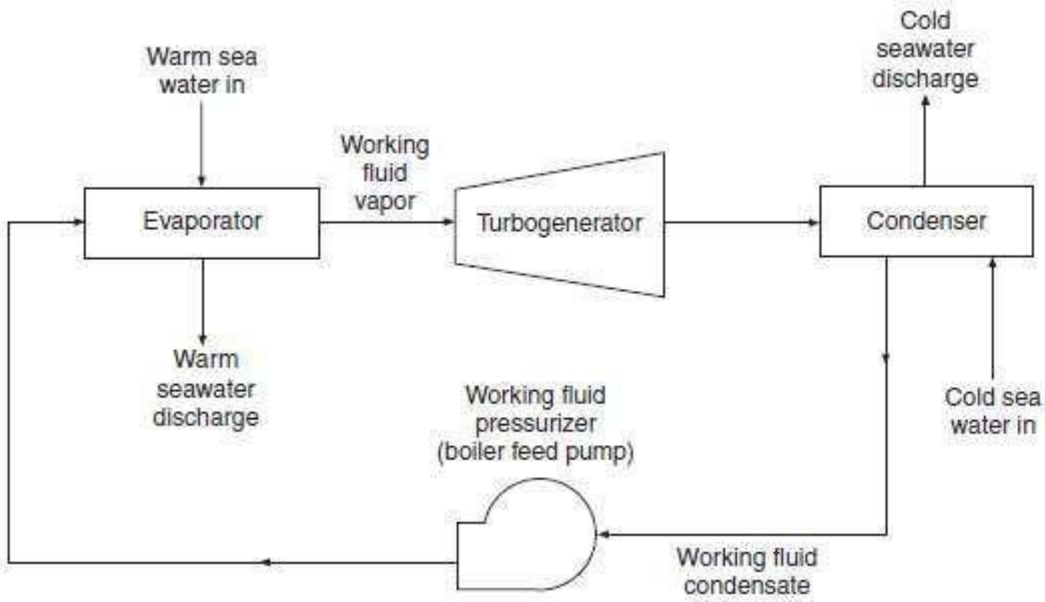


Figure 2: Schematic diagram of a closed-cycle OTEC system.

The working fluid is vaporized by heat transfer from the warm sea water in the evaporator. The vapor expands through the turbo generator and is condensed by heat transfer to cold sea water in the condenser. Closed-cycle OTEC power systems, which operate at elevated pressures, require smaller turbines than open-cycle systems.

The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional (e.g., combustion) Rankine systems, this yields net electrical power. For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. (One misconception about OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 1000 meters. The natural hydrostatic pressure gradient provides for most of the increase in the gravitational potential energy of a fluid particle moving with the gradient from the ocean depths to the surface.) Irreversibility in the turbomachinery and heat exchangers reduce cycle efficiency below the Carnot value. irreversibility in the heat exchangers occur when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperatures established by the surface and deep-sea water. Insofar as many substances can meet this requirement (because pressures and the pressure ratio across the turbine and pump are design parameters), other factors must be considered in the selection of a working fluid including: cost and availability, compatibility with system materials, toxicity, and environmental hazard.

Leading candidate working fluids for closed cycle
OTEC applications are ammonia and various fluorocarbon refrigerants. Their primary disadvantage is the environmental hazard posed by leakage; ammonia is toxic in moderate concentrations and certain fluorocarbons have been banned by the Montreal Protocol because they deplete stratospheric ozone. The Kalina, or adjustable proportion fluid mixture (APFM), cycle is a variant of the OTEC closed cycle. Whereas simple closed cycle OTEC systems use a pure working fluid, the Kalina cycle proposes to employ a mixture of ammonia and water with varying proportions at different points in the system.

The advantage of a binary mixture is that, at a given pressure, evaporation or condensation occurs over a range of temperatures; a pure fluid, on the other hand, changes phase at constant temperature. This additional degree of freedom allows heat transfer-related irreversibility in the evaporator and condenser to be reduced. Although it improves efficiency, the Kalina cycle needs additional capital equipment and may impose severe demands on the evaporator and condenser. The efficiency improvement will require some combination of higher heat transfer coefficients, more heat transfer surface area, and increased seawater flow rates. Each has an associated cost or power penalty. Additional analysis and testing are required to confirm whether the Kalina cycle and assorted variations are viable alternatives.

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

The essential features of an open cycle OTEC system are presented in Figure 3. The entire system, from evaporator to condenser, operates at partial vacuum, typically at pressures of 1-3% of atmospheric. Initial evacuation of the system and removal of non-condensable gases during operation are performed by the vacuum compressor, which, along with the sea water and discharge pumps, accounts for the bulk of the open cycle OTEC parasitic power consumption. The low system pressures of open cycle OTEC are necessary to induce boiling of the warm sea water. Flash evaporation is accomplished by exposing the sea water to pressures below the saturation pressure corresponding to its temperature. This is usually accomplished by pumping it into an evacuated chamber through spouts designed to maximize heat and mass transfer surface area. Removal of gases dissolved in the sea water, which will come out of solution in the low-pressure evaporator and compromise operation, may be performed at an intermediate pressure prior to evaporation.
Vapor produced in the flash evaporator is relatively pure steam. The heat of vaporization is extracted from the liquid phase, lowering its temperature and preventing any further boiling. Flash evaporation may be perceived, then, as a transfer of thermal energy from the bulk of the warm sea water of the small fraction

of mass that is vaporized. Less than 0.5% of the mass of warm sea water entering the evaporator is converted into steam.

The pressure drop across the turbine is established by the cold seawater temperature. At 43°C, steam condenses at 813 Pa. The turbine (or turbine diffuser) exit pressure cannot fall below this value. Hence, the maximum turbine pressure drop is only about 3000Pa, corresponding to about a 3:1 pressure ratio. This will be further reduced to account for other pressure drops along the steam path and differences in the temperatures of the steam and seawater streams needed to facilitate heat transfer in the evaporator and condenser. Condensation of the low-pressure steam leaving the turbine may employ a direct contact condenser (DCC), in which cold sea water is sprayed over the vapor, or a conventional surface condenser that physically separates the coolant and the condensate. DCCs are inexpensive and have good heat transfer
characteristics because they lack a solid thermal boundary between the warm and cool fluids. Surface condensers are expensive and more difficult to maintain than DCCs; however, they produce a marketable freshwater by-product. Effluent from the condenser must be discharged to the environment. Liquids are pressurized to ambient levels at the point of release by means of a pump, or, if the elevation of the condenser is suitably high, can be compressed hydrostatically. As noted previously, non-condensable gases, which include any residual water vapor, dissolved gases that have come out of solution, and air that may have leaked into the system, are removed by the vacuum compressor.

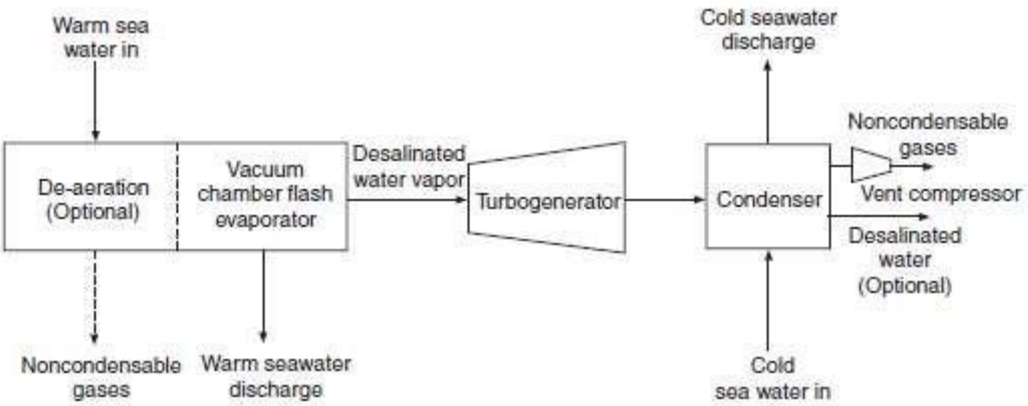


Figure 3: Schematic diagram of an open-cycle OTEC system.

In open-cycle OTEC, warm sea water is used directly as the working fluid. Warm sea water is flash evaporated in a partial vacuum in the evaporator. The vapor expands through the turbine and is condensed with cold sea water. The principal disadvantage of open-cycle OTEC is the low system operating pressures, which necessitate large components to accommodate the high volumetric flow rates of steam.
Open cycle OTEC eliminates expensive heat exchangers at the cost of low system pressures. Partial vacuum operation has the disadvantage of making the system vulnerable to air in-leakage and promotes the evolution of non-condensable gases dissolved in sea water. Power must ultimately be expended to pressurize and remove these gases. Furthermore, because of the low steam density, volumetric flow rates are very high per unit of electricity generated. Large components are needed to accommodate these flow rates. Only the largest conventional steam turbine stages have the potential for integration into open cycle OTEC systems of a few megawatts gross generating capacity.

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

WAVE ENERGY
Wave energy, also known as ocean energy or sea wave energy, is energy harnessed from ocean or sea waves. The rigorous vertical motion of surface ocean waves contains a lot of kinetic (motion) energy that is captured by wave energy technologies to do useful tasks, for example, generation of electricity, desalinization of water and pumping of water into reservoirs.

Wave energy or wave power is essentially power drawn from waves. When wind blows across the sea surface, it transfers the energy to the waves. They are powerful source of energy. The energy output is measured by wave speed, wave height, wavelength and water density. The stronger the waves, the more capable it is to produce power. The captured energy can then be used for electricity generation, powering plants or pumping of water. It is not easy to harness power from wave generator plants and this is the reason that they are very few wave generator plants around the world.

When you look out at a beach and see waves crashing against the shore, you are witnessing wave energy. It's not being harnessed or used for the benefit of anyone in that state, but it is there producing power. And some enterprising individuals would say it is just waiting to be used to make our lives better and our energy consumption cleaner and cheaper. Wave energy is often mixed with tidal power, which is quite different.

Formation of Waves
When wind blows across the surface of the water strongly enough it creates waves. This occurs most often and most powerfully on the ocean because of the lack of land to resist the power of the wind. The kinds of waves that are formed, depend on from where they are being influenced. Long, steady waves that flow endlessly against the beach are likely formed from storms and extreme weather conditions far away. The power of storms and their influence on the surface of the water is so powerful that it can cause waves on the shores of another hemisphere. For example, when Japan was hit with a massive tsunami in 2011, it created powerful waves on the coast of Hawaii and even as far as the beaches of the state of Washington. When you see high, choppy waves that rise and fall very quickly, you are likely seeing waves that were created by a nearby weather system. These waves are usually newly formed occurrences. The power from these waves can then be harnessed through wave energy converter (WEC).

Conversion of Wave Energy into Electricity
To harness wave energy and make it create and energy output for us, we must go where the waves are. Successful and profitable use of wave energy on a large scale only occurs in a few regions around the world. The places include the states of Washington, Oregon and California and other areas along North America's west coast. This also includes the coasts of Scotland Africa and Australia. Wave energy is, essentially, a condensed form of solar power produced by the wind action blowing across ocean water surface, which can then be utilized as an energy source. When the intense sun rays hit the atmosphere, they get it warmed up. The intensity of sun rays hitting the earth's atmosphere varies considerably in different parts of the world. This disparity of atmospheric temperature around the world causes the atmospheric air to travel from hotter to cooler regions, giving rise to winds.

As the wind glides over the ocean surface, a fraction of the kinetic energy from the wind is shifted to the water beneath, resulting in waves. As a matter of fact, the ocean could be a gigantic energy storehouse collector conveyed by the sun rays to the oceans, with the waves transporting the conveyed kinetic energy across the ocean surface. With that in mind, we can safely conclude that waves are a form of energy and it's the same energy, not water that glides over the surface of the ocean. These waves can travel throughout the expansive oceans without losing a lot of energy. However, when they reach the shoreline, where the depth of water is considerable shallow, their speed reduces, while their size significantly increases. Ultimately, the waves strike the shoreline, discharging huge quantities of kinetic energy.

Wave Energy Converter

The Wave energy hitting the shore is converted into electricity using a wave energy converter (WEC), essentially, a power station. The operating principle of this power station is both simple and ingenious. It's an enclosed chamber with an opening under the sea, which allows strong sea waves to flow into the chamber and back.

The water level in the chamber rises and falls with the rhythm of the wave, and so air is forced forwards and backward via the turbines joined to an upper opening in the chamber. The compressed and decompressed air has enough power to propel the turbines. The turbine is propelled in the same direction by the back and forth airflow through the turbine. The propelling turbine turns a shaft connected to a generator.

The generator produces electricity, which is transported to electrical grids and later supplied to demand centers and distribution lines that connect individual homes and industries. The advantage of this wave energy converter is that even considerably low wave motions can produce sufficient airflow to maintain the movement of the turbine to generate energy.

Tidal Energy

Tidal Energy or Tidal Power as it is also called, is another form of hydro power that utilizes large amounts of energy within the oceans tides to generate electricity. Tidal Energy is an "alternative energy" that can also be classed as a "renewable energy source", as the Earth uses the gravitational forces of both the moon and the sun every day to move vast quantities of water around the oceans and seas producing tides. As the Earth, its Moon and the Sun rotate around each other in space, the gravitational movement of the moon and the sun with respect to the earth, causes millions of gallons of water to flow around the Earth's oceans creating periodic shifts in these moving bodies of water. These vertical shifts of water are called "tides".

Tidal Effects of the Sun and Moon

Alignment of the Moon and Sun on Tides: When the earth and the moons gravity lines up with each other, the influences of these two gravitational forces becomes very strong and causes millions of gallons of water to move or flow towards the shore creating a "high tide" condition. Likewise, when the earth and the moons gravity are at 90o to each other, the influences of these two gravitational forces is weaker and the water flows away from the shore as the mass of water moves to another location on the earth, creating a "low tide" condition. This ebbing and flowing of the tides happens twice during each period of rotation of the earth with stronger weekly and annual lunar cycles superimposed onto these tides. When the moon is in perfect alignment with the earth and the sun, the gravitational pull of the moon and sun together becomes much stronger than normal with the high tides becoming very high and the low tides becoming very low during each tidal cycle. Such tides are known as spring tides (maximum). These spring tides occur during the full or new moon phase.

The other tidal situation arises during neap tides (minimum) when the gravitational pull of the moon and the sun are against each other, thus cancelling their effects. The net result is a smaller pulling action on the sea water creating much smaller differences between the high and low tides thereby producing very weak tides. Neap tides occur during the quarter moon phase. Then spring tides and neap tides produce different amounts of potential energy in the movement of the sea water as their effects differ from the regular high and low sea levels and we can use these tidal changes to produce renewable energy. So, we can say that the tides are turning for alternative energy.

So, we now know that the constant rotational movement of the earth and the moon with regards to each other causes huge amounts of water to move around the earth as the tides go in and out. These tides are predictable and regular resulting in two high tides and two low tides each day with the level of the oceans constantly moving between a high tide and a low tide, and then back to a high tide again. The time taken for a tidal cycle to happen is about 12 hours and 24 minutes (called the "diurnal cycle") between two consecutive high tides allowing Oceanographers and Meteorologist to accurately predict the ebb and flow of the tides around the oceans many years in advance.

The main big advantage of this is that the tides are therefore perfectly predictable and regular unlike wind energy or solar energy, allowing miles of coastline to be used for tidal energy exploitation and the larger the tidal influence, the greater the movement of the tidal water and therefore the more potential energy that can be harvested for power generation. Therefore, Tidal Energy can be considered as a renewable energy source as the oceans energy is replenished by the sun as well as through tidal influences of the moon and suns gravitational forces.

Tidal Energy Generation

Since the position of the earth and the moon with respect to the sun changes throughout the year, we can utilize the potential energy of the water contained in the daily movement of the rising and falling sea levels to generate electricity. The generation of electricity from tides is similar in many ways to hydro-electric generation we looked at in the hydro energy tutorials. The difference this time is that the water flows in and out of the turbines in both directions instead of in just one forward direction.

Tidal energy, just like hydro energy transforms water in motion into a clean energy. The motion of the tidal water, driven by the pull of gravity, contains large amounts of kinetic energy in the form of strong tidal currents called tidal streams. The daily ebbing and flowing, back and forth of the oceans tides along a coastline and into and out of small inlets, bays or coastal basins, is little different to the water flowing down a river or stream. The movement of the sea water is harnessed in a similar way using waterwheels and turbines to that used to generate hydroelectricity. But because the sea water can flow in both directions in a tidal energy system, it can generate power when the water is flowing in and when it is ebbing out. Therefore, tidal generators are designed to produce power when the rotor blades are turning in either direction. However, the cost of reversible electrical generators is more expensive than single direction generators.

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RET (ME-604 C)

Energy is necessary for all activities in and around us. Energy provides comfort, increases productivity and allows us to live the way we want to. At present most of our energy demand is met by the energy obtained from conventional fossil fuels such as coal, petrol, diesel, natural gas, kerosene etc. It is estimated that we could run out of oil in about 40 years and of natural gas soon after. Not only are fossil fuels running out, but they're adding to our environmental problems by releasing harmful byproducts that increase pollution and contribute to global warming. In view of the limited store of fossil fuels and ever-increasing gap between the demand and supply of energy, it is necessary to switch to new and renewable sources of energy. It is a fact that India has one of the highest potentials for effective use of renewable energy. During the last one decade, there has been a visible impact of renewable energy in the Indian energy scenario. Apart from contributing to about 12.5 per cent in the national electric installed capacity, renewable energy based applications have benefitted millions of people in the Indian villages by providing for their energy needs in an environment friendly manner. India is the world's fifth largest producer of wind power after Denmark, Germany, Spain, and the USA. Other renewable energy technologies, including solar photovoltaic (PV), solar thermal, small hydro power, geothermal, sea wave and biomass energy are also spreading. As greater reliance on renewable energy sources offers enormous economic, social, and environmental benefits, we need to explore more sources of renewable energy. Geothermal energy is one of the renewable sources of energy available in the form of vast natural reservoirs of heat energy in the earth's interior. Several geothermal power plants, which generate more than 10,000 MW power are operational in at least 24 countries of the world. Besides, geothermal energy is being used directly for heating in at least 78 countries. The largest producer of this energy is USA that generates about 3,086 MW of electricity.

Overview of Geothermal Energy

Geothermal energy is one of the potential alternative sources of energy which has been successfully catering to both industrial and domestic energy requirements in many parts of the world over the last few decades. Geothermal is made of two Greek words – geo which means 'earth', and therme, which means 'heat'. Thus, geothermal energy is the heat from the earth. It is a clean and sustainable source of energy. Resources of geothermal energy range from the moderate-to-low temperature hot spring systems to hot rock found a few miles beneath the earth's surface, and down even deeper to the extremely high temperatures of molten rocks. Below the earth's crust, there is a layer of hot and molten rocks called magma. Heat is continually produced there, mostly from the decay of naturally radioactive materials such as uranium and potassium. Heat flows outward from the earth's interior.

Normally, the crust of the earth insulates us from earth's interior heat. The mantle is semi-molten, the outer core is liquid, and the inner core is solid. It is interesting to mention here that the amount of heat within 10,000 meters of earth's surface is 50,000 times more energy than all the oil and natural gas resources in the world. In fact, geothermal energy is one of the oldest natural sources of heat and dates to the Roman times, when the heat from the earth was used instead of fire to heat rooms and/or warm water for baths. Presently, it is being used as a source for producing electricity, mainly along plate margins.

Capture of Geothermal Energy

Now, the basic question is how do we use geothermal energy for the benefit of mankind? Normally geothermal energy is captured from geothermal hotspots. Basically, a hotspot is an area of reduced thickness in the mantle which allows the excess internal heat from the interior of the earth to flow to the outer crust. These hotspots include the volcanic islands, mineral deposits, and geysers normally known as hot springs. Following are some ways in which heat from these geothermal hotspots is obtained.

Hot Springs for Geothermal Power Plants: The most common way of capturing energy from geothermal heat is to tap into naturally occurring 'hydrothermal convection' systems where cooler water seeping into earth's crust is heated up, and it then rises to the surface. When heated water from the hot springs is forced to the surface, it is a relatively simple matter to capture that steam and use it to drive electric generators. To set up geothermal power plants, holes are drilled into the rock to capture steam more effectively to drive electric generators. If the water comes out of the hot spring as steam, it can be used directly whereas the hot water can be used as a flash system.

Direct uses of Geothermal Heat: Geothermal reservoirs of hot water, which are found a couple of miles or more beneath the Earth's surface, can also be used to provide heat directly. This is called the direct use of geothermal energy. Direct use of geothermal energy is a very old method when people used hot springs for bathing, cooking food, and other day to day heating purposes. Besides, the hot spring water was used to heat greenhouses, fish farms and spas, to dry fish, de-ice roads, and improve oil recovery, and to heat. But now, modern systems are being used for direct-using in which a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well and a mechanical system - piping, a heat exchanger, controls, which delivers the heat directly for its intended use.

Ground-source heat pumps: It is found that the temperature of the upper 10 feet of the earth is nearly constant - between 10°-16°C. During winter this region is warmer than the air above it, whereas in summer it is cooler. To take advantage of this resource, geothermal heat pumps can be set up to heat and cool buildings. Geothermal heat pump systems consist of a ground heat exchanger, a heat pump unit, and an air delivery system. The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. Geothermal heat pumps use much less energy than conventional systems, since they draw heat from the ground. A much more conventional way to tap geothermal energy is by using geothermal pumps to provide heating and cooling to buildings.

Advantages and limitations of Geothermal Energy: Geothermal energy is used for heating homes and for generating electricity without producing any harmful emissions. The first advantage of using geothermal heat as a source of energy is that, unlike most power stations, a geothermal power plant does not create any pollution and geothermal energy can be used to produce electricity 24 hours a day. Thus, geothermal energy is an excellent source of clean, inexpensive and renewable energy. If the geothermal energy is harnessed correctly, it leads to no harmful by-products. Geothermal power plants are generally small and have little effect on the natural landscape, or the nearby environment. As no fuel is used to generate the power from the geothermal heat, running costs for geothermal power plants are very low. Moreover, the cost of the land to build a geothermal power plant, is usually less as compared to the cost of constructing an oil, gas, coal, or nuclear power plant. Though geothermal energy has several advantages, it also has certain disadvantages and limitations. If harnessed incorrectly, geothermal energy can sometime produce pollutants. Improper drilling into the earth can release hazardous minerals and gases from deep down inside the earth, which can be contained quite easily. It is also feared that the geothermal power plant sites may run out of steam in the long run.

Prospects of geothermal energy In India

India has huge potential to become a leading contributor in generating eco-friendly and cost effective geothermal power. Around 6.5 per cent of electricity generation in the world would be done with the help of geothermal energy and India would have to play a bigger role in the coming years in this direction. But, the power generation through geothermal resources is still in nascent stages in India. Geological Survey of India has identified about 340 geothermal hot springs in the country. Most of them are in the low surface temperature range from 37 C-90 C which is suitable for direct heat applications. These springs are grouped into seven

geothermal provinces i.e. Himalayan (Puga, Chhumathang), Sahara Valley, Cambay Basin, Son-Narmada-Tapi
(SONATA) lineament belt, West Coast, Godavari basin and Mahanadi basin. Some of the prominent geothermal resources include Puga Valley and Chhumathang in Jammu and Kashmir, Manikaran in Himachal Pradesh, Jalgaon in Maharashtra and Tapovan in Uttarakhand. A new location of geothermal power energy has also been found in Tattapani in Chhattisgarh. In addition, Gujarat is set to tap geothermal electricity through resources which are available in Cambay between Narmada and Tapi river. Puga, which is located at about 180 km from Leh in the Ladakh region of Jammu and Kashmir across the great Himalayan range, is a good potential of geothermal energy. In Puga valley, hot spring temperatures vary from 30C to 84C (boiling point at Puga) and discharge up to 300 liters /minute. A total of 34 boreholes ranging in depths from 28.5 m to 384.7 m have been drilled in Puga valley. Thermal manifestations come in the form of hot springs, hot pools, sulphur condensates, borax evaporates with an aerial extent of 4 km. The hottest thermal spring shows a temperature of 84oC and the maximum discharge from a single spring is 5 liters /second.

Chhumathang spring is another geothermal area located about 40 km north of Puga. The thermal water from
Chhumathang is quite similar to the thermal waters at Puga except the difference that its water has relatively
higher pH and sulphate. Geothermal activity at Manikaran occurs in the form of hot springs over about 1.25 km on the right bank of Parvati river with a temperature range of 34 C-96 C whereas on the left bank over a distance of about 450 m with a temperature range of 28 C-37 C. At Tapovan geothermal area, the highest temperature recorded is 65 C. The discharge from this spring varies between 0.83-9.2 litre/second. Similarly, Tattapani is a promising geothermal resource in Peninsular India. Thermal manifestation at Tattapani is very intense in an area of 0.05 sq. km with several hot spots, hot water pools and marshy land. The surface manifestations show occurrence of white to dirty white deposits identified as silica and moderate to low sag activity. Sixty thermal water springs occur at eighteen localities in the West Coast hot spring belt. One geothermal power project has a capacity of 25MW. Himurja, Himachal Pradesh has decided to select some geothermal resources in Beas valley, Parvati valley, Satluj valley and Spiti valley in Himachal Pradesh for deep drilling up to 2 km for exploitation of geothermal energy.

Obviously, geothermal energy has great potential as a clean, green and naturally occurring renewable source of energy. Geothermal hot water can be used for many applications that require heat including heating buildings, raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes. It can be used for generating electricity as well. It is therefore necessary to explore the possibility of setting up more geothermal power plants to use the naturally occurring renewable source of energy.

Site Selection

Underground rocks with a high thermal gradient, permeability of these rocks to allow the flow of fluids, and perpetual supply of fluids are the main requirements of a geothermal source. Generally, locations near to places with volcanic activity, places with geysers, hot water springs and the like are potential geothermal sites. Areas subject to tectonic plate movements and frequent earthquakes are also potential areas. However, it is not necessary that these must lead to a viable thermal reservoir. There could be blind geothermal resources as well with no indications at the top surface. Thermal imaging and electric and magnetic imaging are some of the methods applied in searching for geothermal energy sources. Shallow temperature prospecting is another method to make a preliminary find, as is finding the ratio of Helium isotopes in groundwater. More Helium 3 can indicate potential geothermal reservoirs. Trial and error drills are the best way, but a costly proposition. The risk of the unknown is what makes the initial investments in geothermal much costlier than other forms of power generation. Developing in established areas to augment capacity is less risky. In most cases, it is accidental finds during oil prospecting that lead to the discovery of geothermal reserves.

Hydrogen Energy

Of all elements present in the universe, hydrogen is the most abundant. Hydrogen gas has remarkable characteristics including colorless, tasteless and invisible that make it hotly pursued. It can also be transformed into a renewable, nonpolluting and zero emission energy resource. It's considered the cornerstone of the new energy economy. The pursuit of hydrogen energy began way back in 1776 by the British scientist Henry Cavendish. He first identified it as a distinct element after he developed hydrogen gas by subjecting zinc metal to hydrochloric acid. Henry Cavendish made another remarkable discovery during a demonstration to the Royal Society of London when he introduced a spark to hydrogen gas, producing water in the process. This historic development led to his conclusion that water (H2O) is composed of hydrogen and oxygen. Since then, hydrogen technology has grown in leaps and bounds, and today, it is used as an energy source to power cars, electric systems, and production of pure water.

Hydrogen is the simplest and most abundant element in the universe. It does not occur naturally. While it exists pretty much everywhere- in the air, in space, in the ground- it is rarely alone. It's obtainable in combination with other elements such as water. Water is made up of hydrogen and oxygen. This means that it is usually combined with another element, making it necessary to extract and convert it to make it a usable energy source. Hydrogen also occurs in numerous organic compounds, for example, hydrocarbons that result in fuels like natural gas, gasoline, propane, and methanol. The biggest challenge to harnessing hydrogen is harvesting it in its purest form. Hydrogen's chemistry is very simple- a single atom is made up of only a proton and an electron. In a gaseous form, it can be burned as a fuel. It can be stored in power cells that generate explosive energy and propel rockets and spaceships. It is volatile and combustible, and very, very powerful. Hydrogen can be stored cryogenically (frozen) or in compressed air containers as a gas. It takes a lot of storage space to house significant amounts of hydrogen. This is because the molecules are far apart, and the gas is lightweight, making it very spread out. To contain the same amount of hydrogen in a cylinder as gasoline, for example, creates a much heavier container.

Production of Hydrogen

Hydrogen gas is an expensive and complex fuel to make because it has to be separated from whatever element it is joined to. It often takes a lot of energy to make hydrogen gas, making it a costly power source. There are a number of ways to separate hydrogen from its companion elements.

Before we look at how hydrogen is converted into electricity, it would be beneficial to know how hydrogen is produced. Hydrogen is produced using two main methods; steam reforming and electrolysis (commonly referred to as water splitting).

Steam reforming

This method produces hydrogen from hydrocarbon fuels such as methane, oil, renewable liquid fuels, gasified biomass, gasified coal and natural gas. A processing device called a reformer is used in this hydrogen production process. The reformer react steam with the hydrocarbon fuels at extremely high temperatures to generate hydrogen. Today, over 90% of hydrogen gas is produced using the steam reforming technique.

Electrolysis

Electrolysis is a method that utilizes direct current (DC) to instigate a chemical reaction. In the production of hydrogen, electrolysis decomposes water and splits it into its main elements, which are hydrogen and oxygen by use of an electric current. The electricity used in the electrolysis process can be derived from fossil fuels such as oil, natural gas, and coal or hydrocarbons.

Conversion of hydrogen into electricity

The most effective way to convert hydrogen into oxygen is using a fuel cell. A fuel cell converts chemical energy into electrical energy. A fuel cell enables hydrogen and oxygen to blend in an electrochemical reaction. The result is production of electricity, water, and heat. Fuel cells mimic batteries since they both convert the energy generated by the electrochemical reaction into useful electric power. Nonetheless, the fuel cell will generate electric power if fuel, mainly hydrogen, is available.

Fuel cells represent a potential technology for use a source of electricity and heat for buildings. It's also a promising source of power for electric and hybrid vehicles. Fuel cells function best on pure hydrogen. However, other fuels such as gasoline, methanol, or natural gas can be reformed to generate the needed hydrogen for fuel cells. With technology moving fast, hydrogen could come on par with electricity as a vital energy carrier. An energy carrier transmits energy to the customer in a ready to use form. Some renewable energy sources such as wind and sun may not be able to generate energy around the clock, but are able to produce hydrogen and electric power and stored for later use.

Storage of Hydrogen

Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption).

Fuel Cells

A fuel cell uses the chemical energy of hydrogen or another fuel to cleanly and efficiently produce electricity. If hydrogen is the fuel, electricity, water, and heat are the only products. Fuel cells are unique in terms of the variety of their potential applications; they can provide power for systems as large as a utility power station and as small as a laptop computer.

Fuel cells can be used in a wide range of applications, including transportation, material handling, stationary, portable, and emergency backup power applications. Fuel cells have several benefits over conventional combustion-based technologies currently used in many power plants and passenger vehicles. Fuel cells can operate at higher efficiencies than combustion engines, and can convert the chemical energy in the fuel to electrical energy with efficiencies of up to 60%. Fuel cells have lower emissions than combustion engines. Hydrogen fuel cells emit only water, so there are no carbon dioxide emissions and no air pollutants that create smog and cause health problems at the point of operation. Also, fuel cells are quiet during operation as they have fewer moving parts.

Working

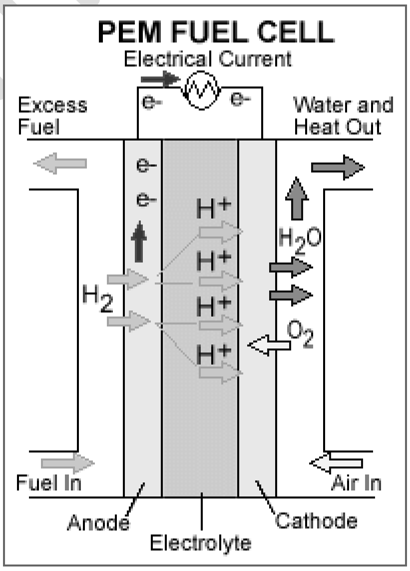
Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat if fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Types of Fuel Cells

Fuel cells are classified primarily by the kind of electrolyte they employ. This classification determines the kind of electro-chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. Learn more about the following types of fuel cells.

1. *Polymer electrolyte membrane Fuel Cell*

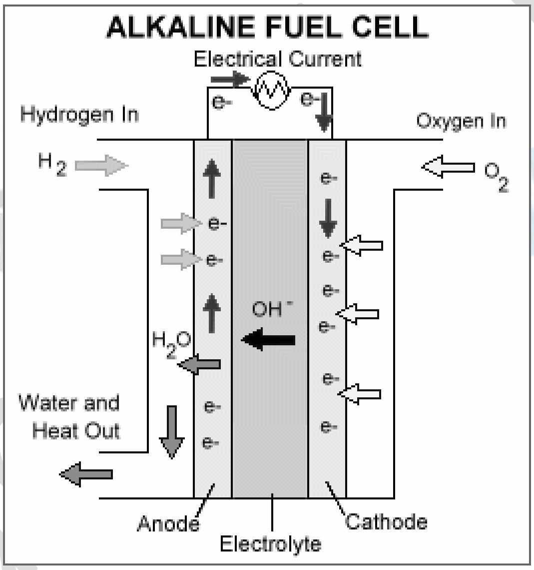
Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume compared with other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. They need only hydrogen, oxygen from the air, and water to operate. They are typically fueled with pure hydrogen supplied from storage tanks or reformers. PEM fuel cells operate at relatively low temperatures, around 80°C (176°F). Low-temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide poisoning, making it necessary to employ an additional reactor to reduce carbon monoxide in the fuel gas if the hydrogen is derived from a hydrocarbon fuel. This reactor also adds cost. PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.



2. *Alkaline fuel cell*

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. In recent years, novel AFCs that use a polymer membrane as the electrolyte have been developed. These fuel cells are closely related to conventional PEM fuel cells, except that they use an alkaline membrane instead of an acid membrane. The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications.

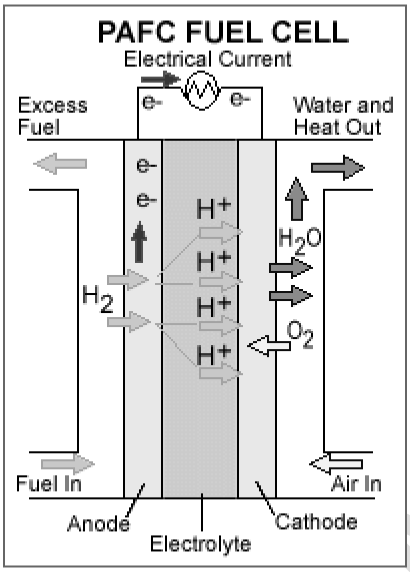
A key challenge for this fuel cell type is that it is susceptible to poisoning by carbon dioxide (CO2). In fact, even the small amount of CO2 in the air can dramatically affect cell performance and durability due to carbonate formation. Alkaline cells with liquid electrolytes can be run in a recirculating mode, which allows for electrolyte regeneration to help reduce the effects of carbonate formation in the electrolyte, but the recirculating mode introduces issues with shunt currents. The liquid electrolyte systems also suffer from additional concerns including wettability, increased corrosion, and difficulties handling differential pressures. Alkaline membrane fuel cells (AMFCs) address these concerns and have lower susceptibility to CO2 poisoning than liquid-electrolyte AFCs do. However, CO2 still affects performance, and performance and durability of the AMFCs still lag that of PEMFCs. AMFCs are being considered for applications in the W to kW scale. Challenges for AMFCs include tolerance to carbon dioxide, membrane conductivity and durability, higher temperature operation, water management, power density, and anode electro catalysis.



3. *Phosphoric acid fuel cell*

Phosphoric acid fuel cells (PAFCs) use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The electro-chemical reactions that take place in the cell are shown in the diagram to the right. The PAFC is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells, which are easily "poisoned" by carbon monoxide because carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. PAFCs are more than 85% efficient when used for the co-generation of electricity and heat but they are less efficient at generating electricity alone (37%–42%). PAFC efficiency is only slightly more than that of combustion-based power plants, which typically operate at around 33% efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. They require much higher loadings of expensive platinum catalyst than other types of fuel cells do, which raises the cost.

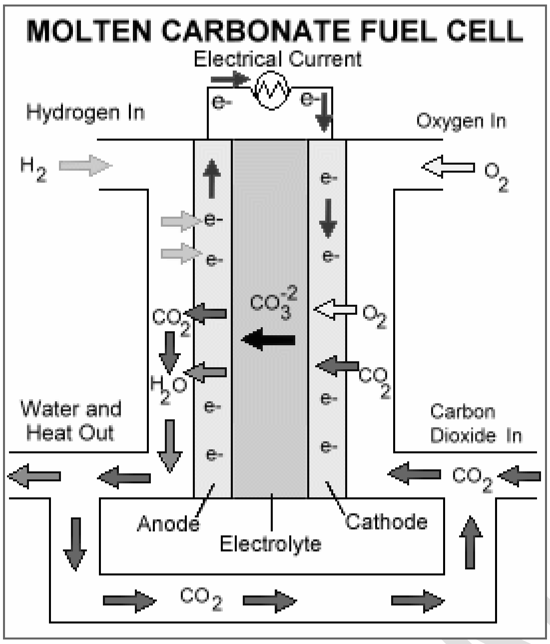


4. *Molten carbonate fuel cell*

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. Because they operate at high temperatures of 650°C (roughly 1,200°F), non-precious metals can be used as catalysts at the anode and cathode, reducing costs.

Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells. Molten carbonate fuel cells, when coupled with a turbine, can reach efficiencies approaching 65%, considerably higher than the 37%–42% efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be over 85%. Unlike alkaline, phosphoric acid, and PEM fuel cells, MCFCs do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. At the high temperatures at which MCFCs operate, methane and other light hydrocarbons in these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost.

The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate, and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that double cell life from the current 40,000 hours (~5 years) without decreasing performance.



Thermodynamics of Fuel Cell

Electrode potential and Electrochemical Potential

It is the electromotive force of a cell built of two electrodes:

Suppose,

on the left-hand side (LHS) is the standard hydrogen electrode (SHE, EH2/H+ = 0.0 V), and

on the right-hand side (RHS) is the electrode the potential of which is being defined.

Note, by convention potential of SHE is zero.

ECell =Eeft - Erigh =0- Eright=- Eelectrode

Thus, if the potential of RHS electrode is positive then Ecell is negative and if it is negative Ecell is positive. Instead of writing LHS and RHS electrode based on the positive side or negative side of EH2/H+ = 0.0 V, an electrode is named positive (anode) or negative (cathode) electrode.

By convention:

ECell= (ECathode -EH2/H+)- (EAnode- EH2/H+)

ECell= ECathode- EAnode

Or, take the sum of the electrode potentials from the LHS and RHS side of standard potential, i.e., EH2/H+= 0.0 V, from the standard electrode potential series or electrochemical series.

Standard electrode potential (E°), is the measure of individual potential of a reversible electrode at standard state. The basis for an electrochemical cell is always a redox reaction which can be broken down into two half-reactions: oxidation at anode (loss of electron) and reduction at cathode (gain of electron). Electricity is generated due to electric potential difference between two electrodes. This potential difference is created because of the difference between individual potentials of the two metal electrodes with respect to the electrolyte. Although the overall potential of a cell can be measured, there is no simple way to accurately measure the electrode/electrolyte potentials in isolation. The electric potential also varies with temperature, concentration and pressure. Since the oxidation potential of a half-reaction is the negative of the reduction potential in a redox reaction, it is sufficient to calculate either one of the potentials. Therefore, standard electrode potential is commonly written as standard reduction potential.

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