SURENDRANATH EVENING COLLEGE

Renewable Energy Sources

Semester IV

Skill Enhancement Course

by

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1. Introduction:

Renewable energy sources derive their energy from existing flows of energy from ongoing natural processes, such as sunshine, wind, flowing water, biological processes, and geothermal heat flows. A general definition of renewable energy sources is that renewable energy is captured from an energy resource that is replaced rapidly by a natural process such as power generated from the sun or from the wind. Currently, the most promising (aka economically most feasible) alternative energy sources include wind power, solar power, and hydroelectric power. Other renewable sources include geothermal and ocean energies, as well as biomass and ethanol as renewable fuels.

1.1 Solar Energy:

The recent climate crisis around the globe and limited resources of conventional fuel based energy, forcing us to begin considering other energy options. One promising technology, solar power is worth considering for its sustainable, renewable and emissions reducing qualities. Modern residential solar power systems use photovoltaic (PV) to collect the sun’s energy. “Photo” means “produced by light,” and “voltaic” is “electricity produced by a chemical reaction.” PV cells use solar energy to generate a chemical reaction that produces electricity. Each cell contains a semiconductor; most commonly silicon in one of several forms (single-crystalline, multi-crystalline, or thin-layer), with impurities (either boron or phosphorus) diffused throughout, and is covered with a silk screen. Cells are joined together by a circuit and frame into a module. Semiconductors allow the electrons freed from impurities by the sun’s rays to move rapidly and into the circuit, generating electricity. Commercial residential PV modules range in power output from 10 watts to 300 watts, in a direct current. A PV module must have an inverter to change the DC electricity into alternating current energy in order to be usable by electrical devices and compatible with the electric grid. PV modules can also be used to create large-scale power plants. Using PV modules to generate electricity can significantly reduce pollution. The most energy used in creating solar panels is used to purify and crystallize the semiconductor material. No

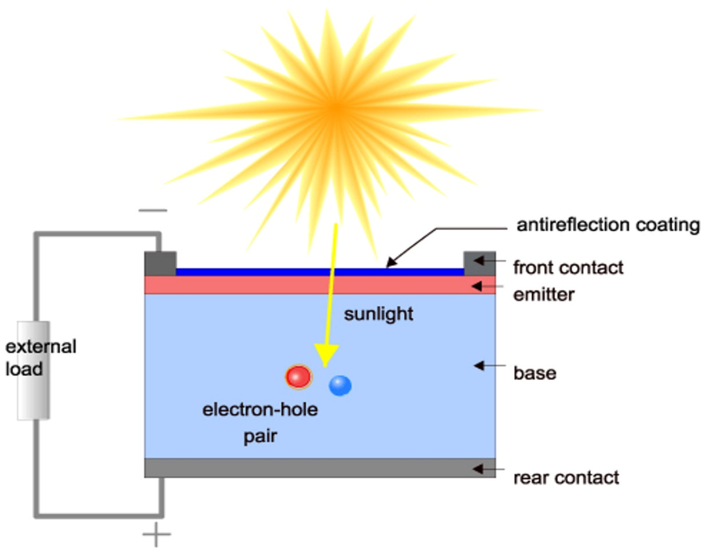


Figure 1: Mechanism of a semiconductor solar cell.

official numbers are available on the exact amount of energy used to create solar panels because there is no industry standard for making the crystals. A number of researchers have done work in attempt to address concerns about energy payback for PV systems. Assuming 12% conversion efficiency and 1,700 kWh/m^2 of sunlight per year, the estimates range between 2 and 4 years for rooftop PV systems to generate the energy it took to make them. Over twenty years, a 100-megawatt solar thermal electric power plant can avoid producing over three million tons of carbon dioxide. Estimates regarding pollution prevention suggest that producing 1,000 kWh of electricity through solar power can reduce emissions by 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxide, and 1,400 pounds of carbon dioxide. Lifetime estimates (over a projected 28 years) average in the thousands of pounds of prevented emissions. As PV technology advances, more efficient, easily affordable, standardized, reliable and longer-lasting modules will become available. PV systems' value to the energy sector especially in residential capacities is increasingly apparent. However, the continued high cost means that many homeowners will be deterred from purchasing and installing PV systems. The only way to encourage further growth in this sector is for consumers to purchase such systems. The energy emissions reductions are substantial enough to be worth the consideration of the government. In order to encourage consumers' interest in PV systems and growth in the renewable energy sector at a faster rate, the government should create an incentive program to help homeowners and businesses purchase and install PV systems, especially on new constructions.

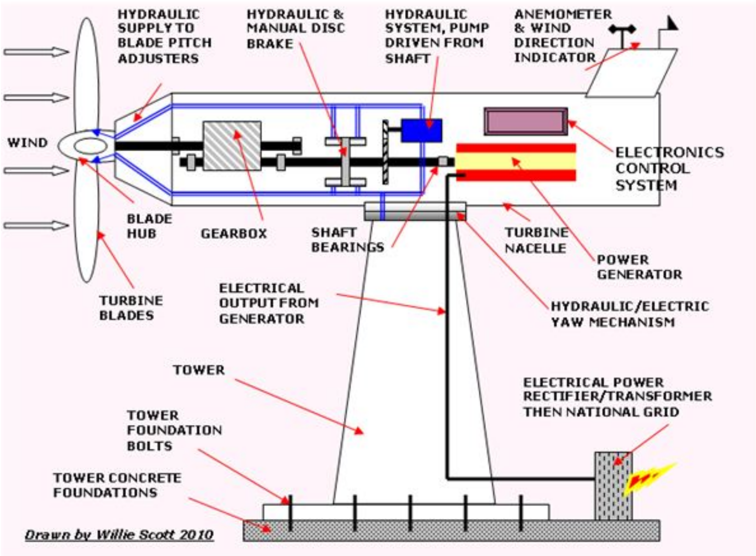


Figure 2: Mechanism of a wind mill.

1.2 Wind Energy:

Wind energy is one of the most promising alternative energy technologies of the future. Throughout recent years, the amount of energy produced by wind-driven turbines has increased exponentially due to significant breakthroughs in turbine technologies, making wind power economically compatible with conventional sources of energy. Wind energy is a clean and renewable source of power. The use of windmills to generate energy has been utilized as early as 5000 B.C., but the development of wind energy to produce electricity was sparked by the industrialization. The new windmills, also known as wind turbines, appeared in Denmark as early as 1890. The popularity of wind energy however has always depended on the price of fossil fuels. For example, after World War II, when oil prices were low, there was hardly any interest in wind power. However, when the oil prices increased dramatically in the 1970s, so did worldwide interest in the development of commercial use of electrical wind turbines. Today, the wind-generated electricity is very close in cost to the power from conventional utility generation in some locations. Where does wind come from? Wind is a form of solar energy and is caused by the uneven heating of the atmosphere by the Sun, the irregularities of the Earth's surface, and rotation of the Earth. The amount and speed of wind depends on the Earth's terrain and other factors. The wind turbines use the kinetic energy of the wind and convert that energy into mechanical energy, which in turn can be converted into electricity by means of a generator. There are essentially two types of wind turbines: The horizontal-axis variety, and the vertical axis design. The horizontal-axis design is used more commonly and looks like an Old Dutch windmill, whereas the vertical-axis design looks like and eggbeater. These wind turbines generally have either two or three blades, called rotors, which are angled at a pitch to maximize the rotation of the rotors. The horizontal-axis design is slightly more efficient and dependable than the vertical-axis windmill. Most of the windmill models that are currently in production are thus horizontal-axis windmills. Utility scale turbines can produce anywhere from 50 kilowatts to several megawatts of energy. These large windmills are generally grouped together in a windy area in what is called a wind farm. The proximity of the windmills in a wind farm makes it easier to feed the produced electricity into the power grid. Wind energy offers many advantages compared to fossil based power and even some other types of alternative energy, which explains why it is the fastest growing energy source in the world. The two main reasons are cleanliness and abundance. The fact that wind is a renewable resource gives it a major advantage over oil and the nonrenewable resources. Considering that environmental pollution is being linked to several global problems that might eventually threaten the existence or at the very least worsen human living conditions, the fact that windmills do not produce any emissions whatsoever is another reason to increase the use of wind turbines. Even though wind energy has many environmental and supply advantages, there are several disadvantages that limit the usability of wind power. The main disadvantage to wind power is that it is unreliable. Wind does not blow at a constant rate, and it does not always blow when energy is needed. Furthermore, the windiest locations are often in remote locations, far away from big cities where the electricity is needed. Just like with any other energy plant, people oppose it because of aesthetic reasons. The rotor noise produced by the rotor blades is another reason for opposition. Wind seems to be a very good source of alternative energy. Its biggest setback is its unreliability, but in combination with other, more reliable sources, wind energy should be used extensively to supplement the demand for energy.

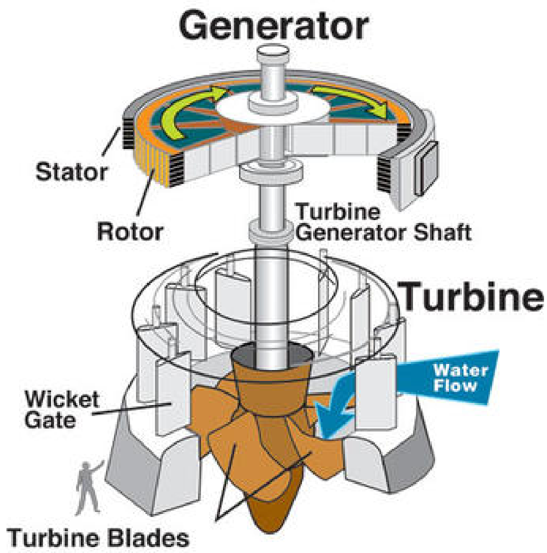


Figure 3: Mechanism of a hydroelectric generator.

1.3 Hydroelectric Power:

Hydropower is India’s leading renewable energy resource. This notable success can be attributed to the fact that out of all the renewable power sources, hydropower the most reliable, efficient, and economical. Furthermore, the concept behind hydroelectric power is fairly simple and has been in use for a significant span of time. The earliest reference to the use of the energy of falling water is found in the work of the Greek poet Antipater in the 4th century BC. Indeed, the word “hydro” comes from the Greek language meaning “water.” Several centuries later, the Romans were the first to utilize the water wheel. Due to the Romans’ powerful influence on Europe through conquest, the waterwheel was soon

Harvesting energy from water is possible due to the gravitational potential energy stored in water. As water flows from a high potential energy (high ground) to lower potential energy (lower ground), the potential energy difference thereby created can be partially converted into kinetic, and in this case electric, energy through the use of a generator. There are essentially two major designs in use that utilize water to produce electricity: the hydroelectric dam, and the pumped-storage plant. The waterwheel discussed at the beginning of this paper is currently no longer in use and has been replaced by the far more economical and efficient dam. Both the water wheel and the dam work on the same general principle, but the dam has the advantage of being more reliable due to the reservoir behind it. The principle is simple: the force of the water being released from the reservoir through the penstock of the dam spins the blades of a turbine. The turbine is connected to the generator that produces electricity. After passing through the turbine, the water re-enters the river on the downstream side of the dam. A pumped-storage plant is very similar to the hydroelectric dam, the main difference being that the pumped-storage plant uses two reservoirs, one being considerably higher than the other. The advantage of this design is that during periods of low demand for electricity, such as nights and weekends, energy is stored by reversing the turbines and pumping water from the lower to the upper reservoir. The stored water can later be released to turn the turbines and generate electricity as it flows back into the lower reservoir. Now that the two types of facilities have been discussed, there are also two way of obtaining the water: dam and run-of-the-river. A dam raises the water level of a stream or river to an elevation needed to create the necessary water pressure. In a run-of-the river scenario, the water is diverted from its natural path, enters the turbine, and is later returned to the river.

Hydroelectric power offers several significant advantages compared to fossil based power, and even other types of alternative energy. Probably the most important asset of hydroelectric power is its reliability. Furthermore, it creates no pollution, and once the dam is built, even though that process is very expensive, the produced energy is virtually free. A dam has the ability to continuously produce electricity and can adjust to peaks in demand by storing water above the dam and by being able to increase production to full capacity very quickly. Other than the high construction and planning costs, the major drawbacks of large dams are mostly environmental. The dam does not produce harmful emissions as in the case of fossil fuel burning. It does however alter the landscape dramatically, producing several severe, even unbearable changes to the habitat of fish and other plants and animals. Building a large dam will of course flood a large area of land upstream of the dam, causing problems for the animals that used to live there. It furthermore affects the water quantity and quality downstream of the dam which in turn affects plants and animals. Blocking the river also disallows certain migration pattern of fish. Finding sites that are suitable for dams is also a challenge. Overall, hydroelectric power seems to be a very good source of alternative energy: one that should be maintained at the maximum level possible. It has the main advantage over all the other forms of alternative energy production in that it is reliable, whereas the other forms of alternative energy are not.

1.4 Geothermal Energy:

Geothermal energy is one of the only renewable energy sources not dependent on the Sun. Instead, it relies on heat produced under the surface of the Earth. Geothermal energy already has several applications and could potentially provide a significant source of renewable power for the India. However, it is limited by a multitude of factors revolving around the issues of sustainability and economics. There are two main applications of geothermal energy, which include producing electricity at specialized power plants, and direct-heating, which puts to direct use the temperature of water piped under the earth’s surface. Geothermal power plants take on several types of forms, depending on the type of geothermal area from which they extract energy. In any case, the plants depend on steam to power turbines and generate electricity, though the methods of producing steam vary depending on the type of geothermal reservoir. Direct-heating, on the other hand, provides immediate, usable energy. But more energy could be extracted using developing technology, which doesn’t rely on existing hot water and steam reservoirs. The process involves drilling deep into the surface of the Earth where temperatures are hot, and then injecting water into cracks of rock, which is heated and then pumped back to the surface. If this “hot dry rock” (HDR) technology proves effective, then more geothermal plants could operate in more locations, since much of the Earth’s surface is underlain by hot, dry rock. Some problems that geothermal energy faces are depletion of both water and heat in geothermal areas. The first problem has been partially addressed by re-injecting water into reservoirs, thus sustaining the plant’s ability to operate. However, it has been shown that water re-injection can cause small earthquakes, which raises the question of whether the plants should be liable for the damages caused. Heat depletion of geothermal areas is more problematic than water depletion in the long run, since it cannot be avoided. It is caused by a natural cooling-off of the earth’s crust, and in these cases, plants would become less and less efficient over several decades until they were rendered useless. Other issues facing geothermal power in the United States are building costs and economic competitiveness with other energy sources. Geothermal plants can be expensive, depending on factors such as how deep the wells must be drilled and the temperature of the water or steam. These initial costs of an economically competitive plant can be as high as 2 lakh to 3 lakh per kW installed capacity, which accounts for about two thirds of total costs for the plant. The plants are economically competitive in the long run however, because their fuel is free, whereas natural gas or coal plants spend up to two thirds of their total operating costs on fuel. Another problem that adds cost to geothermal plants is the problem of connecting to energy grids. This is a critical issue because geothermal plants are built where geothermal resources permit- such as geysers and areas with less-heated water. Over time, however, the plants pay for themselves and all the necessary costs because of low operating costs; namely, the fact that the plants energy is free and always available. The

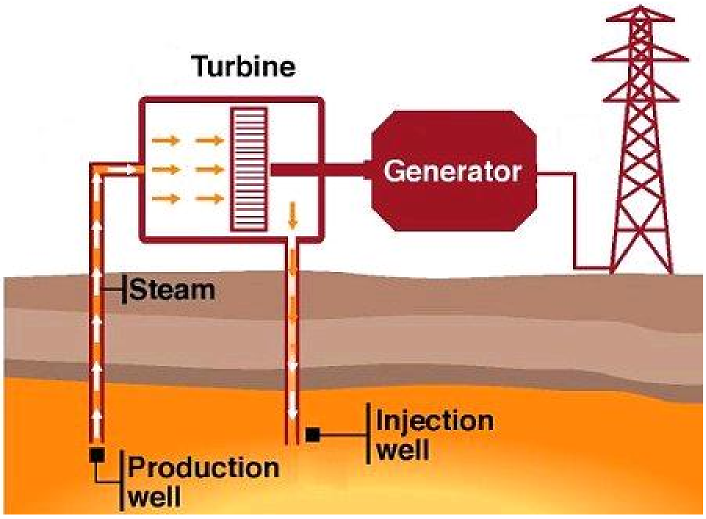


Figure 4: Mechanism of a geothermal power plant.

projected low cost therefore depends on the availability an exploitation of existing geothermal resource Because of its reliability, accessibility, low impact on the environment, and potential low cost, geothermal energy is a very attractive source of renewable energy for the India. Expanding use of geothermal energy depends largely upon the success of the hot dry rock technology and the simultaneous prevention of earthquakes caused by water injection at those plants and water re-injection at other plants. If the HDR technology proves to be viable and safe, geothermal plants can be built in closer proximity to electricity grids, without worrying about geothermal resources like geysers. This would make the plants more cost effective and enable geothermal energy to compete with other energy types.

1.5 Biomass Energy:

As a pending global energy crisis appears more and more imminent, it is important to consider many different options for new energy sources. Renewable energy sources are ideal because they are more efficient, environmentally friendly and, ultimately, better for consumers. Biomass can be converted into fuels through a number of different processes, including solid fuel combustion, digestion, pyrolysis, and fermentation and catalyzed reactions. Electricity is generated in many places through solid fuel combustion. The majority of America's electricity is fueled by coal combustion. These products are usually wood matter, vegetation, and waste from lumber yards. Power plants burn such fuels to heat a boiler, and the resulting steam powers turbines & generators. This process still releases a lot of carbon dioxide and other polluting gases into the environment, but helps eliminate waste efficiently. Digestion is another process that makes use of existing waste. The term is a misnomer. Digestion is the naturally occurring process of bacteria feeding on decaying matter and making it decompose. It is that which releases gases like methane, hydrogen, carbon monoxide, etc. In many landfills, owners are experimenting with set-ups to best collect the gases produced by such bacteria. The standard system includes pipelines running through the waste to collect the gases. Animal feed lots and other facilities are also exploring tapping such resources. A third process, pyrolysis, creates a product much like charcoal, with double the energy density of the original biomass, making the fuel highly transportable and more efficient. Anhydrous pyrolysis heats the biomass at intense temperatures in the absence of oxygen or water. Scientists assume that this is the process that originally produced fossil fuels (under different conditions). Most industrial processes of pyrolysis convert the biomass under pressure and at temperatures above 800° F (430° C). A liquid fuel can also be produced using this process.

The most widely used alternative fuel, ethanol, is created through fermentation of organic materials. Ethanol has a current capacity of 1.8 billion gallons per year, based on starch crops such as corn. Again, the fuel conversion process takes advantage of a natural process. Microorganisms, especially bacteria and yeasts, ferment starchy, sugary biomass products (like corn), yielding products like ethanol, which can be used as fuels in a variety of applications. Biodiesel is an increasingly popular fuel, especially in the transportation sector. This monoalkyl ester is formed by combining fuel-grade oil, processed from sources like vegetable oil, animal fats, algae and even used cooking grease, with an alcohol (like methanol or ethanol), using a catalyst. It shows great promise as both a neat fuel (used alone) and as an additive to petroleum diesel. Using biomass could be the

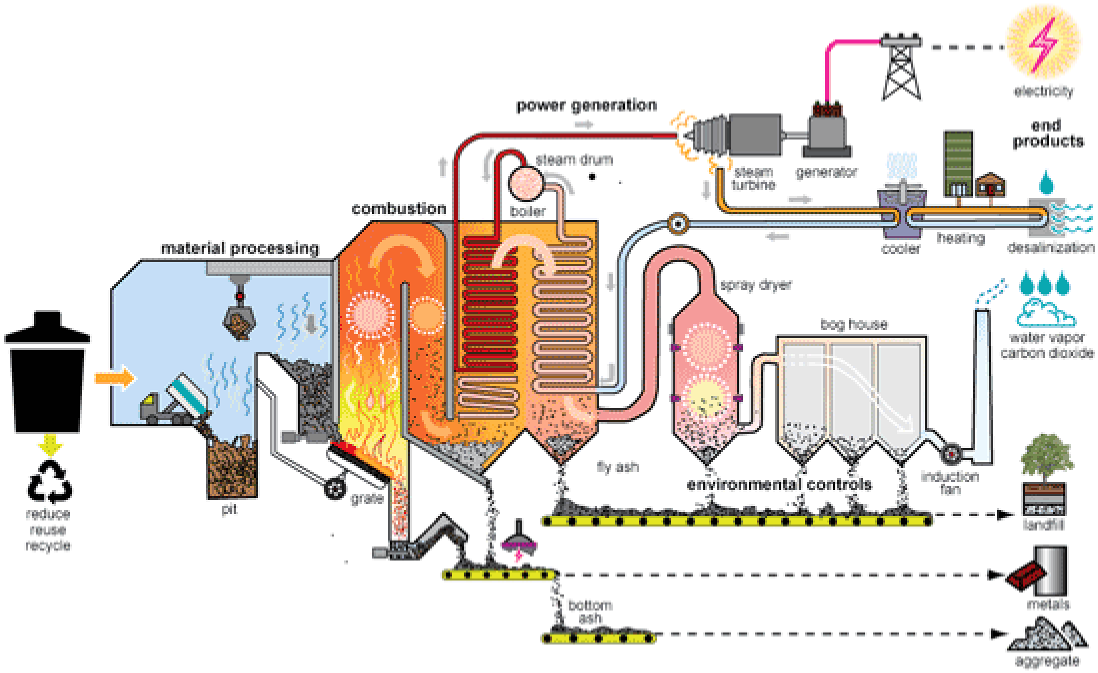


Figure 5: mechanism of a Biomass plant.

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

SOLAR ENERGY

2. Introduction:

Solar energy is an abundant and renewable energy source. The annual solar energy incident at the ground in India is about 20,000 times the current electrical energy consumption. The use of solar energy in India has been very limited. This is because solar energy is a dilute energy source (average daily solar energy incident in India is 5 kWh/m 2 day) and hence energy must be collected over large areas resulting in high initial capital investment; it is also an intermittent energy source. Hence solar energy systems must incorporate storage in order to take care of energy needs during nights and on cloudy days. This results in further increase in the capital cost of such systems. One way to overcome these problems is to use a large body of water for the collection and storage of solar energy. This concept is called a solar pond.

2.1 Solar pond

In a clear natural pond about 30~ solar radiation reaches a depth of 2 metres. This solar radiation is absorbed at the bottom of the pond. The hotter water at the bottom becomes lighter and hence rises to the surface. Here it loses heat to the ambient air and, hence, a natural pond does not attain temperatures much above the ambient. If some mechanism can be devised to prevent the mixing between the upper and lower layers of a pond, then the temperatures of the lower layers will be higher than of the upper layers. This can be achieved in several ways. The simplest method is to make the lower layer denser than the upper layer by adding salt in the lower layers. The salt used is generally sodium chloride or magnesium chloride because of their low cost. Ponds using salts to stabilize the lower layers are called 'salinity gradient

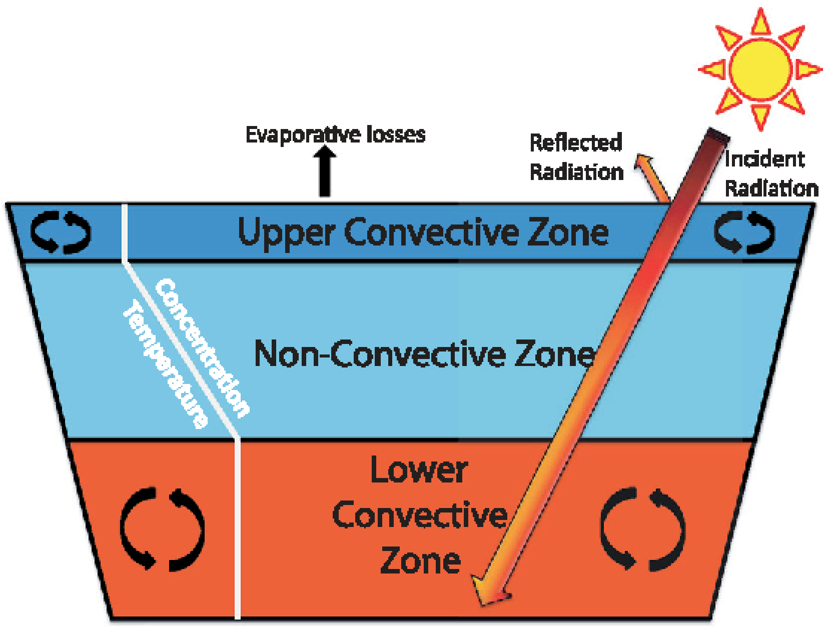


Figure 1: Mechanism of a solar pond.

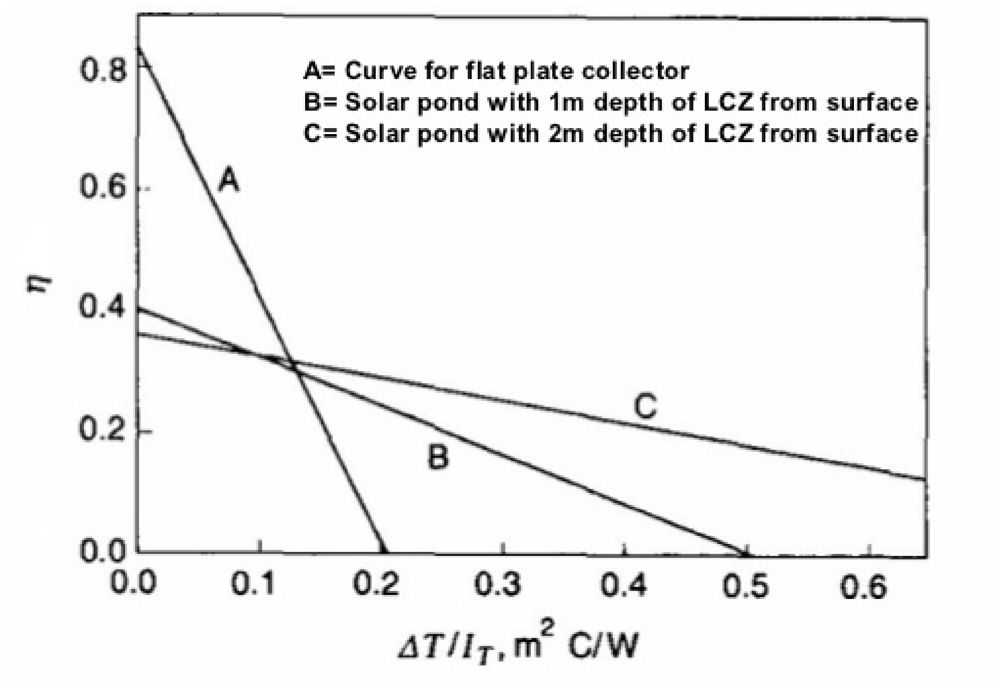
ponds'. There are other ways to prevent mixing between the upper and lower layers. One of them is the use of a transparent honeycomb structure which traps stagnant air and hence provides good transparency to solar radiation while cutting down heat loss from the pond. The honeycomb structure is made of transparent plastic material. Ortabasi & Dyksterhuis (1985) have discussed in detail the performance of a honeycomb-stabilized pond. One can also use a transparent polymer gel as a means of allowing solar radiation to enter the pond but cutting down the losses from the pond to the ambient. Wilkins & Lee (1987) have discussed the performance of a gel (cross-linked polyacrylamide) pond. In this review we discuss salinity gradient solar ponds as this technology has made tremendous progress in the last fifteen years. Typical temperature and density profiles in a large salinity gradient solar pond are shown in figure 1. We find that there are three distinct zones in a solar pond. The lower mixed zone has the highest temperature and density and is the region where solar radiation is absorbed and stored. The upper mixed zone has the lowest temperature and density. This zone is mixed by surface winds, evaporation and nocturnal cooling. The intermediate zone is called the nonconvective zone (or the gradient zone) because no convection occurs here. Temperature and density decrease from the bottom to the top in this layer, and it acts as a transparent insulator. It permits solar radiation to pass through but reduces the heat loss from the hot lower convective zone to the cold upper convective zone. Heat transfer through this zone is by conduction only. The thicknesses of the upper mixed layer, the non-convective layer and the lower mixed layer are usually around 0"5, 1 m and 1 m, respectively.

2.2 Thermal Performance:

The hermal performance of a solar pond can be represented in a form similar to that used for conventional flat plate collectors. Assuming a steady state condition,

$Q_u = Q_a - Q_e$,

where Q_u = useful heat extracted, Q_a = solar energy absorbed, Q_e = heat losses. The thermal efficiency of a solar pond can be defined as $\eta = (Q_u/I)$ where I is the solar energy incident on the pond. Thermal efficiency can be written as $\eta = \eta_0 - Q_e/I$, where η_0 is called the optical efficiency of the pond (Q_a/I). We express $Q_e = U_o (T_s - T_a)$, where T_s is the pond storage-zone temperature, T_a is the ambient temperature and U_o is the overall heat-loss coefficient. If we neglect heat losses from the bottom and sides of the pond and assume that the temperature of the upper mixed layer is the same as the ambient, then $U_o = K_w/b$ where K_w is the thermal conductivity of water and b is the thickness of the gradient zone. Kooi (1979) has compared the efficiency of a solar pond with those of conventional flat plate collectors as shown in figure 2. We find that the thermal efficiency of a solar pond is higher than that of a flat plate collector when the operating temperatures are higher, and is in the range of 20 to 30% when the temperature difference is around 60°C. The thermal efficiency is strongly dependent upon the transparency of the pond which is influenced by the presence of algae and dust. Even if the solar pond is free of



dust and algae, the absorption properties of pure water influence the transmission of solar radiation in the pond.

Figure 2: Variation of thermal efficiency with ΔT/I

The transmissivity of solar radiation in pure distilled water is shown in figure 3. We observe that about half the solar radiation is absorbed in the first 50 cm of water. This is on account of strong infrared absorption bands in water. At a depth of 2 metres the transmission is about 40%. This sets the upper limit on the thermal efficiency of a solar pond. The thickness of the gradient zone must be chosen depending on the temperature at which thermal energy is needed. If the thickness of the gradient zone is too high the transmission of solar radiation is reduced while if it is too small it causes high heat losses from the bottom to the top of the pond. The optimum value of the thickness depends on the temperature of the storage zone of the pond. Nielsen (1980) has provided a steady state analysis of a solar pond and has included the effect of solar radiation absorption in the gradient zone on the temperature profile.

2.3 Solar pond applications:

In the last thirty years more than sixty solar ponds have been built all around the world. The largest solar pond built so far is the 250,000m 2 pond at Bet Ha Arava in Israel. This pond has been used to generate 5 MWe (peak) power using an organic Rankine cycle. The heat stored in the solar pond can be used in a variety of applications. The first solar pond in India was a 1200 m 2 pond built at the Central Salt and Marine Chemicals Research Institute in Bhavnagar, Gujarat, in 1970. This solar pond was based on bittern, which is a waste product during the production of sodium chloride from sea water. The second solar pond was a 100 m 2 circular pond built in Pondicherry in 1980. This pond used sodium chloride and was operational for two years. Patel & Gupta (1981) have discussed the performance of this pond. The LDPE liner used in this pond developed a leak and hence had to be replaced. Patel & Gupta (1981) have shown that a new liner could be placed in the pond without too much loss of thermal energy. The third solar pond was a 1600m 2 solar pond built at Bhavnagar in 1980. This pond was based on bittern and hence had problems with the clarity of bittern. The fourth solar pond was a 240 m 2 solar pond commissioned at the Indian Institute of Science, Bangalore, in 1984. This pond has provided long-term data on continuous heat extraction from small solar ponds and has demonstrated the technical and economic viability of small solar ponds for low temperature process heat. Srinivasan (1985) has argued that low temperature process heat from small solar ponds can be used in hatcheries, hostels and dairies. A 400 m 2 solar pond has been constructed at Masur on the West Coast of India to supply hot water needs of a rural community. A 300 m 2 solar pond is being built for an engineering college at Hubli (Karnataka) to supply hot water for student hostels. A 6000m 2 solar pond has been completed in Bhuj (Gujarat) and is expected to supply hot water for a dairy. This project is expected to explore the potential for desalination and power generation. A 6000 m^2 solar pond is under construction at Pondicherry for generation of 100 kWe (peak) powers. The solar ponds at Masur and Bhuj experienced salt leakages on account of the failure of LDPE liners. In India, Gujarat and Tamil Nadu are the two states where common salt is produced on a large-scale. These two states have arid regions where the land is unsuitable for agriculture and have more than 300 clear days a year. Gujarat and Tamil Nadu constitute 10% of India's area. If 4% of the land in these two states were used as solar pond power plants, they can generate about 200 billion kilowatt hours of electrical energy. Thus, solar pond power plants could have met all the electrical energy needs of India in 1988. Solar ponds should therefore play an important role in meeting the future energy needs of India using a locally available and renewable energy source.

3. Flat Panel collector:

A Flat Plate Collector is a heat exchanger that converts the radiant solar energy from the sun into heat energy using the well known greenhouse effect. It collects, or captures, solar energy and uses that energy to heat water in the home for bathing, washing and heating, and can even be used to heat outdoor swimming pools and hot tubs. For most residential and small commercial hot water applications, the solar flat plate collector tends to be more cost effective due to their simple design, low cost, and relatively easier installation compared to other forms of hot water heating systems. Also, solar flat plate collectors are more than capable of delivering the necessary quantity of hot water at the required temperature.

A solar flat plate collector typically consists of a large heat absorbing plate, usually a large sheet of copper or aluminium as they are both good conductors of heat, which is painted or chemically etched black to absorb as much solar radiation as possible for maximum efficiency. This blackened heat absorbing surface has several parallel copper pipes or tubes called risers, running length ways across the plate which contains the heat transfer fluid, typically water. These copper pipes are bonded, soldered or brazed directly to the absorber plate to ensure maximum surface contact and heat transfer. Sunlight heats the absorbing surface which increases in temperature. As the plate gets hotter this heat is conducted through the risers and absorbed by the fluid flowing inside the copper pipes which is then used by the household.The pipes and absorber plate are enclosed in an insulated metal or wooden box with a sheet of glazing material, either glass or plastic on the front to protect the enclosed absorber plate and create an insulating air space. This glazing material does not absorb the suns thermal energy to any significant extent and therefore most of the incoming radiation is received by the blackened absorber.The air gap between the plate and glazing material traps this heat preventing it from escaping back into the atmosphere. As the absorber plate warms up, it transfers heat to the fluid within the collector but it also loses heat to its surroundings. To minimize this loss of heat, the bottom and sides of a flat plate collector are insulated with high temperature rigid foam or aluminium foil insulation as shown.

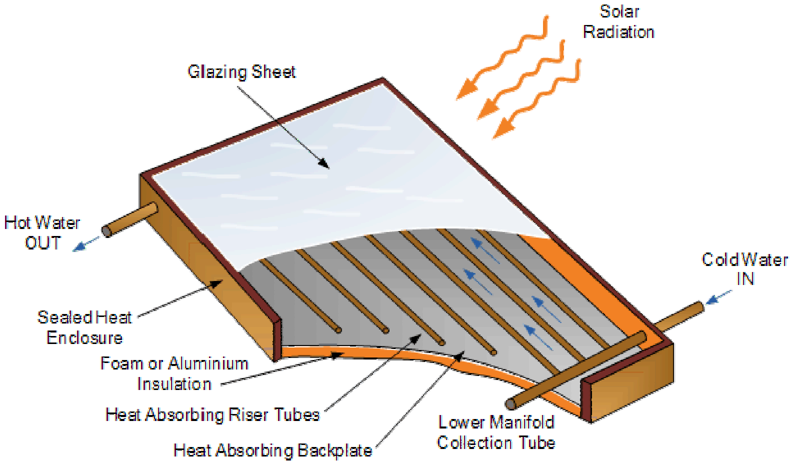


Figure 3: Structure of a flat plate solar collector.

Hot Water Systems:

There are several different ways to heat water for use in the home. Solar water heating systems that use flat plate solar collectors to capture the suns energy can be classed as either direct or indirect systems by the way in which they transfer the heat around the system. In order to heat your water successfully and use it during both the day and the night, you will need to have both a solar collector to capture the heat and transfer it to the water and also a hot water tank to store this hot water for use as needed.

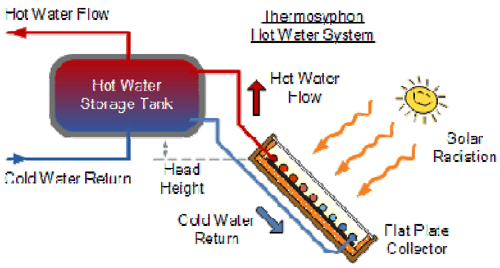
Direct Hot Water System.

A direct solar water heating system, also known as an active open-loop system, uses a pump to circulate the water around the system. The cooler water is pumped directly from the home to a central water storage or immersion tank and passes through the solar collector for heating. The hot water leaves the flat plate collector and returns back to the tank flowing in a continuous loop. From there, the water is pumped back into the house as hot usable water. A low voltage 12 volt pump can be used which can be powered by a small photovoltaic cell or electronic controller making the system more green. Direct systems are usually used in warmer climates with few cold days or drained in winter to stop the water in the pipes from freezing. Chemicals cannot be added to the water for protection as the same water that circulates through the flat plate collector is used in the home.

In a passive direct hot water system, the system does not use pumps or control mechanisms to transfer the heat created to the storage tank. Instead, passive systems are what are called “open-loop systems” which use the natural force of gravity to help circulate the water around the system. This type of system uses a solar flat plate collector combined with a horizontally mounted storage tank of some kind located immediately above the collector. The water heated by the sun rises naturally using convection through the solar collectors pipes and enters the storage tank situated above. As the heated water enters the storage tank above, the cooler water is forced out and flows down to the bottom of the collectors aided by gravity as cold water is more dense than hot water. This cycle of hot water rising and cooler water falling is known as a “thermosyphon flow” and continuously repeats unaided while the sun is shining.

Thermosyphon Hot Water System

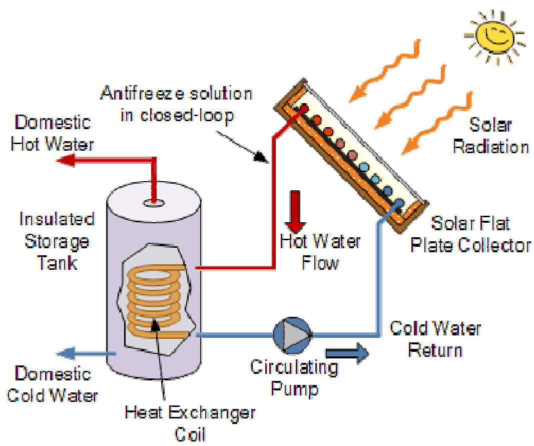
The thermosyphon system is the most common type of solar heated hot water system on the market and most commercially available passive direct solar hot water systems use this type of roof-mounted flat plate collector and storage tank combination. However, care must be taken when installing such a system as the combined weight of the solar collector, storage tank and the water itself may be too much for the design of the supporting roof. When passive solar hot water systems are used for bigger buildings than for houses, businesses or offices, there is often more than one storage tank for the heated water. So called remote thermosyphon system works on



the same principle as the previous passive direct thermosyphon system, except that the storage tank is located away within the roof space or void dissipating the weight over a larger area and also protecting the storage tank from cold weather and temperatures. However, for the thermosyphoning process to work correctly, the base of the water storage tank must be situated at least 1 to 2 feet (300 to 500 mm) above the top of the flat plate collectors. This distance is also known as the systems “head height”.

Indirect Hot Water System.

Indirect hot water systems, which are also known as closed-loop systems, differ from the previous thermosyphon system in that it uses a heat exchanger which is separate from the solar flat plate collector to heat the water in the storage tank. Indirect hot water systems are active systems and require pumps to circulate the heat transfer liquid around the closed-loop system from the collector to the heat exchanger in the tank. The system contains an antifreeze solution, typically a 50% Glycol/water mixture, in the primary closed-loop instead of just water which is heated and is kept separate from the main domestic hot water supply. The heat exchanger transfers the heat from the collector’s antifreeze solution to the water located in the water storage tank. The heat exchanger can either be a copper coil inside the lower part of the storage tank or a flat plate exchanger outside the storage tank. One of the main advantages to this closed loop indirect heating system is that the antifreeze solution gives all year round operation in areas where the



temperature falls below the freezing point as well as protecting the system from corrosion of the collectors by untreated tap water containing gases and various dissolved salts. The main advantage of a forced circulation indirect hot water system is that an existing domestic water heating system can easily be converted to solar heating of the water just by adding a flat plate collector and a single pump as most homes use gas or oil fired boilers as well as a hot water storage tank with built-in heat exchanger coil. The system is also likely to be more efficient, and the hot water storage tank can be placed anywhere in the home because it does not need to be higher than the collectors as in the previous passive or thermosyphon system. One disadvantage, however, is that the closed-loop system is dependent on electricity for the circulating pump which may be expensive or unreliable. Some designs use a small low voltage pump and photovoltaic panel alongside the collector making the system more efficient and greener. For larger installations and in cooler climates the hot-water tanks are included below the roof within buildings, so forced circulation indirect solar water heating is the norm.