Energy Situation and Renewable Energy Sources

Renewable and Non-renewable Energy Sources

Renewable energy is energy obtained from sources that are essentially inexhaustible.

Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power.

The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

Energy and Environment

The usage of energy resources in industry leads to environmental damages by polluting the atmosphere.

Few of examples of air pollution are sulphur dioxide (SO_2), nitrous oxide (NO_X) and carbon

monoxide (CO) emissions from boilers and furnaces,Chlorofluro carbons (CFC) emissions from refrigerants use, etc. In

chemical and fertilizers industries, toxic gases are released. Cement plants

and power plants spew out particulate matter.

Air Pollution

A variety of air pollutants have known or suspected harmful effects on human health and the environment. These air pollutants are basically the products of combustion from fossil fuel use. Air pollutants from these sources may not only create problems near to these sources but also can cause problems far away. Air pollutants can travel long distances, chemically react in the atmosphere to produce secondary pollutants such as acid rain or ozone.

Climatic Change

Human activities, particularly the combustion of fossil fuels, have made the blanket of green- house gases (water vapour, carbon dioxide, methane, ozone etc.) around the earth thicker. The resulting increase in global temperature is altering the complex web of systems that allow life to thrive on earth such as rainfall, wind patterns, ocean currents and distribution of plant and animal species.

Current Evidence of Climatic Change

Cyclones, storm, hurricanes are occurring more frequently and floods and draughts are more intense than before. This increase in extreme weather events cannot be explained away as random events.

This trend toward more powerful storms and hotter, longer dry periods is predicted by computer models. Warmer temperatures mean greater evaporation, and a warmer atmosphere is able to hold more moisture and hence there is more water aloft that can fall as precipitation. Similarly, dry regions are prone to lose still more moisture if the weather is hotter and hence this leads to more severe droughts and desertification.

Origin of Renewable Energy Sources

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth.

Potential of Renewable Energy Sources

The most sustainable energy sources are renewable bioenergy (wood, biomass, energy crops), geothermal (deep or shallow), solar energy (photovoltaic, solar thermal), hydro and wind energy. Since much more, orders of magnitudes more, solar energy hits the earth than is required for human needs, the total potential of renewable energies seems to be almost infinite.

Direct-use Technology

“Renewable energy technologies” is an umbrella term that stands for energy production using a renewable energy source like solar, wind, water (hydro and tidal), biomass (biofuels and wastes), and geothermal heat.

Renewable energy technologies are on the verge of a new era. In many countries and regions, renewable energy is already responsible for meeting a substantial share of energy demand. The rapid and substantial progress of renewable energy in recent years has been driven by policies of local, national and regional authorities, in close cooperation with the business community, as well as continued technological innovation and cost reductions in energy generated with renewable sources.

Solar Radiation & Collectors

Solar Radiation Through Atmosphere

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the technical feasibility and economical operation of these technologies at a specific location depends on the available solar resource.

BASIC PRINCIPLES

Every location on Earth receives sunlight at least part of the year. The amount of solar radiation that reaches any one spot on the Earth's surface varies according to:

Geographic location

Time of day

Season

Local landscape

Local weather.

Because the Earth is round, the sun strikes the surface at different angles, ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse. Because the Earth is round, the frigid polar regions never get a high sun, and because of the tilted axis of rotation, these areas receive no sun at all during part of the year.

The Earth revolves around the sun in an elliptical orbit and is closer to the sun during part of the year. When the sun is nearer the Earth, the Earth's surface receives a little more solar energy. The Earth is nearer the sun when it is summer in the southern hemisphere and winter in the northern hemisphere. However, the presence of vast oceans moderates the hotter summers and colder winters one would expect to see in the southern hemisphere as a result of this difference.

DIFFUSE AND DIRECT SOLAR RADIATION

As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by:

Air molecules

Water vapor

Clouds

Dust

Pollutants

Forest fires

Volcanoes.

This is called diffuse solar radiation. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

Terrestrial Solar Radiation

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

atmospheric effects, including absorption and scattering;

local variations in the atmosphere, such as water vapour, clouds, and pollution;

latitude of the location; and the season of the year and the time of day.

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

Solar radiation at the Earth's surface varies from the solar radiation incident on the Earth's atmosphere. Cloud cover, air pollution, latitude of a location, and the time of the year can all cause variations in solar radiance at the Earth's surface.

The amount of energy reaching the surface of the Earth every hour is greater than the amount of energy used by the Earth's population over an entire year.

Measurement of Solar Radiation

Solar radiation is a term used to describe visible and near-visible (ultraviolet and near-infrared) radiation emitted from the sun. The different regions are described by their wavelength range within the broad band range of 0.20 to 4.0 µm (microns). Terrestrial radiation is a term used to describe infrared radiation emitted from the atmosphere. The following is a list of the components of solar and terrestrial radiation and their approximate wavelength ranges:

Ultraviolet: 0.20 – 0.39 µm

Visible: 0.39 – 0.78 µm

Near-Infrared: 0.78 – 4.00 µm

Infrared: 4.00 – 100.00 µm

Approximately 99% of solar, or shortwave, radiation at the earth’s surface is contained in the region from 0.3 to 3.0 µm while most of terrestrial, or longwave, radiation is contained in the region from 3.5 to 50 µm.

Outside the earth's atmosphere, solar radiation has an intensity of approximately 1370 watts/meter2. This is the value at mean earth-sun distance at the top of the atmosphere and is referred to as the Solar Constant. On the surface of the earth on a clear day, at noon, the direct beam radiation will be approximately 1000 watts/meter2 for many locations. While the availability of energy is affected by location (including latitude and elevation), season, and time of day, the biggest factors affecting the available energy are cloud cover and other meteorological conditions which vary with location and time.

ULTRAVIOLET MEASUREMENTS

For the measurement of sun and sky ultraviolet radiation in the wavelength interval 0.295 to 0.385 µm, which is particularly important in environmental, biological, and pollution studies the Total Ultraviolet Radiometer (Model TUVR) was developed. This instrument utilizes a photoelectric cell protected by a quartz window. A specially designed teflon diffuser not only reduces the radiant flux to acceptable levels but also provides close adherence to the Lambert cosine law. An encapsulated narrow bandpass (interference) filter limits the spectral response of the photocell to the wavelength interval 0.295-.0385 µm.

SHORTWAVE MEASUREMENTS: DIRECT, DIFFUSE AND GLOBAL

As solar radiation passes through the earth's atmosphere, some of it is absorbed or scattered by air molecules, water vapor, aerosols, and clouds. The solar radiation that passes through directly to the earth's surface is called Direct Normal Irradiance (DNI). The radiation that has been scattered out of the direct beam is called Diffuse Horizontal Irradiance (DHI). The direct component of sunlight and the diffuse component of skylight falling together on a horizontal surface make up Global Horizontal Irradiance (GHI). The three components have a geometrical relationship.

Direct radiation is best measured by use of a pyrheliometer, which measures radiation at normal incidence. The Normal Incidence Pyrheliometer (Model sNIP) consists of a wirewound thermopile at the base of a tube with a viewing angle of approximately 5º which limits the radiation that the thermopile receives to direct solar radiation only.

The pyrheliometer is mounted on a Solar Tracker (Models ST-1 and ST-3) or an Automatic Solar Tracker (Model SMT) for continuous readings.

Diffuse radiation can either be derived from the direct radiation and the global radiation or measured by shading a pyranometer from the direct radiation so that the thermopile is only receiving the diffuse radiation. Eppley has developed Shade Disk Adaption Kit (Model SDK) that mounts on the SMT which allows you to measure the diffuse and direct at the same time. We also manufacture the Shadow Band Stand, (Model SBS) for Diffuse measurements in sites where there is no power available to operate an Automatic Tracker.

Global radiation is measured by a pyranometer. The modern pyranometer manufactured by the Eppley Laboratory, using wirewound plated thermopiles, can be one of three models: the Standard Precision Pyranometer (Model SPP), the Global Precision Pyranometer (Model GPP), and the Black & White Pyranometer (Model 8-48). The SPP has a black sensor protected by two precision ground, polished hemispheres and is the preferred instruments for Global measurements. Based on the SPP, the GPP is specifically designed as a lower cost alternative for the PV/CSP industry. The 8-48 has a black and white sensor that is protected by a single polished hemisphere and is the preferred instrument for Diffuse measurements.

LONGWAVE (INFRARED) MEASUREMENTS

The Precision Infrared Radiometer, (Model PIR) was a development of the PSP Pyranometer (forerunner to the SPP Pyranometer) and continues to be the industry standard for precise measurement of incoming or outgoing longwave radiation. The PIR comprises the same wirewound thermopile detector and temperature compensation circuitry as found in the PSP/SPP. This thermopile detector is used to measure the "net radiation" of the PIR and a case thermistor (YSI 44031) is used to determine the outgoing radiation from the case. A dome thermistor is also included if one wishes to measure the dome temperature as compared to the case temperature to make any "corrections" to the final result.

ALBEDO / BIFACIAL MEASUREMENTS

Albedo is the ratio of incoming shortwave divided by the reflected shortwave on a horizontal plane. The best way to measure albedo is with two distinct pyranometers – one facing upward and the other facing downward. The smaller, lightweight GPP is perfect for these measurements. If one tilts the UP/DOWN orientation of these two instruments to match the orientation of their PV array, they are able to measure the Plane of Array Irradiance (POA or Gi) and the In-Plane Rearside Irradiance (GiREAR) for Bifacial testing.

NET RADIATION MEASUREMENTS

Net radiation is the sum of four individual measurements: Incoming Shortwave, Reflected Shortwave, Incoming Longwave and Outgoing Longwave. Eppley recommends measuring each of the four componants separately using two (2) SPPs and two (2) PIRs.

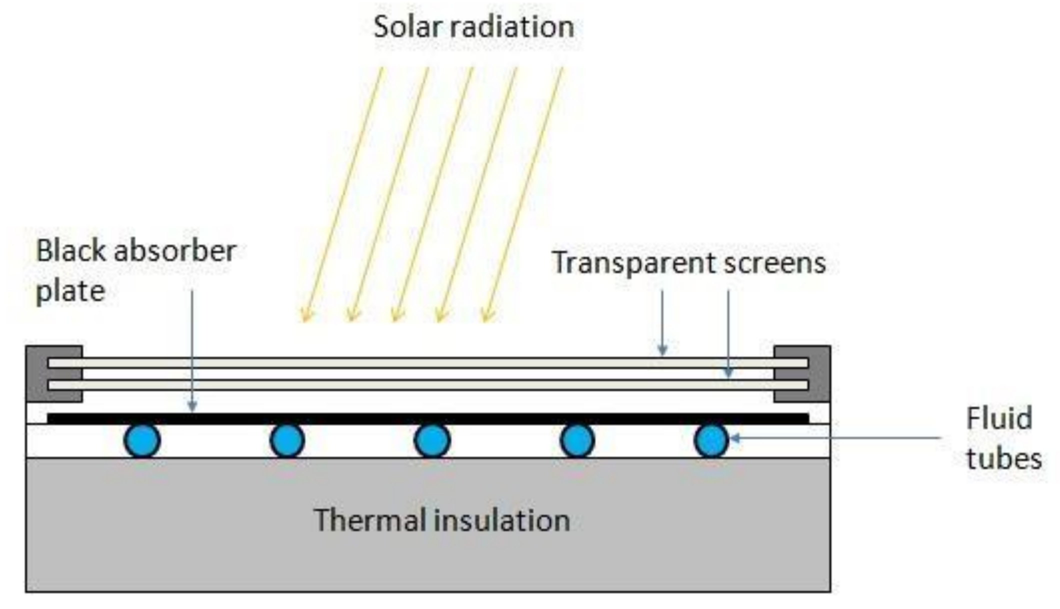
SUNSHINE DURATION MEASUREMENTS

Sunshine duration is typically defined as the amount of time that the Direct Normal Irradiance (DNI) is greater than 120 Wm-2. This can be determined by using the data collected from the sNIP.

The flat-plate solar collectors are probably the most fundamental and most studied technology for solar-powered domestic hot water systems. The overall idea behind this technology is pretty simple. The Sun heats a dark flat surface, which collect as much energy as possible, and then the energy is transferred to water, air, or other fluid for further use.

Flat Plate Collectors

These are the main components of a typical flat-plate solar collector:



Black surface - absorbent of the incident solar energy

Glazing cover - a transparent layer that transmits radiation to the absorber, but prevents radiative and convective heat loss from the surface

Tubes containing heating fluid to transfer the heat from the collector

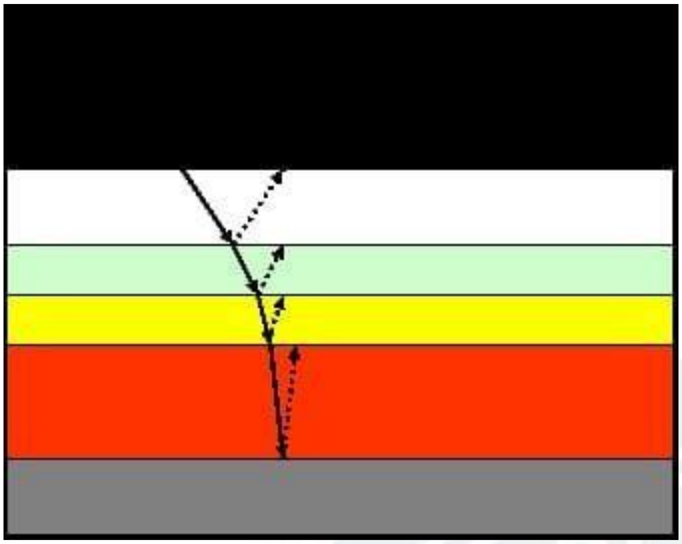
Support structure to protect the components and hold them in place

Insulation covering sides and bottom of the collector to reduce heat losses

The flat-plate systems normally operate and reach the maximum efficiency within the temperature range from 30 to 80 oC (Kalogirou, 2009), however, some new types of collectors that employ vacuum insulation can achieve higher temperatures (up to 100 oC). Due to the introduction of selective coatings, the stagnant fluid temperature in flat-plate collectors has been shown to reach 200 oC.

Optical Characteristics

In this section we will deal with the optical aspects of the materials used in solar cells. Generally, solar cells are built from different elements, and beside their electric importance most of them also have to fulfill important optical requirements.



The figure shows a typical stack of the active layers in a solar cell. The incident light first strikes the encapsulation (not shown), ususally consisting of a glass plate and some orgainc glue. The first active functional layer of a solar cell is the antireflection coating. Its job is the minimisation of reflection losses by means of optical interference.

The next element is the front contact. This layer must combine high optical transparency with high electric conductivity, two properties which normally exclude each other. Electric conduction is usually observed in metals but they are not transparent. However, highly doped semiconductors are transparent for light with energy less than the bandgap and they can transport certain amounts of current. For transmission of visible light we need either bandgaps of more than 3 eV or low absorption coefficients like those of indirect semiconductors, e.g. silicon. For heterojunction devices oxides like ZnO and SnO2 are used due to their high bandgaps and easy dopability.

The next layer on the way into the solar cell is the n-layer, a vital part of the pn-junction. Usually it is intended to avoid absorption in the n-layer, thus, also this layer should consist of a wide bandgap semiconductor or one with low absorption.

Further on the light enters the p-layer where the absorption takes place. Direct bandgaps are a good choice because they have high absorption coefficients and allow for thin absorbers and a low material input. Indirect bandgap abosorbers like silicon require thick absorbers or light trapping techniques. The absorbed photons create electron hole pairs, the electric field of the pn-junction separates them and directs them to the electric contacts. It is particularly important to ensure a reasonable transport of the photo generated minority charge carriers because they dominate the electric behaviour of the pn-junction. In most semiconductors the mobility is higher for electrons than for holes, thus, the absorber should be p-type.

Finally, if light has not been absorbed and reaches the back contact, it should be reflected back into the absorber. Thus, the back contact must be a good electric contact and a good optical reflector. Recently, in thin film solar cells transparent back contacts have attracted much attention, they allow for bifacial illumunation or the application of separate, highly reflecting mirrors.

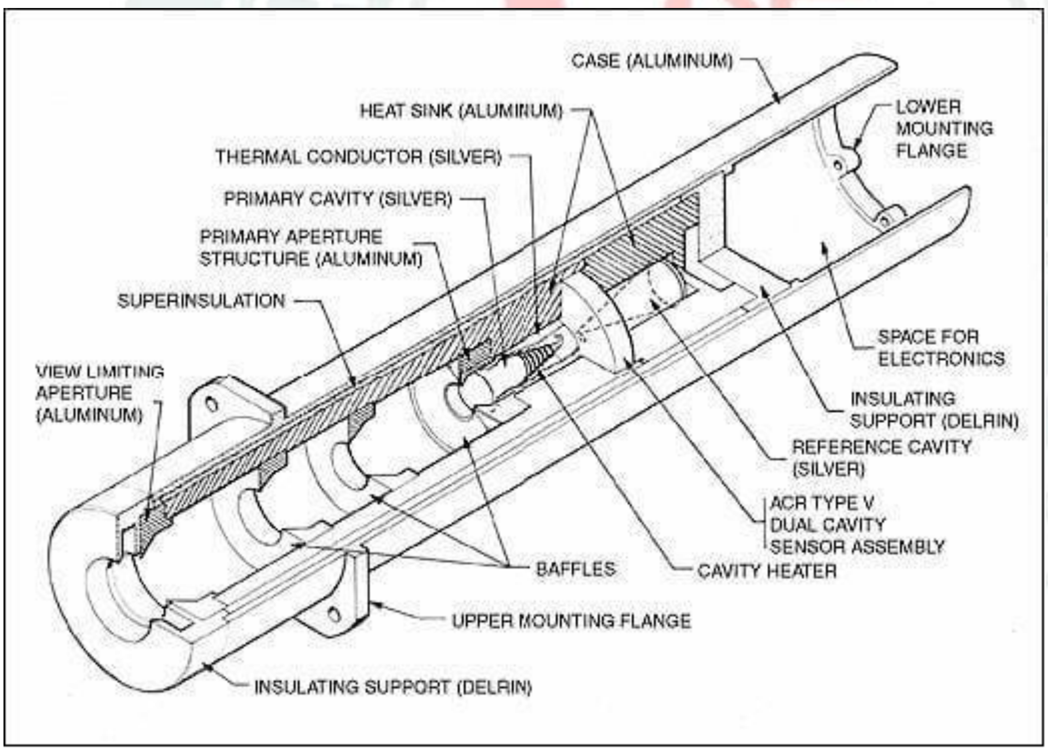
Device Types

Solar radiation is measured by some type of radiometer. Meteorologists and climatologists use various types of radiometers depending upon the type of solar radiation they intend to measure.

Pyranometers

Pyranometers measure hemispherical solar irradiance, or broadband solar radiation within a 180-degree field of view; this may be considered the global solar radiation of a given hemisphere.

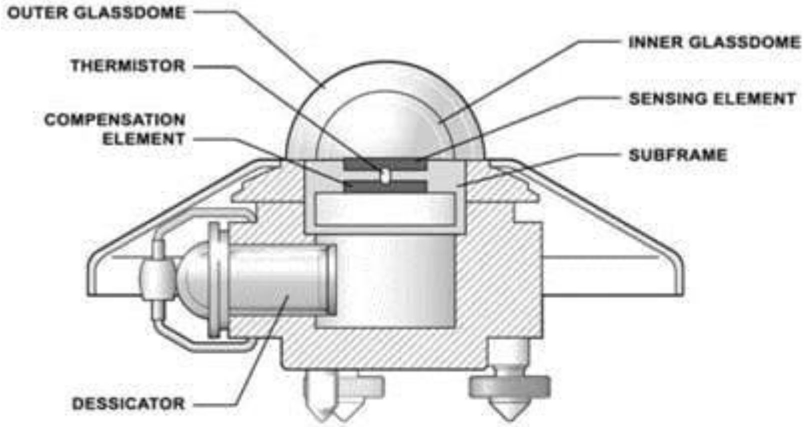
A typical analog pyranometer does not require power to operate and consists of a thermopile sensor beneath a glass dome. The thermopile absorbs all the solar radiation which encounters it and generates a small, proportional output voltage. Pyranometers are typically used on or near solar panels to facilitate optimum panel positioning.



Pyrheliometers

Pyrheliometers are similar to pyranometers, but they are designed to measure only direct beam solar irradiance. To this end they are occasionally used in identical pyranometer applications, but are also used with solar tracking systems to ensure the system is consistently aimed toward the sun. The device itself is often mounted directly on the tracking system so that it is always measuring direct beam sunlight.

Sunlight enters pyrheliometers through an integral lens, which projects sunlight onto a thermocouple within the device. Most pyrheliometers can convert a thermopile's small voltage output into watts per square meter and either output or record this data.



<u>Quantum Sensors</u>

Quantum sensors are specialized devices which measure the quantity of photosynthetically active radiation — or the portion of the visible spectrum which can be used by photosynthetic organisms — within a band of solar radiation. Specifically, quantum sensors measure the photosynthetic photon flux density (PPFD) of sunlight. This measurement is useful in agriculture for choosing productive farmland locations or maintaining growhouses, and is also used in oceanography to calculate the boundaries of an ocean's sunlight zone. (For the latter reason, quantum sensors are often built with waterproof housing.)

Quantum sensors typically use photovoltaic technology to generate a potential output.

Low-Temperature Applications of Solar Energy

Swimming Pool Heating

You can significantly reduce swimming pool heating costs by installing a solar pool heater. They're cost competitive with both gas and heat pump pool heaters, and they have very low annual operating costs. Actually, solar pool heating is one of the most cost-effective use of solar energy in some climates.

How They Work

Most solar pool heating systems include the following:

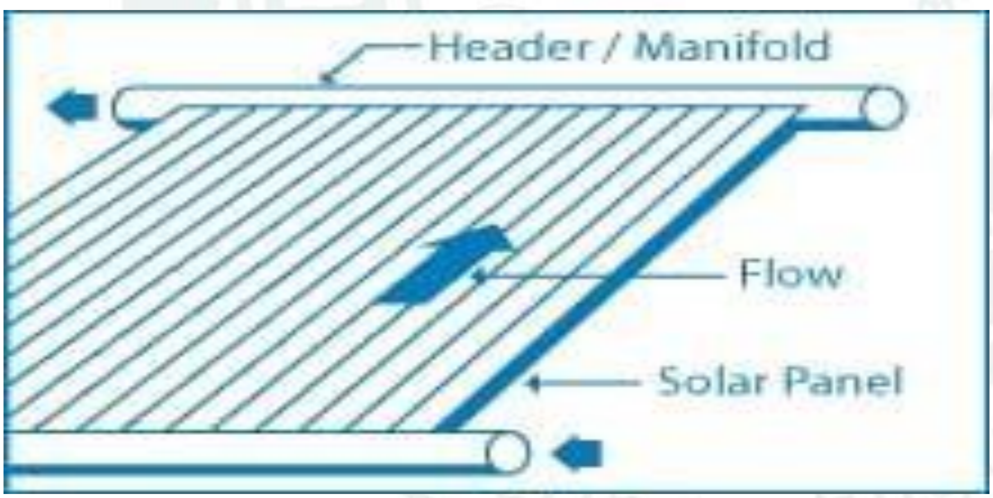
A solar collector - the device through which pool water is circulated to be heated by the sunAn illustration of a solar panel. A tube is at each end of the panel, and arrows show the flow going through one tube, across the panel, and out the end of the other tube, which is labeled the header/manifold.

A filter -removes debris before water is pumped through the collector

A pump - circulates water through the filter and collector and back to the pool

A flow control valve - Automatic or manual device that diverts pool water through the solar collector.

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



Solar water Heating Systems

Sometimes called solar domestic hot water systems can be a cost-effective way to generate hot water for your home. They can be used in any climate, and the fuel they use sunshine is free.

How They Work

Solar water heating systems include storage tanks and solar collectors. There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which don't.

Active Solar Water Heating Systems

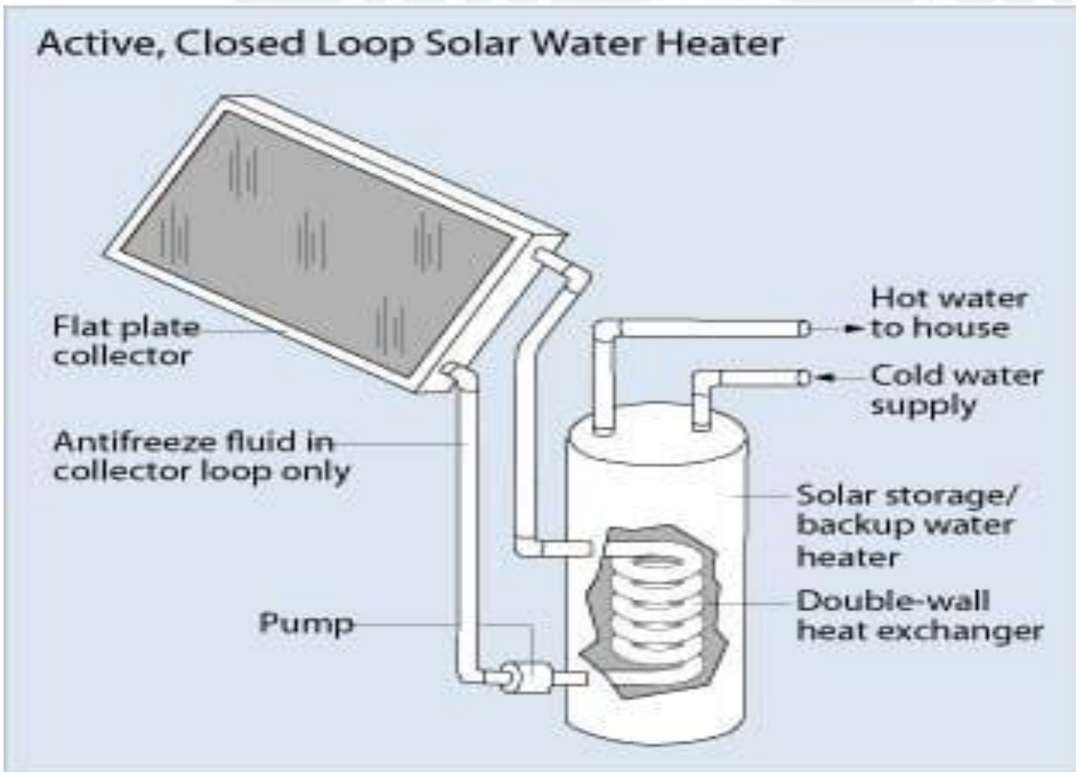
There are two types of active solar water heating systems:

Direct circulation systems

Pumps circulate household water through the collectors and into the home. They work well in climates where it rarely freezes.

Indirect circulation systems

Pumps circulate a non-freezing, heat-transfer fluid through the collectors and a heat exchanger. This heats the water that then flows into the home. They are popular in climates prone to freezing temperatures.



Natural Convection water Heating Systems

Passive Solar Water Heating Systems

Passive solar water heating systems are typically less expensive than active systems, but they're usually not as efficient. However, passive systems can be more reliable and may last longer. There are two basic types of passive systems:

Integral collector-storage passive systems

These consist of a storage tank covered with a transparent material to allow the sun to heat the water. Water from the tank then flows into the plumbing system. These work best in areas where temperatures rarely fall below freezing. They also work well in households with significant daytime and evening hot-water needs.

Thermosyphon systems

Water is heated in a collector on the roof and then flows through the plumbing system when a hot water faucet is opened. The majority of these systems have a 40 gallon capacity.

Storage Tanks and Solar Collectors

Most solar water heaters require a well-insulated storage tank. Solar storage tanks have an additional outlet and inlet connected to and from the collector. In two-tank systems, the solar water heater preheats water before it enters the conventional water heater. In one-tank systems, the back-up heater is combined with the solar storage in one tank.

Three types of solar collectors are used for residential applications:

Flat-plate collector

Glazed flat-plate collectors are insulated, weatherproofed boxes that contain a dark absorber plate under one or more glass or plastic (polymer) covers. Unglazed flat-plate collectors -- typically used for solar pool heating -- have a dark absorber plate, made of metal or polymer, without a cover or enclosure.

Integral collector-storage systems

Also known as ICS or batch systems, they feature one or more black tanks or tubes in an insulated, glazed box. Cold water first passes through the solar collector, which preheats the water. The water then continues on to the conventional backup water heater, providing a reliable source of hot water. They should be installed only in mild-freeze climates because the outdoor pipes could freeze in severe, cold weather.

Evacuated-tube solar collectors

They feature parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin's coating absorbs solar energy but inhibits radiative heat loss. These collectors are used more frequently for U.S. commercial applications.

<u>Solar Drying</u>

Solar energy can be used to increase temperatures needed for most of the drying applications. Solar dryers use air heated through solar energy collectors, which can be installed in modules according to the requirements of hot air.

Types of solar dryers

Integrated solar dryers

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

Distributed solar dryers

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

Mixed-mode solar dryers

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

Uses of solar dryer

Solar dryers can be utilized for various domestic purposes. They also find numerous applications in industries such as textiles, wood, fruit and food processing, paper, pharmaceutical, and agro-industries. Solar driers have the following advantages.

Solar dryers are more economical compared to dryers that run on conventional fuel/electricity.

The drying process is completed in the most hygienic and eco-friendly way.

Solar drying systems have low operation and maintenance costs.

Solar dryers last longer. A typical dryer can last 15-20 years with minimum maintenance.

Solar Pond

A solar pond is a solar energy collector, generally fairly large in size, that looks like a pond. This type of solar energy collector uses a large, salty lake as a kind of a flat plate collector that absorbs and stores energy from the Sun in the warm, lower layers of the pond.These ponds can be natural or man-made, but generally speaking the solar ponds that are in operation today are artificial.

How they Work

The key characteristic of solar ponds that allow them to function effectively as a solar energy collector is a salt-concentration gradient of the water. This gradient results in water that is heavily salinated collecting at the bottom of the pond, with concentration decreasing towards the surface resulting in cool, fresh water on top of the pond. This collection of salty water at the bottom of the lake is known as the "storage zone", while the freshwater top layer is known as the "surface zone". The overall pond is several meters deep, with the "storage zone" being one or two meters thick.

These ponds must be clear for them to operate properly, as sunlight cannot penetrate to the bottom of the pond if the water is murky. When sunlight is incident on these ponds, most of the incoming sunlight reaches the bottom and thus the "storage zone" heats up. However, this newly heated water cannot rise and thus heat loss upwards is prevented. The salty water cannot rise because it is heavier than the fresh water that is on top of the pond, and thus the upper layer prevents convection currents from forming. Because of this, the top layer of the pond acts as a type of insulating blanket, and the main heat loss process from the storage zone is stopped. Without a loss of heat, the bottom of the pond is warmed to extremely high temperatures - it can reach about 90°C. If the pond is being used to generate electricity this temperature is high enough to initiate and run an organic Rankine cycle engine.

It is vital that the salt concentrations and cool temperature of the top layer are maintained in order for these ponds to work. The surface zone is mixed and kept cool by winds and heat loss by evaporation. This top zone must also be flushed continuously with fresh water to ensure that there is no accumulation of salt in the top layer, since the salt from the bottom layer diffuses through the saline gradient over time. Additionally, a solid salt or brine mixture must be added to the pond frequently to make up for any upwards salt loses.

Applications

The heat from solar ponds can be used in a variety of different ways. First, since the heat storing abilities of solar ponds are so great they are ideal for use in heating and cooling buildings as they can maintain a fairly stable temperature. These ponds can also be used to generate electricity either by driving a thermo-electric device or some organic Rankine engine cycle - simply a turbine powered by evaporating a fluid (in this case a fluid with a lower boiling point). Finally, solar ponds can be used for desalination purposes as the low cost of this thermal energy can be used to remove the salt from water for drinking or irrigation purposes.

Solar Thermal Power Plants

Introduction

Solar energy is the energy obtained by capturing heat and light from the Sun. Energy from the Sun is referred to as solar energy. Technology has provided a number of ways to utilize this abundant resource. It is considered a green technology because it does not emit greenhouse gases. Solar energy is abundantly available and has been utilized since long both as electricity and as a source of heat.

Solar technology can be broadly classified as −

Active Solar − Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Active solar is directly consumed in activities such as drying clothes and warming of air.

Passive Solar − Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

Energy Conversion

Conversion of Solar Energy

The solar energy is the energy obtained by capturing heat and light from the Sun. The method of obtaining electricity from sunlight is referred to as the Photovoltaic method. This is achieved using a semiconductor material.

The other form of obtaining solar energy is through thermal technologies, which give two forms of energy tapping methods.

The first is solar concentration, which focuses solar energy to drive thermal turbines.

The second method is heating and cooling systems used in solar water heating and air conditioning respectively.

The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below −

Absorption of energy carrying particles in Sun's rays called photons.

Photovoltaic conversion, inside the solar cells.

Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.

Conversion of the resultant DC to AC.

Solar Collection System

A solar collector is a device that collects and/or concentrates solar radiation from the Sun. These devices are primarily used for active solar heating and allow for the heating of water for personal use. These collectors are generally mounted on the roof and must be very sturdy as they are exposed to a variety of different weather conditions.

The use of these solar collectors provides an alternative for traditional domestic water heating using a water heater, potentially reducing energy costs over time. As well as in domestic settings, a large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants.

Thermal Storage for Solar Power Plants

One challenge facing the widespread use of solar energy is reduced or curtailed energy production when the sun sets or is blocked by clouds. Thermal energy storage provides a workable solution to this challenge.

In a concentrating solar power (CSP) system, the sun's rays are reflected onto a receiver, which creates heat that is used to generate electricity that can be used immediately or stored for later use. This enables CSP systems to be flexible, or dispatchable, options for providing clean, renewable energy.

Several sensible thermal energy storage technologies have been tested and implemented since 1985. These include the two-tank direct system, two-tank indirect system, and single-tank thermocline system.

TWO-TANK DIRECT SYSTEM

Solar thermal energy in this system is stored in the same fluid used to collect it. The fluid is stored in two tanks—one at high temperature and the other at low temperature. Fluid from the low-temperature tank flows through the solar collector or receiver, where solar energy heats it to a high temperature, and it then flows to the high-temperature tank for storage. Fluid from the high-temperature tank flows through a heat exchanger, where it generates steam for electricity production. The fluid exits the heat exchanger at a low temperature and returns to the low-temperature tank.

Two-tank direct storage was used in early parabolic trough power plants (such as Solar Electric Generating Station I) and at the Solar Two power tower in California. The trough plants used mineral oil as the heat-transfer and storage fluid; Solar Two used molten salt.

TWO-TANK INDIRECT SYSTEM

Two-tank indirect systems function in the same way as two-tank direct systems, except different fluids are used as the heat-transfer and storage fluids. This system is used in plants in which the heat-transfer fluid is too expensive or not suited for use as the storage fluid.

The storage fluid from the low-temperature tank flows through an extra heat exchanger, where it is heated by the high-temperature heat-transfer fluid. The high-temperature storage fluid then flows back to the high-temperature storage tank. The fluid exits this heat exchanger at a low temperature and returns to the solar collector or receiver, where it is heated back to a high temperature. Storage fluid from the high-temperature tank is used to generate steam in the same manner as the two-tank direct system. The indirect system requires an extra heat exchanger, which adds cost to the system.

This system will be used in many of the parabolic power plants in Spain and has also been proposed for several U.S. parabolic plants. The plants will use organic oil as the heat-transfer fluid and molten salt as the storage fluid.

Capacity Factor

The capacity factor is the fraction of time that a plant operates at full (or nominal, or rated) power; it is therefore given by(2) CF = λ τ SE P rated , SE being the electricity generated in a whole year with solar energy, being the conversion factor from kWh to J, and being the time (seconds) in one year.

SOLAR COOKER

We normally use a stove or an oven for cooking vegetables, meat and rice. Using a solar cooker, we cook the same things, but by using sunlight instead of gas or electricity. In the article, let us discuss the working and construction of a solar cooker. A **solar cooker** is a device which uses theenergy of direct sunlight to heat, cook or pasteurize drink and other food materials

Using Light to Cook

Sunlight isn't hot in and of itself. It is radiation generated by fluctuating electric and magnetic fields.

The sunlight to heat conversion occurs when the photons of light waves interact with molecules of the substance. The electromagnetic radiation emitted by the Sun possesses energyin them. When they strike, the energy causes the molecules of the matter to vibrate. The molecules get excited and jump to higher levels. This activity generates heat.

Working Principle

Concentrating Sunlight:

A mirror surface with high specular reflection is used to concentrate and channelise light fromthe sun into a small cooking space. The sunlight can be concentrated by several orders of magnitude, producing magnitudes high enough to melt salt and metal. For household solar cooking applications, such high temperatures are not required. Solar cookers available in the market are designed to achieve temperatures of 65^0C to 400^0C.

Converting Light Energy to Heat Energy:

The concentrated sunlight is focused onto a receiver such as a cooking pan. The interaction between the light energy and the receiver material helps to converts light into heat by a processcalled conduction. The conversion is maximised by making use of materials that conduct and retain heat. Pots and pans used in solar cookers should be matte black in colour to maximise theabsorption.

Trapping Heat Energy:

The occurrence of convection is reduced by isolating the air inside the cooker from the air outside. Using a glass lid on the pot enhances light absorption from the top of the pan and decreases the convection energy loss along with improving heat holding capacity of the cooker.The glazing taps the incoming sunlight but is opaque to escaping infrared thermal rays.

CLASSIFICATION

1. Direct Type : Use some solar energy concentrator to focus sunlight onto an area. Eg: Parabolic solar cooker

2. Indirect Type: A box covered with transparent material like glass. Employs greenhouse effect for cooking Eg: Solar box cooker

3. Advanced Type: The cookers use either a flat piece or focusing collector, which collect the solar heat and transfer this to the cooking vessel. Eg: Thermal storage solar cooker

Common Types Of Solar Cookers

• Box Cooker

• Panel Cooker

• Parabolic Cooker

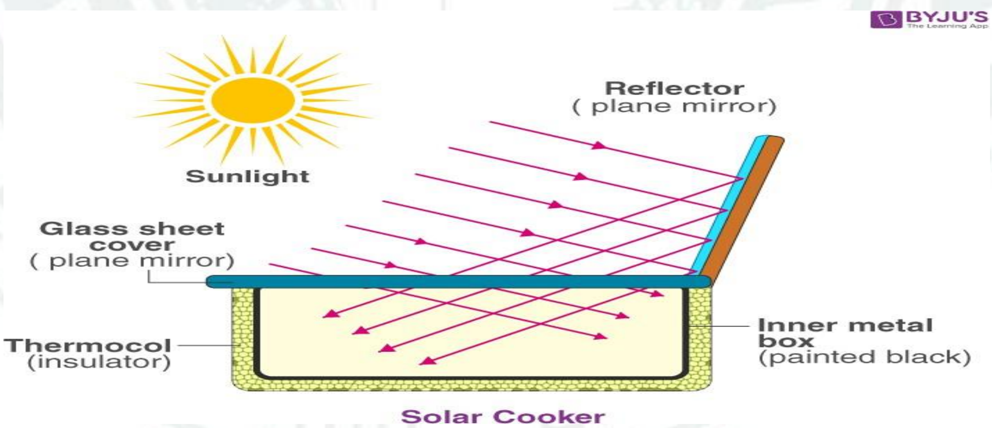
Box-Type Solar Cooker

The most commonly used form of solar cooker is the box-type solar cooker. In this section, wewill be discussing the construction and working principle of a box-type solar cooker.

A box-type solar cooker consists of the following components:

- **Black Box –** The box is an insulated metal or wooden box which is painted black from the inside to absorb more heat.
- **Glass Cover –** A cover made two sheets of toughened glass held together in an aluminium frame is used as a cove for box B.
- **Plane Mirror reflector –** The plane mirror reflector is fixed to the box B with the help of hinges. The mirror reflector can be positioned at any desired angle to the box. The mirror is positioned so as to allow the reflected sunlight to fall on the glass cover of the box.
- **Cooking Containers –** A set of aluminium containers blackened from the outside are kept in box B.

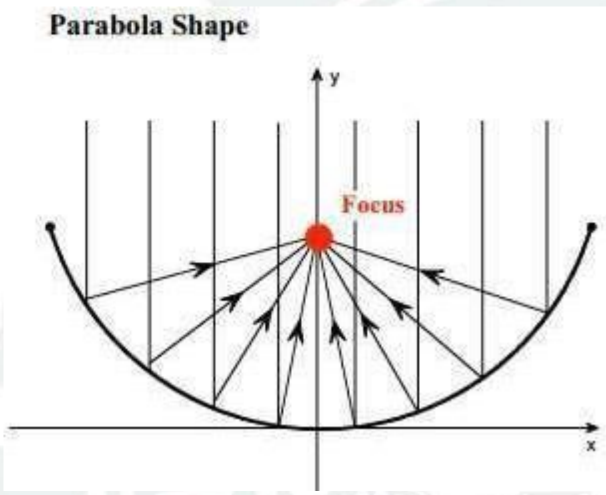
The solar cooker placed in sunlight and a plane mirror reflector is adjusted in a way such that thestrong beam of sunlight enters the box through the glass sheet. The blackened metal surfaces in the wooden box absorb infra-red radiations from the beam of sunlight and heat produced raises the temperature of a blackened metal surface to about 100°C.

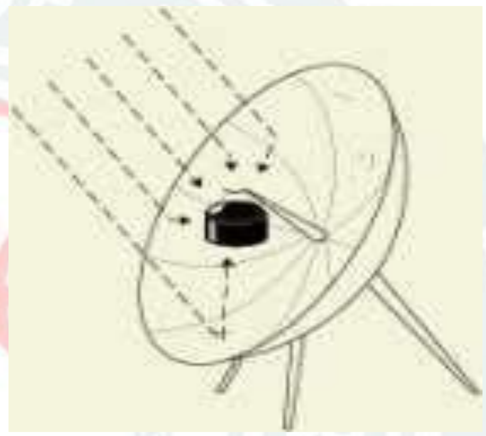


Parabolic Cooker

Parabolic solar cookers concentrate sunlight to a single point. When this point is focused on thebottom of a pot, it can heat the pot quickly to very high temperatures which can often be comparable with the temperatures achieved in gas and charcoal grills. These types of solar cookers are widely used in several regions of the world, most notably in China and India wherehundreds of thousands of families currently use parabolic solar cookers for preparing food andheating water.

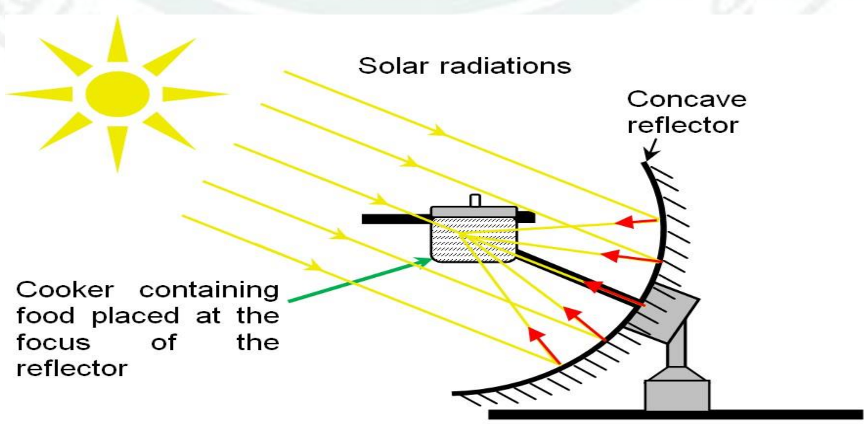
- It Focus a lot of sun energy onto a very small space, using parabolic shapes .
- It Works on the principle that when a 3D parabola is aimed at sun , the rays are reflected on to the focus.
- It Cooks nearly as fast as a conventional oven
- It Costly and complicated to make and use –have to turn frequently to follow the sun Consists of a large parabolic reflector and cooking pot holder.
- When the reflector surface is aimed at the sun , the rays falling on the parabolic surface converges to the focus of the parabola.
- The cooking pot is placed at the focus of the reflector.
- The pot surfaces are blacked to improve the absorption.





Spherical Reflector Type Solar Cooker

A spherical reflector type solar cooker consists of a large spherical (concave) reflector which reflects the sun's energy to a single focus point due to which a high temperature is produced inthe focus area. Since, a spherical reflector type solar cooker reflects and concentrates the heat energy of sunlight into a small area; it is referred as solar concentrator. As much higher temperature is produced in spherical reflector type solar cooker as compared to box type solarcooker, so they are used to cook those food materials which require strong heating.



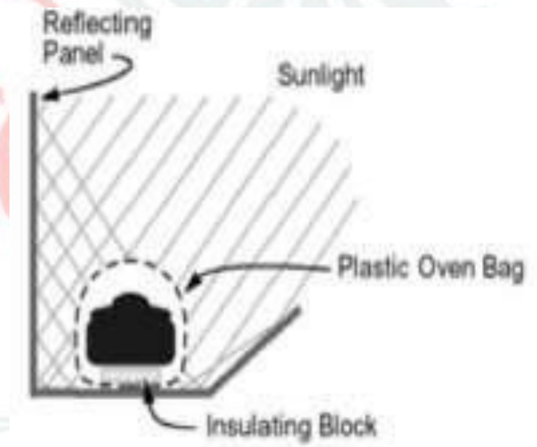
Spherical reflector type solar cooker

To cook food by this cooker the position of spherical reflector is adjusted in such a manner that it receives maximum sun rays. When sun rays fall on spherical reflector, they get reflected and concentrated at the focus point and produce very high temperature. Now, the cooking utensil containing raw food is placed at the focus of the cooker with the help of a stand. The temperature produced in solar concentrator is usually in the range of 180^0C to 200^0C depending on its size andthe quality of reflecting surface

Panel Cooker

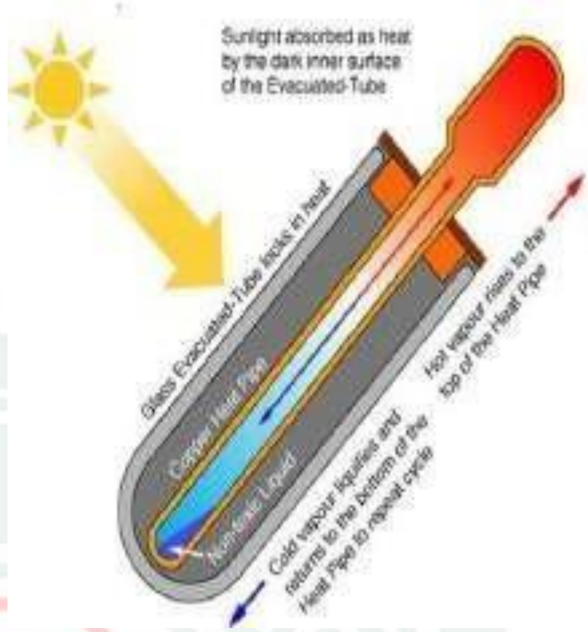
In this type of cooker Cooking pot is enclosed by a panel of reflectors..unlight is reflected off of multiple panels onto a pot under a glass lid or in a bag .It Can be built quickly and at low cost. Many different varieties are available.

WORKING -It incorporates elements of both parabolic andmbox solar cookers.The reflective panel directs sunlight onto a dark colored pot. The pot is enclosed in an insulating shell such ashigh temperature cooking bag or an inverted bowl.Can attain temperatures in the range of 95 –125 oC.



VACCUM OR EVACUATED TUBE SOLAR COOKER

The design is a simple flat plate collector housed in an evacuated glass tube.The tubes are made from a type of glass called Borosilicate, which is resistant to thermal shock. Borosilicate glass hasthe characteristic of being very strong and also has excellent light transparency.



It consists of two concentric glass tubes with vacuum in between. The outer tube is transparent while the inner is coated with Aluminium nitride for better absorption. The evacuated glass tubetube receives the solar rays that pass through and is absorbed by the inner lining. The combination of the highly efficient absorber coating and the vacuum insulation means that the coating can be well over 200o C. Due to the presence of vacuum , the heat losses will be negligible.A reflector is provided for concentrating sunlight onto the tubes.A tray is provided inside the glass tube for cooking purposes.

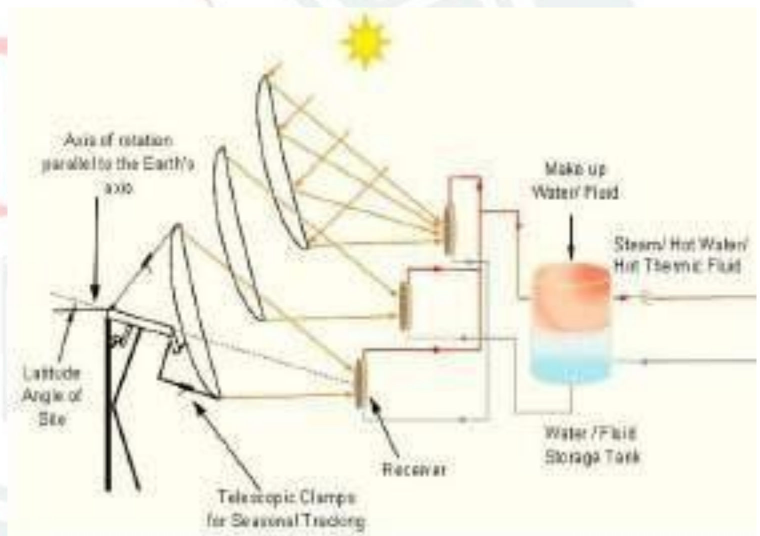
COMMUNITY SOLAR COOKER

Cook using solar energy within the kitchen itself. Due to high temperature and power at focal point, the cooking rate is significantly higher. Cooking for about 40 to 50 persons is possible with7 sq. m,. size dish cooker. The most popular version is the scheffler community kitchen

HELIOSTAT

A device that reflects sunlight in a fixed direction as the sun moves is known as a Heliostat. The heliostats are mirrors with solar tracking on two axes and capable of concentrating the reflected solar radiation on a focal point. Heliostats are generally made from iron glass. Scheffler heliostats are used for community solar cookers. A Scheffler reflector is a small lateral section of a paraboloid which concentrates sun's radiation over a fixed focus. The collector of Scheffler Dish isan assembly of flat shaped solar grade glass mirrors or Aluminium mirror reflectors arranged on a structural steel framework. The receiver of scheffler dish is placed at the focus of the dish to capture the incident solar radiation and transfer it to the thermal medium. Tracking system enables the dish to be focused towards the sun to capture maximum possible direct radiation during the day. It Consists of heliostat and secondary reflector. Heliostat concentrates the beam on to the secondary reflector which focuses it on

to the bottom of pot. When not cooking the energy can be used for heating water or can be stored. The Sai Baba temple complex at Shirdi, Maharashtra's Ahmednagar district, has installed one of the world's largest solar cooking system based on schfeller dishes.The solar rays are used to heat up water to generate steam which is directed through pipes in to steam cookers to cook food .The steam cooked food along with food cooked with LPG is enough to feed 50,000 persons a day. The system saves 242kg of cooking gas



Advantages

- High-performance parabolic solar cookers and vacuum tube cookers can attain temperatures above 290 °C (550 °F). They can be used to grill meats, stir-fry vegetables, make soup, bake bread, and boil water in minutes. Vacuum tube type cookers can heat up even in the clouds and freezing cold.
- Conventional solar box cookers attain temperatures up to 165 °C (325 °F). They can sterilize water or prepare most foods that can be made in a conventional oven or stove, including bread, vegetables and meat over a period of hours.

- Solar cookers use no fuel. This saves cost as well as reducing environmental damage caused by fuel use. Since 2.5 billion people cook on open fires using biomass fuels, solar cookers could have large economic and environmental benefits by reducing deforestation.
- When solar cookers are used outside, they do not contribute inside heat, potentially saving fuel costs for cooling as well. Any type of cooking may evaporate grease, oil, and other material into the air, hence there may be less cleanup.
- Reduces your carbon footprint by cooking without the use of carbon based fuels or grid electricity from traditional sources.

Disadvantages

- Solar cookers are less useful at night, in cloudy weather and near the poles, where the sun is low in the sky, so an alternative cooking source is still required in these conditions. Solar cooking advocates suggest three devices for an integrated cooking solution: a) a solar cooker; b) a fuel-efficient cookstove; c) an insulated storage container such as a basket filled with straw to store heated food. Very hot food may continue to cook for hours in a well-insulated container. With this three-part solution, fuel use is minimized while still providing hot meals at any hour, reliably.
- Some solar cookers, especially solar ovens, take longer to cook food than a conventional stove or oven. Using solar cookers may require food preparation start hours before the meal. However, it requires less hands-on time during the cooking, so this is often considered a reasonable trade-off.
- Cooks may need to learn special cooking techniques to fry common foods, such as fried eggs or flatbreads like chapatis and tortillas. It may not be possible to safely or completely cook some thick foods, such as large roasts, loaves of bread, or pots of soup, particularly in small panel cookers; the cook may need to divide these into smaller portions before cooking.
- Some solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food due to convective losses, and disturb the reflector. It may be necessary to anchor the reflector, such as with ring and weighted objects like bricks.

E GY FROM WIND

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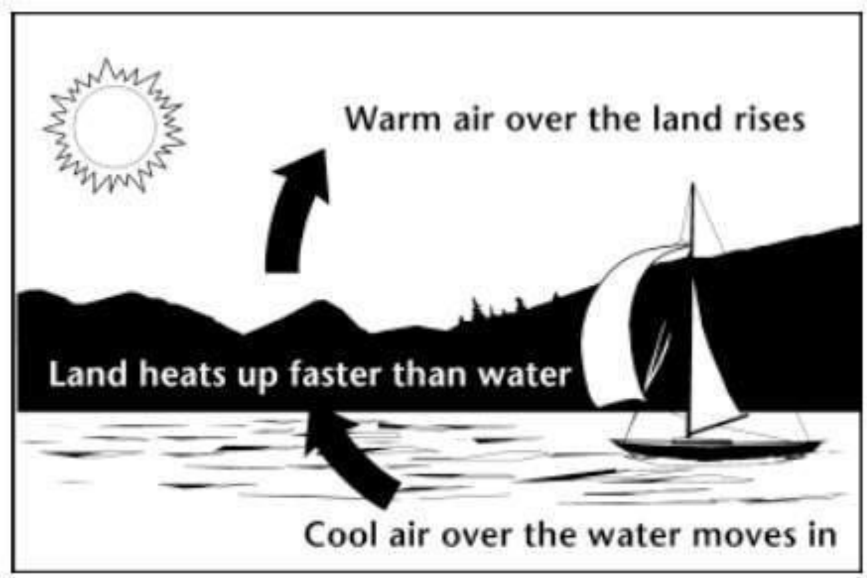
Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by thesun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates.



During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun thanthe land near the North and South Poles. Today, wind energy is mainly used to generate electricity. Wind is called a renewable energy source because the wind will blow as long asthe sun shines.

Or we can say Wind results from the movement of air due to atmospheric pressure gradients. Wind fl ows from regions of higher pressure to regions of lower pressure. The larger the atmospheric pressure gradient, the higher the wind speed and thus, the greaterthe wind power that can be captured from the wind by means of wind energy-converting machinery. The generation and movement of wind are complicated due to a number of factors. Among them, the most important factors are uneven solar heating, the Coriolis
effect due to the earth's self-rotation, and local geographical conditions.

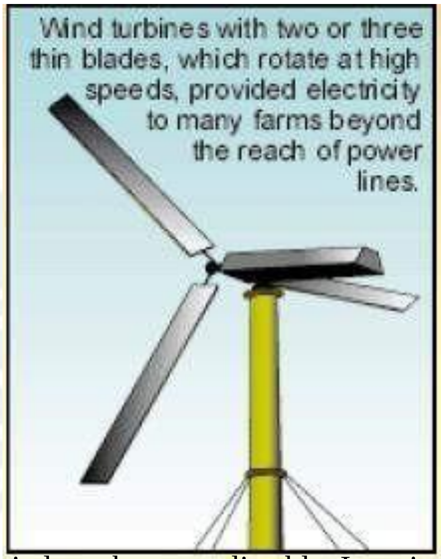
The History of Wind

Since ancient times, people have harnessed the winds energy. Over 5,000 years ago, the ancient Egyptians used wind to sail ships on the Nile River. Later, people built windmills togrind wheat and other grains. The earliest known windmills were in Persia (Iran). These early windmills looked like large paddle wheels. Centuries later, the people of Holland improved the basic design of the windmill. They gave it propeller-type blades, still made with sails. Holland is famous for its windmills. American colonists used windmills to grind wheat and corn, to pump water, and to cut wood at sawmills. As late as the 1920s, Americans used small windmills to generate

History of Wind-Mills:

- The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas.
- The wind has played an important role in the history of human civilization . The first known use of wind dates back 5,000 years toEgypt, where boats used sails to travel from shore to shore.
- The first true windmill, a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. In ancient Babylon. By the 10th century A.D., windmills with wind-catching surfaces having 16 feet length and 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan.
- The earliest written references to working wind machines in western world date from the 12th century.These too were used for milling grain. It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea.The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century.
- In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export.
- Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives.
- Farm windmills are still being produced and used, though in reduced numbers. They are best suited for pumping ground water in small quantities to livestock water tanks.
- In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb.
- By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines. Wind turbine development lay nearly dormant for the next 20 years

A typical modern windmill looks as shown in the following figure.The wind-mill contains three blades about a horizontal axis installed on a tower.A turbine connected to a generator is fixed about thehorizontal axis



Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible, it is not easily measured without special instruments. Wind velocity is affected by the trees, buildings, hills and valleys around us.Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time. Like old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmills work because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effecton airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

wind energy conversion system

A wind energy conversion system is an apparatus for converting the kinetic energy available in the wind to mechanical energy that can be used to power machinery.The most modern generations of windmills are more properly called wind turbines, or wind generators, and are primarily used to generate electricity and electrical energy. Modern windmills are designed to convert the energy of the wind into electricityLike old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmillswork because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effect on airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity. The major components of a typical wind energy conversion system include a wind turbine, a **generator**, interconnection apparatus, and control systems. At the present time and for the near future, generators for wind turbines will be synchronous generators, permanent magnet synchronous generators, and **induction generators**, including the squirrel-cage type and wound rotor type. For small to medium power wind turbines, permanent magnetgenerators and squirrel-cage induction generators are often used because of their reliability and cost advantages. Induction generators, permanent magnet synchronous generators, and wound field synchronous generators are currently used in various high p

Interconnection apparatuses are devices to achieve power control, soft start, and interconnection functions. Very often, power electronic converters are used as such devices. Most modern turbine inverters are forced commutated PWM inverters to provide a fixed voltage and fixed frequency output with a high power quality. Both voltage source voltage controlled inverters and voltage source current controlled inverters have been applied in wind turbines. For certain high power wind turbines, effective power control canbe achieved with double PWM (pulse-width modulation) converters which provide a bidirectional power flow between the turbine generator and the utility grid.ower wind turbines.

Wind turbines

A wind turbine is a machine which utilizes the kinetic energy of wind to produce rotational mechanical energy in its shaft. The rotational motion of the shaft turns an electrical generator to generate electricity. There are mainly two types of wind turbine available one is the horizontal axis type another is vertical axis type.

Types of wind turbine

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

1. Horizontal-axis wind turbine
   We call the wind turbines that have horizontal shaft as horizontal axis wind turbines. This is a horizontal axis: a propeller-style design with blades that rotate around a horizontal axis. Horizontal axis turbines are either upwind (the wind hitsthe blades before the tower) or downwind (the wind hits the tower before the blades). Most wind machines being used today are the horizontal-axis type.
   Horizontal-axis wind machines have blades like airplane propellers. A typical horizontal wind machine stands as tall as a 20-story building and has three bladesthat span 200 feet across. The largest wind machines in the world have blades longer than a football field! Wind machines stand tall and wide to capture more wind.

Horizontal axis wind turbine can be further divided into three types:

- Dutch type grain grinding wind mills
- Multi blade water pumping windmills
- High speed propeller type windmills

Dutch Windmill:

Man has used Dutch windmills for a long time. In fact the grain grinding windmills that were widely used in Europe since the middle ages were Dutch. These windmills were operated on the thrust exerted by the wind. The blades, generally four, were inclined at anangle to the plane of rotation. The wind being deflected by the blades exerted a force in thedirection of rotation. The blades were made of sails or wooden slats.

Multiblade Water Pumping Windmill:

Modern water pumping windmills have a large number of blades- generally wooden or metallic- driving a reciprocating pumps. As the mill has to be placed directly over the well, the criterion for site selection concerns about water availability & not windiness. Thereforethe mill must be able to operate at slow winds. The large number of blades gives a high torque, required for driving a centrifugal pump, even at low wind speeds. Hence sometimesthese are called as fan mills. As these windmills are supposed to be installed at remote places, mostly as single units, reliability, sturdiness, and low cost are the prime criteria andnot efficiency. The blades are made of flat steel plates, working on the thrust of wind. Theseare hinged to a metal ring to ensure structural strength, and the low speed of rotation addsto the reliability. The orientation is generally achieved by tail vane.

High speed propeller type wind machines:

The horizontal axis wind turbines that are used today for electricity generation do not operate on thrust force. They depend mainly on the aerodynamic forces that develop whenwind flows around a blade of aerofoil design. Windmills working on thrust force are inherently less efficient. So all the modern wind turbine blades are designed based on aerofoil section.

Vertical axis wind turbines:

There is another type of wind turbine which uses vertically aligned rotating shaft. We call this turbine Vertical Axis Wind Turbines or VAWTs. As it has the vertical axis, it does not have to align itself with the wind and hence using these turbines are more suitable where the direction of wind significantly varies. We can install this turbine even on the rooftop since the height of this turbine is much lesser than that of HAWT. Another significant advantage is that as the shaft is vertical, we can extend it to the bottom level where we cancouple a generator with the vertical shaft with the help of ground-based gearbox which facilitates easier maintenance.

Vertical axis wind turbine It comes in two different designs

- The savonius rotor
- The darrieus rotor

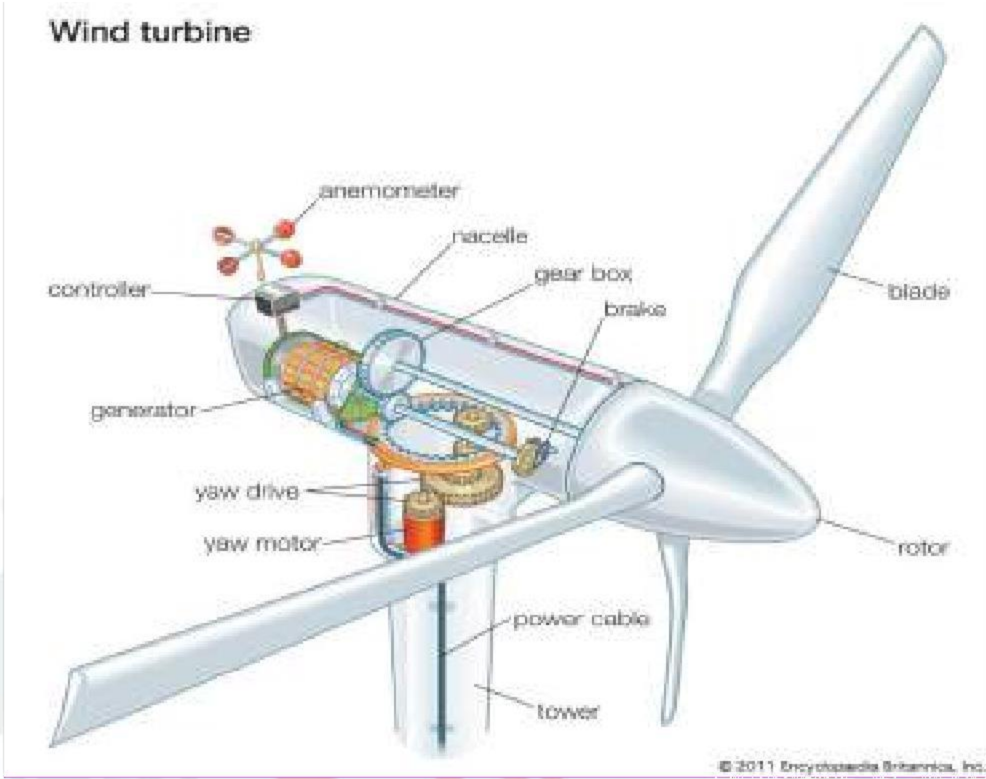
The savonius rotor:

The savonius rotor is extremely simple vertical axis device that works entirely because of the thrust force of wind. The basic equipment is a drum cut in two halves vertically. The two parts are attached to the two opposite sides of a vertical shaft. As the wind blowing into the structure meets with two dissimilar surfaces – one convex and the other concave – the forces exerted on the two surfaces are different, which gives the rotor a torque. By providing a certain amount of overlap between the two drums, the torque can be increased.This is because the wind blowing into the concave surface turn around and give a push to the inner surface of the other drum, partly cancelling the wind thrust on the convex side. It has been found that an overlap of about one third the drum diameter gives optimum result.

The darrieus wind turbine:

The particularity of Darrieus rotor is that its working is not at all evident from its appearance. Two or more flexible blades are attached to a vertical shaft. The blades bow outwards, taking approximately the shape of a parabola and are of symmetrical airfoil section. Here the torque is zero when the rotor is stationary. It develops a positive torqueonly when it is already rotating. This means that such a rotor has mo starting torque and has to be start using some external means.

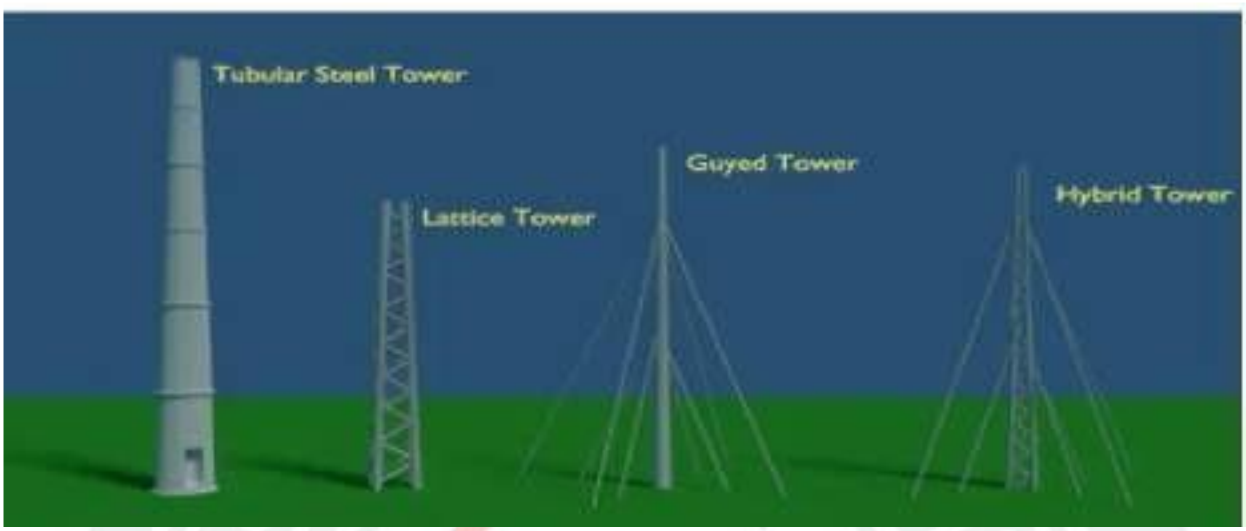
Major Parts of Wind Turbine



Tower of Wind Turbine

Tower is very crucial part of wind turbine that supports all the other parts. It not only supports the turbine but raises the turbine to sufficient height so that its blades tips would be at safe height during rotation. Not only that, we have to maintain the height of the tower,so that it can get sufficiently strong wind. The height of tower ultimately depends on the power capacity of wind turbines. The tower of the turbines in commercial wind power plants usually ranges from 40 meters to 100 meters. These towers may be either tubular steel towers, lattice towers, or concrete towers. We use a tubular steel tower for a large wind turbine. These are normally manufactured in a section of 30 to 40 meters in length.

Each section has flanges with holes. Such sections are fitted together by nut bolts at the siteto form a complete tower. The complete tower is slight conical shape to provide better mechanical stability. We assemble a lattice tower by different members of steel or GI anglesor tubes. All members are bolted or welded together to form a complete tower of desired height. The cost of these towers are much less than that of steel tubular tower, but it aesthetically looks not as good as steel tubular tower. Although, transportation, assembling,and maintenance are quite easy but still use of lattice tower is avoided in modern wind turbine plant due to its aesthetic look. There is another type of tower used for small wind turbines, and this is guyed pole tower. Guyed pole tower is a single vertical pole supported by guy wired from different sides. Because of numbers of guy wires, it is difficult to access the footing area of the tower. Because of that, we avoid this type of tower in the agricultural field. There is another type of wind turbine tower used for small plant, and this is a hybridtype tower. Hybrid type tower is also a guyed type tower, but the only difference is that instead of using a single pole in the middle it uses a thin and tall lattice type tower. Hybridtype tower is hybrid of both lattice type and guyed type tower.



Nacelle of Wind Turbine

The nacelle is a big box or kiosk that sits on the tower and houses all the **components of a wind turbine**. It houses an electrical generator, power converter, gearbox, turbine controller, cables, a yaw drive**.**

Rotor Blades of Wind Turbine

Blades are the main mechanical parts of a wind turbine. The blades convert wind energy into usable mechanical energy. When the wind strikes on the blades, the blades rotate. Thisrotation transfers its mechanical energy to the shaft. We design the blades like airplane wings. The wind turbine blades can be 40 meters to 90 meters long. The blades should be mechanically strong enough to withstand strong wind even during the storm. At the same time, the wind turbine blades should be made as light as possible to facilitate smooth rotation of the blades. For that, we make the blades with fiberglass and carbon fiber layers on synthetic reinforce.In a modern turbine, normally three identical blades are fitted to a central hub using nut bolts. Each identical blades are aligned at 120^{o} to each other. The process makes a better distribution of mass and gives the system more smooth rotation.

Shaft of Wind Turbine

The shaft directly connected to the hub is a low-speed shaft. When the blades rotate, this shaft spins with the same rpm as the rotating hub. We couple this shaft directly to the electrical generator in case of a low-speed generator. But in most cases, the low-speed mainshaft is geared with a high-speed shaft through a gearbox. In this way, the rotor blades transfer its mechanical energy to the shaft which ultimately enters into an electrical generator**.**

Gearbox

The wind turbine does not rotate at high speed rather it rotates gently at low speed. But most of the electrical generators require high-speed rotation, to generate electricity at a desired voltage level. So there must be some speed multiplication arrangement to achievethe high speed of the generator shaft. The gearbox of the wind turbine does this. Gearbox increases the speed to much higher value. For example, if the gearbox ratio is 1:80 and if the rpm of a low-speed main shaft is 15, the gearbox will increase the speed of generator shaft to $15 \times 80 = 1200$ rpm

Generator

The generator is an electrical device that converts mechanical energy received from the shaft into electrical energy. Normally, we use induction generators in modern wind turbines. Previously, synchronous generators were popular for this purpose. Permanent Magnet DC generator also used in some wind turbines. The speed of the shaft can be made high by using gearbox assembly, but we can not make the shaft speed constant. There may be a fluctuation in shaft speed since it depends on wind speed. So, the speed of the rotor also varies. This variation affects the frequency, voltage of the generated electric power. To,overcome these issues, we normally use an induction generator for the purpose.

Because the induction generator always produces electric power synchronized to the connected grid irrespective of the speed of the rotor. If we use the three-phase synchronous generator, then we first rectify the output power to DC and then convert it to AC of desired voltage and frequency using inverter circuit. Because the alternating power generated by the synchronous generator is not constant in voltage and frequency, rather itvaries with speed of the rotor. Because, for the same reason, in some cases, we use a DC generator for the purpose. In these cases, the output DC power from generator inverted to AC of desired voltage and frequency, before feeding it to the grid

Power Converter Because wind is not always constant, so electrical potential generatedfrom a generator is not constant, but we need a very stable voltage to feed the grid. A power converter is an electrical device that stabilizes the alternating output voltage transferred to the grid.

Turbine Controller Turbine controller is a computer (PLC) that controls the entire turbine. It starts and stops the turbine and runs self diagnostic in case of any error in theturbine.

Anemometer It measures the wind speed and passes the speed information to PLC to control the turbine power.

Wind Vane It senses the direction of the wind and passes the direction to PLC then PLCfaces the blades in such a way that it cuts the maximum wind.

Pitch drive Pitch drive motors control the angle of blades whenever the wind changes itrotates the angle of blades to cut the maximum wind, which is called pitching of blades.

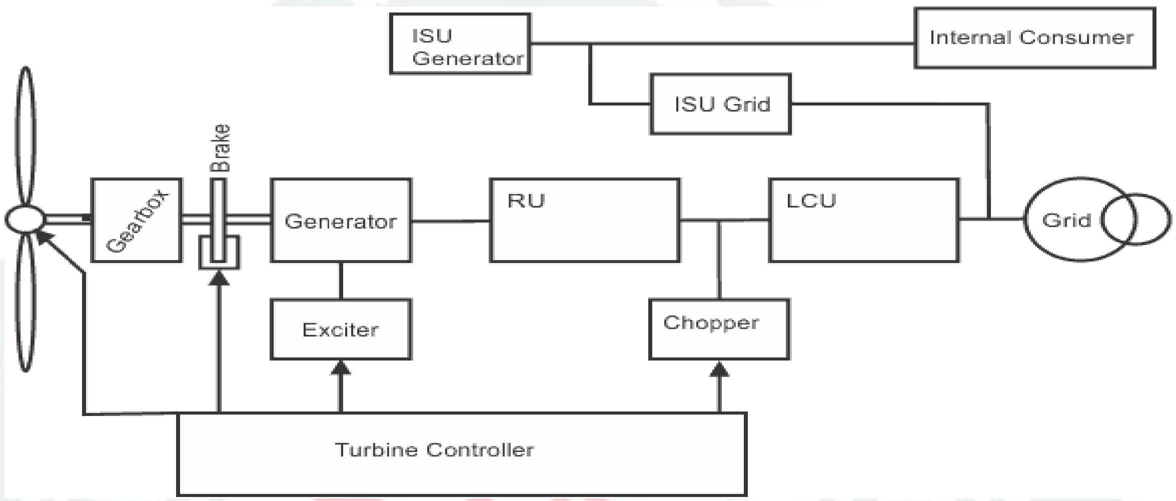
Yaw Drive Blades and other components in wind turbine are housed in a nacelle, whenever any change in wind direction is there, the nacelle has to face in the direction of the wind to extract the maximum energy from wind. For this purpose yaw drive, a motor isused to rotate the nacelle. It is controlled by PLC that uses the wind vane information to sense the wind direction.

Working of Wind Turbine

- When the wind strikes the rotor blades, blades start rotating. The turbine rotor is connected to a high-speed gearbox. Gearbox transforms the rotor rotation from low speed to high speed. The high-speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed.
- An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity.
- The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator.
- The speed is governed by wind power which is out of control. Hence to maintain uniformity of the output power from the alternator, excitation must be controlled according to the availability of natural wind power. The exciter current is controlled by a turbine controller which senses the wind speed.
- Then output voltage of electrical generator(alternator) is given to a rectifier where the alternator output gets rectified to DC. Then this rectified DC output is given to line converter unit to convert it into stabilized AC output which is ultimately fed to either electrical transmission network or transmission grid with the help of step up transformer.
- An extra units is used to give the power to internal auxiliaries of **wind turbine** (like motor, battery etc.), this is called Internal Supply Unit.
  There are other two control mechanisms attached to a modern big wind turbine.
  - Controlling the orientation of the turbine blade.
  - Controlling the orientation of the turbine face.
- The orientation of turbine blades is governed from the base hub of the blades. The blades are attached to the central hub with the help of a rotating arrangement through gears and small electric motor or hydraulic rotary system. The system can be electrically or mechanically controlled depending on its design. The blades are swiveled depending upon the speed of the wind. The technique is called pitch control. It provides the best possible orientation of the turbine blades along the direction of the wind to obtain optimized wind power.

- The orientation of the nacelle or the entire body of the turbine can follow the direction of changing wind direction to maximize mechanical energy harvesting from the wind. The direction of the wind along with its speed is sensed by an anemometer (automatic speed measuring devices) with wind vanes attached to the back top of the nacelle. The signal is fed back to an electronic microprocessor-based controlling system which governs the yaw motor which rotates the entire nacelle with gearing arrangement to face the air turbine along the direction of the wind.

An internal Block diagram of a wind turbine



AERODYNAMICS OF WIND TURBINES

What is aerodynamics?

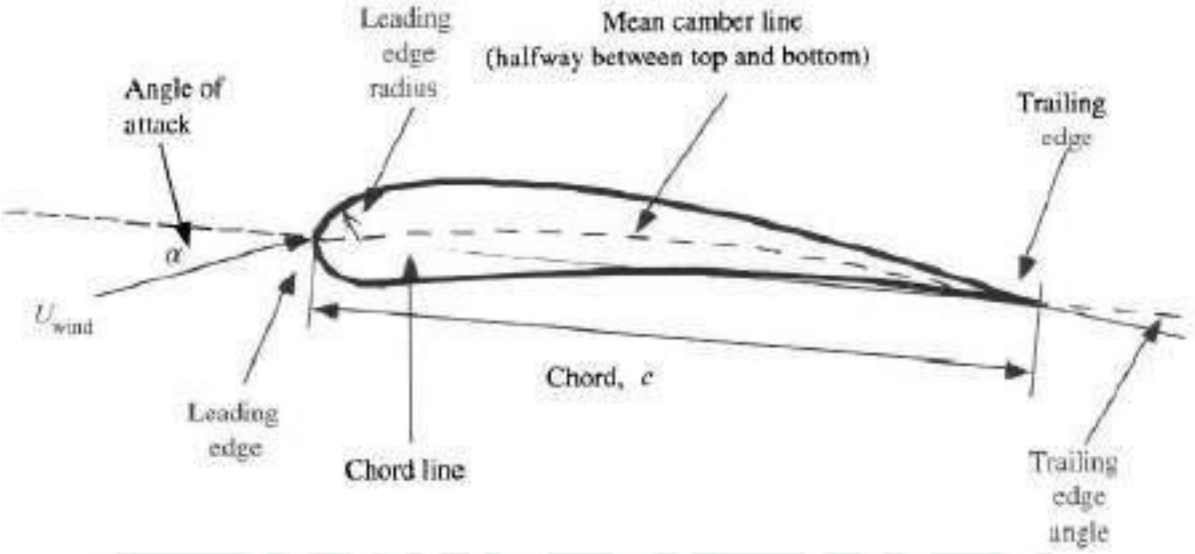
- A branch of dynamics- how things move under the action of forces.
- Aerodynamics is the study of motion of air and how it interacts with a moving or stationary object.
- Aerodynamics is a necessary tool for modeling the loads and power output of a wind turbine. A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade.
- When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

Airfoils and general aerodynamic concepts

- Wind turbine blades use airfoil sections to develop mechanical power.
- The width and length of the blades are a function of the desired aerodynamic performance and the maximum desired rotor power (as well as strength considerations).
- Before examining the details of wind turbine power production, some airfoil aerodynamic principles are reviewed here.

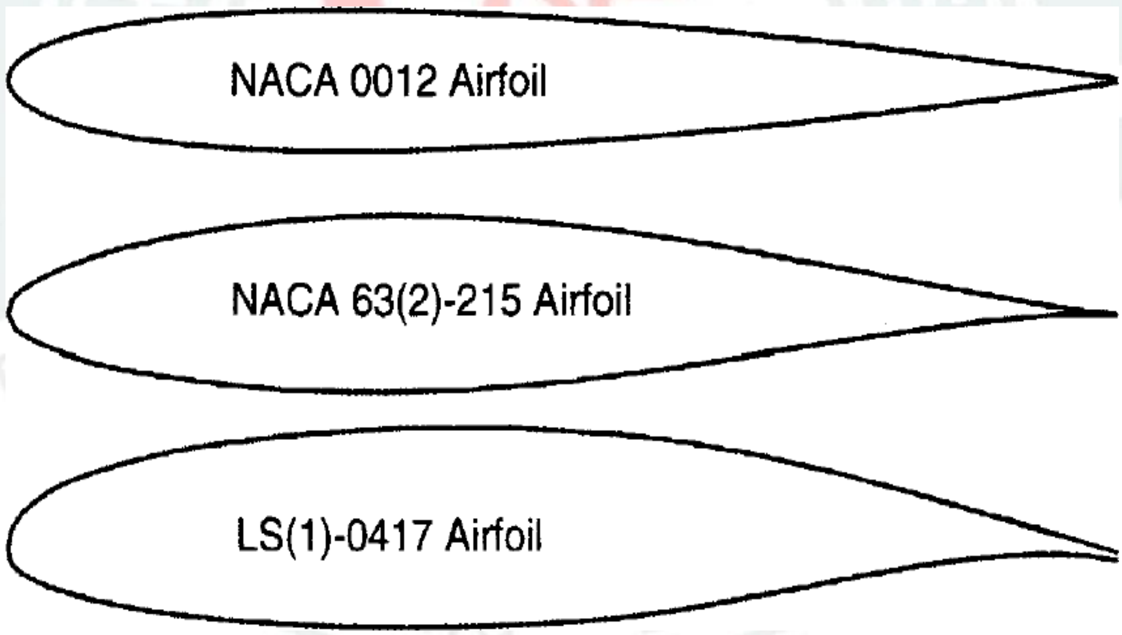
Basic airfoil terminology

- **Camber** = distance between mean camber line (mid-point of airfoil) and the chord line (straight line from leading edge to trailing edge)
- **Thickness** = distance between upper and lower surfaces (measured perpendicular to chord line)
- **Span** = length of airfoil normal to the cross-section



Examples of standard airfoil shapes

National Advisory Committee for Aeronautics



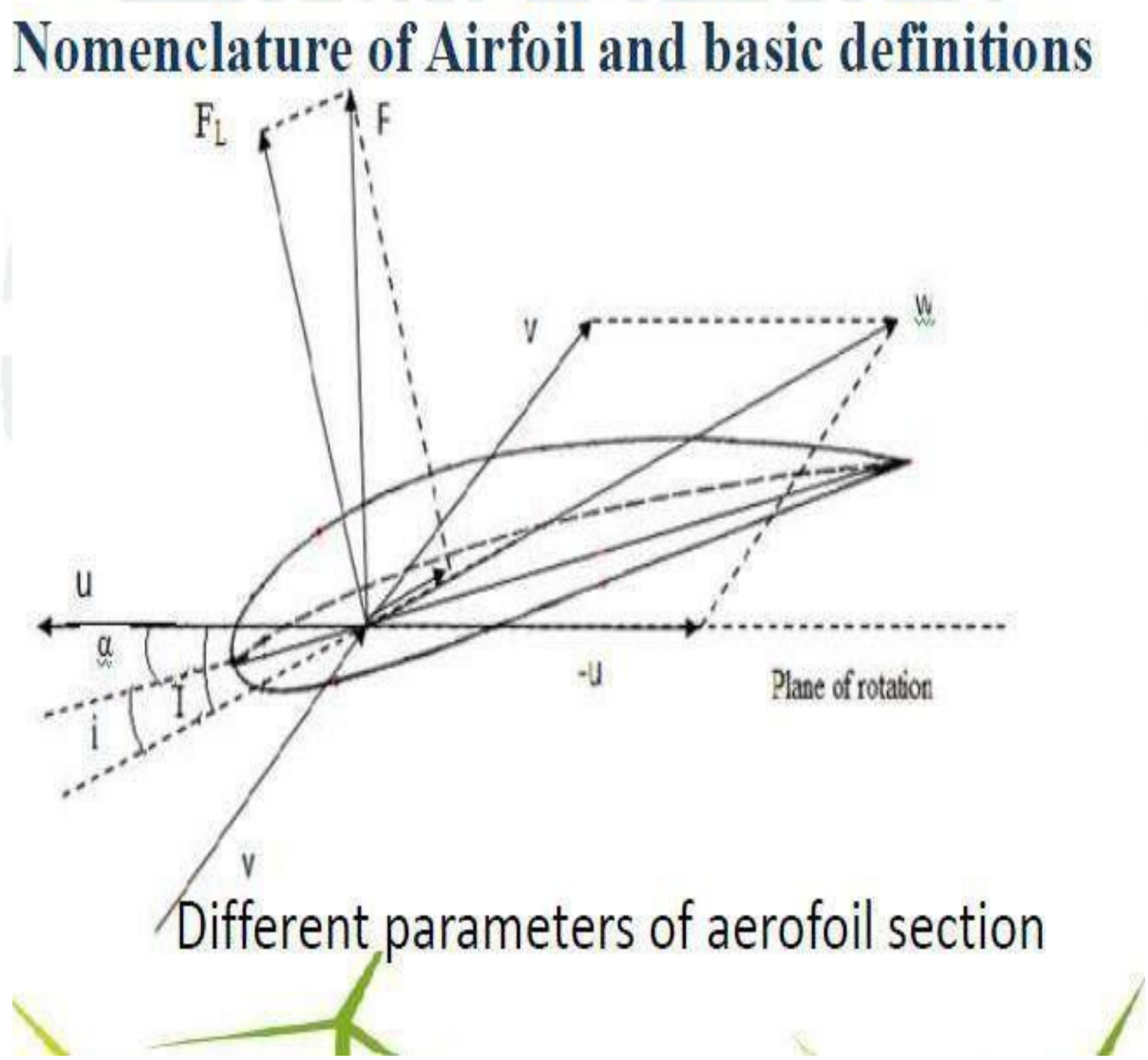
NACA 0012 = 12% thick symmetric airfoil

NACA 63(2)-215 = 15% thick airfoil with slight camber

LS(1)-0417 = 17% thick airfoil with larger camber

Lift, drag and non-dimensional parameters

- Airflow over an airfoil produces a distribution of forces over the airfoil surface.
- The flow velocity over airfoils increases over the convex surface resulting in lower average pressure on the 'suction' side of the airfoil compared with the concave or 'pressure' side of the airfoil.
- Meanwhile, viscous friction between the air and the airfoil surface slows the airflow to some extent next to the surface.



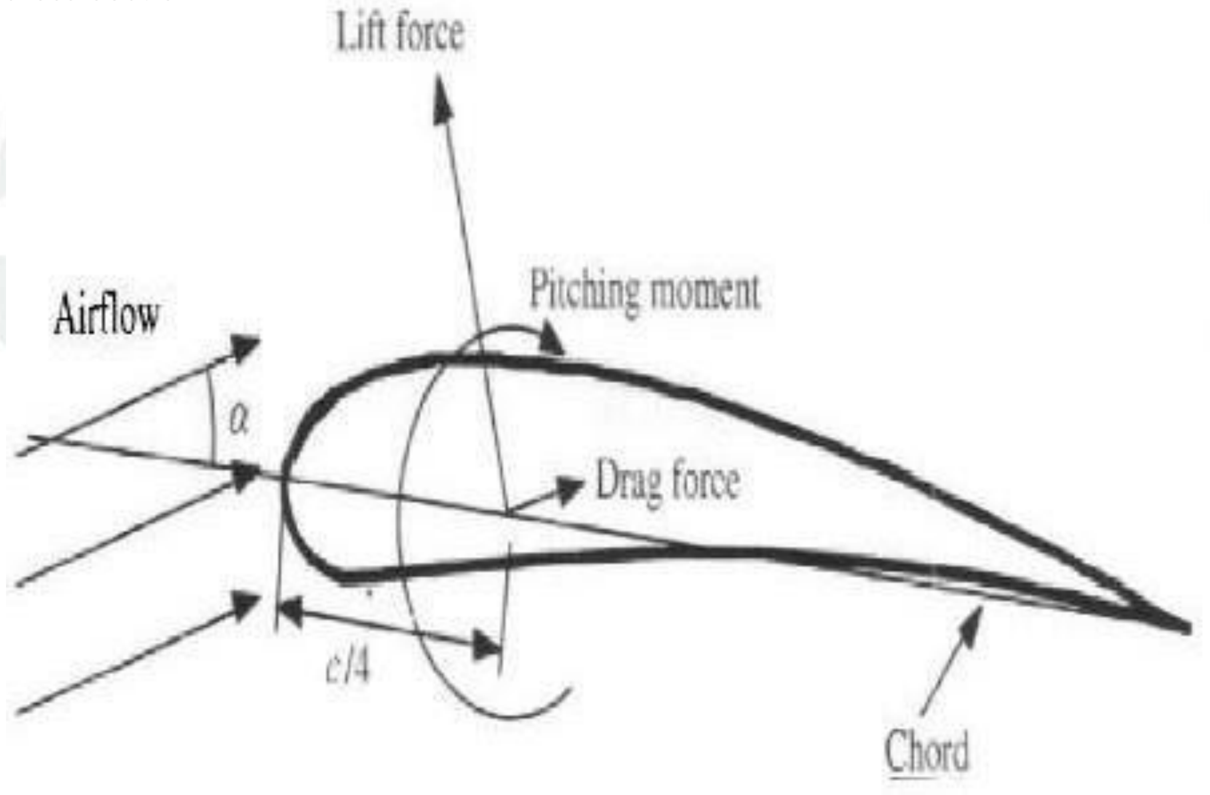
Different parameters of aerofoil section

Different parameters of aerofoil section

Lift force - defined to be perpendicular to direction of the oncoming airflow. The lift force is a consequence of the unequal pressure on the upper and lower airfoil surfaces.

Drag force - defined to be parallel to the direction of oncoming airflow. The drag force is due both to viscous friction forces at the surface of the airfoil and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow

Pitching moment - defined to be about an axis perpendicular to the airfoil cross-section



- The resultant of all of these pressure and friction forces is usually resolved into two forces and a moment that act along the chord at *c* / 4 from the leading edge (at the 'quarter chord').
- These forces are a function of Reynolds number ***Re* = *U L* /** ν (*L* is a

characteristic length, e.g. *c*)

The 2-D airfoil section lift, drag and pitching moment coefficients are normally defined as:

$$c_l = \frac{L/l}{\frac{1}{2}\rho U^2 C} = \frac{\text{Lift force/unit length}}{\text{Dynamic force/Unit length}}$$

$$c_d = \frac{D/l}{\frac{1}{2}\rho U^2 C} = \frac{\text{Drag force/Unit length}}{\text{Dynamic force/Unit length}}$$

$$C_m = \frac{M}{\frac{1}{2}\rho U^2 AC} = \frac{\text{Pitching moment}}{\text{Dynamic moment}}$$

A = projected airfoil area = chord x span = *c l*

Other dimensionless parameters that are important for analysis and design of wind turbines include the power and thrust coefficients and tip speed ratio, mentioned earlier and also the pressure coefficient:

$$C_p = \frac{P - P_\infty}{\frac{1}{2}\rho U^2} = \frac{\text{Static pressure}}{\text{Dynamic pressure}}$$

And blade surface roughness ratio:

$$\frac{\varepsilon}{L} = \frac{\text{Surface roughness height}}{\text{Body length}}$$

Airfoil aerodynamic behaviour

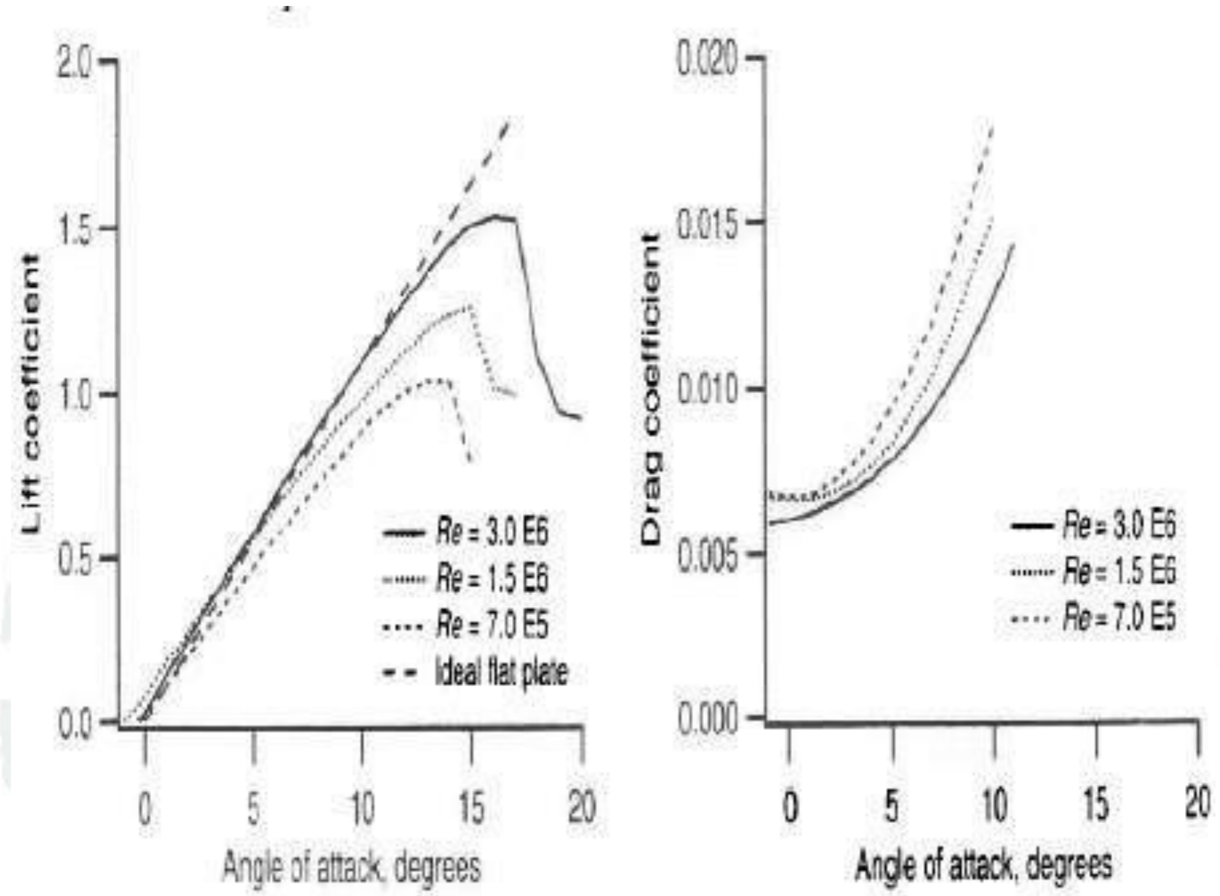
The theoretical lift coefficient for a flat plate is:

$$C_l = 2\pi \sin(a)$$

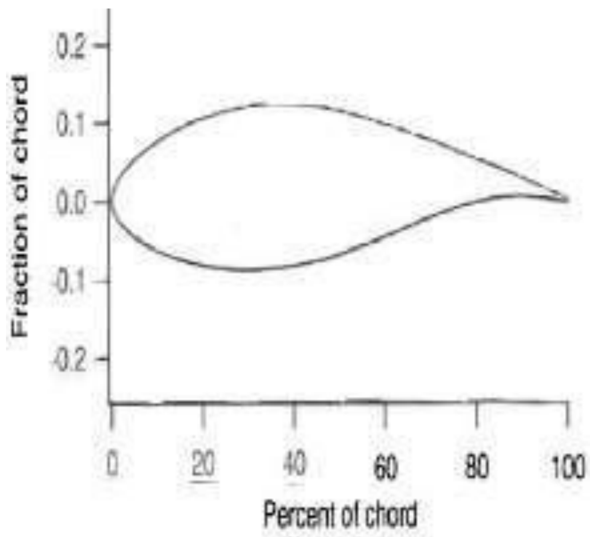
Which is also a good approximation for real, thin airfoils, but only for small α .

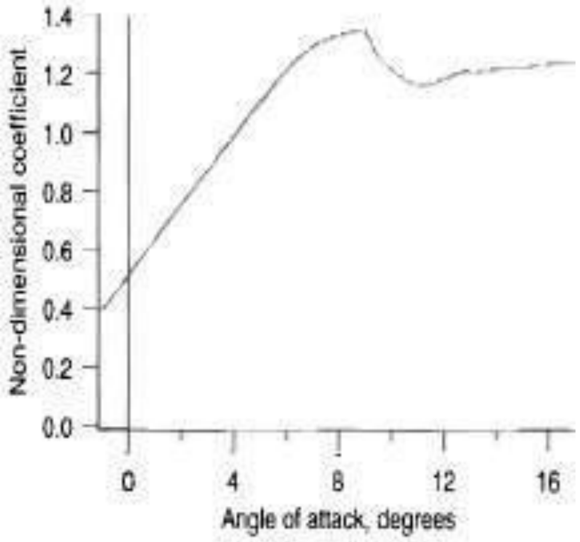
Er.PRAGATI SAHU DEPT. OF ETC
GSE,BERHAMPUR

Lift and drag coefficients for a NACA 0012 airfoil as a function of α and *Re*:-



- Airfoils for HAWT are often designed to be used at low angles of attack, where lift coefficients are fairly high and drag coefficients are fairly low.
- The lift coefficient of this symmetric airfoil is about zero at an angle of attack of zero and increases to over 1.0 before decreasing at higher angles of attack.
- The drag coefficient is usually much lower than the lift coefficient at low angles of attack. It increases at higher angles of attack.
- Note the significant differences in airfoil behaviour at different *Re*. Rotor designers must make sure that appropriate *Re* data are available for analysis.

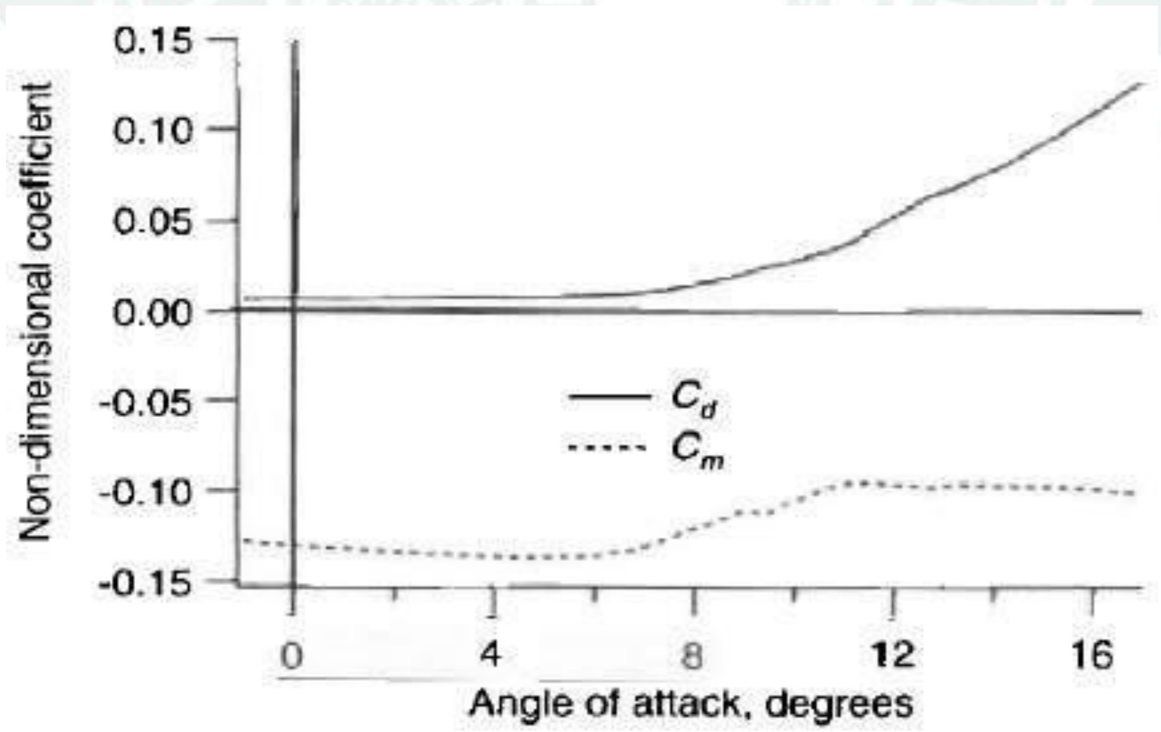




Lift at low α can be increased and drag reduced by using a cambered airfoil such as this DU-93-W-210 airfoil used in some European wind turbines:

Note non-zero lift coefficient at zero incidence.

Data shown: Re = 3 x10^{6}



Attached flow regime

At low α (up to about 7^o for DU-93-W-210), flow is attached to upper surface of the airfoil. In this regime, lift increases with α and drag is relatively low.

High lift/stall development regime

Here (from about 7-11^o for DU-93-W-210), lift coefficient peaks as airfoil becomes increasingly stalled. Stall occurs when α exceeds a critical value (10-16^o, depending on *Re*) and separation of the boundary layer on the upper surface occurs. This causes a wake above the airfoil, reducing lift and increasing drag. This can occur at certain blade locations or conditions of wind turbine operation. It is sometimes used to limit wind turbine power in high winds. For example, many designs using fixed pitch blades rely on power regulation control via aerodynamic stall of the blades. That is, as wind speed increases, stall progresses outboard along the span of the blade (toward the tip) causing decreased lift and increased drag. In a well designed, stall regulated machine, this results in nearly constant power output as wind speeds increase.

Flat plate/fully stalled regime

In the flat plate/fully stalled regime, at larger α up to 90^o, the airfoil acts increasingly like a simple flat plate with approximately equal lift and drag coefficients at α of 45^o and zero lift at 90^o.

Illustration of airfoil stall

Airfoils for wind turbines

- Typical blade chord *Re* range is $5 \times 10^5 - 1 \times 10^7$
- 1970s and 1980s – designers thought airfoil performance was less important than optimizing blade twist and taper.
- Hence, helicopter blade sections, such as NACA 44xx and NACA 230xx, were popular as it was viewed as a similar application (high max. lift, low pitching moment, and low min. drag).

But the following shortcomings have led to more attention on improved airfoil design:

- Operational experience showed shortcomings (e.g. stall controlled HAWT produced too much power in high winds, causing generator damage).
- Turbines were operating with some part of the blade in deep stall for more than 50% of the lifetime of the machine.
- Peak power and peak blade loads were occurring while turbine was operating with most of the blade stalled and predicted loads were 50 – 70% of the measured loads!
- Leading edge roughness affected rotor performance. Insects and dirt → output dropped by up to 40% of clean value!

Momentum theory and Blade Element theory

- The actuator disk approach yields the pressure change across the disk that is, in practice, produced by blades.
- This, and the axial and angular induction factors that are a function of rotor power extraction and thrust, will now be used to define the flow at the airfoils.
- The rotor geometry and its associated lift and drag characteristics can then be used to determine
    - Rotor shape if some performance parameters are known, or
    - Rotor performance if the blade shape has been defined.

Analysis uses

Momentum theory - CV analysis of the forces at the blade based on the conservation of linear and angular momentum.

Blade element theory – analysis of forces at a section of the blade, as a function of blade geometry.

Results combined into "strip theory" or blade element momentum (BEM)

theory.

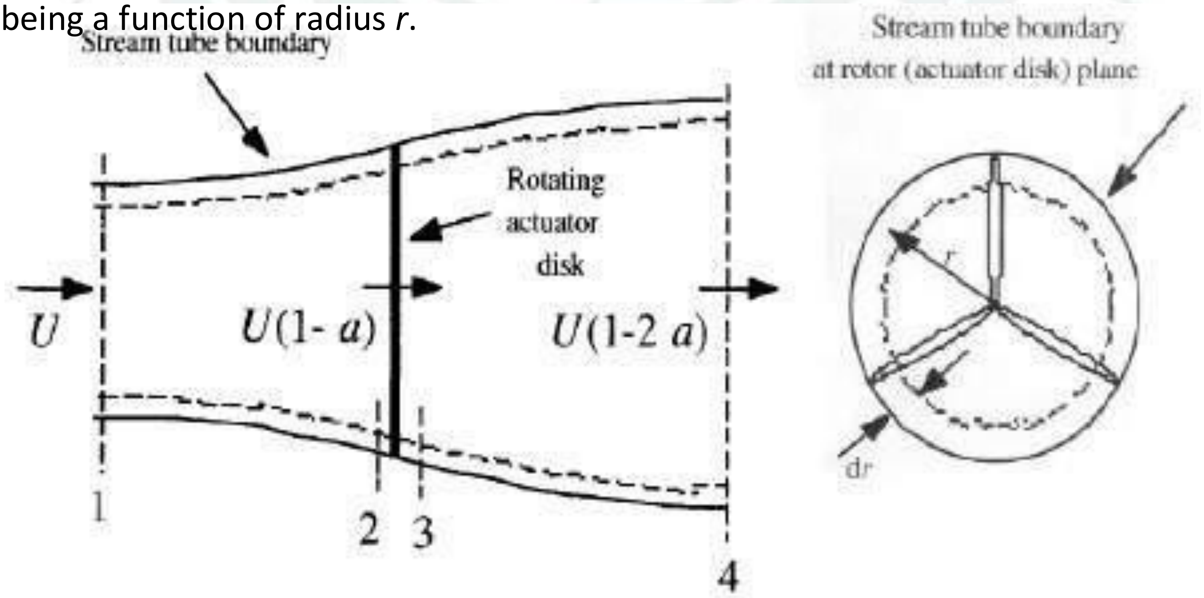
This relates blade shape to the rotor's ability to extract power from the wind.

Analysis encompasses

- Momentum and blade element theory.
- The simplest 'optimum' blade design with an infinite number of blades and no wake rotation.
- Performance characteristics (forces, rotor airflow characteristics, power coefficient) for a general blade design of known chord and twist distribution, including wake rotation, drag, and losses due to a finite number of blades.
- A simple 'optimum' blade design including wake rotation and an infinite number of blades. This blade design can be used as the start for a general blade design analysis.

Momentum theory

We use the annular control volume, as before, with induction factors (*a*, *a′*) being a function of radius *r*.



Applying linear momentum conservation to the CV of radius *r* and thickness *dr* gives the thrust contribution as:

$$dT = \rho U^2 4(1-a)\pi r dr$$

Similarly, from conservation of angular momentum, the differential torque,
***Q*, imparted to the blades (and equally, but oppositely, to the air) is:**

$$dQ = 4a'(1-a)\rho U \pi r^3 \Omega \, dr$$

Together, these define thrust and torque on an annular section of the rotor as functions of axial and angular induction factors that represent the flow conditions.

Rotor Design
(Blade element theory)

The forces on the blades of a wind turbine can also be expressed as a function of C_l , C_d and α.

For this analysis, the blade is assumed to be divided into *N* sections (or elements).

Assumptions

- There is no aerodynamic interaction between elements.
- The forces on the blades are determined solely by the lift and drag characteristics of the airfoil shape of the blades.

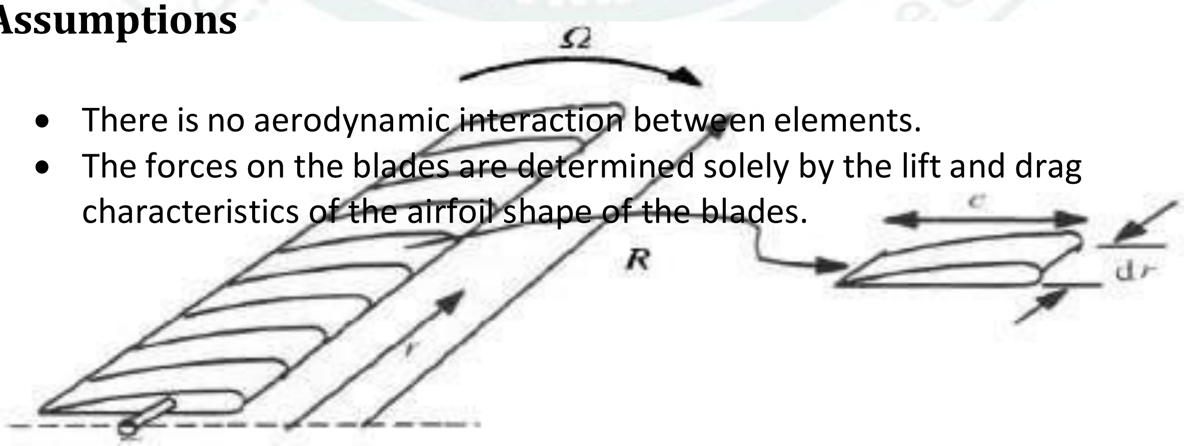
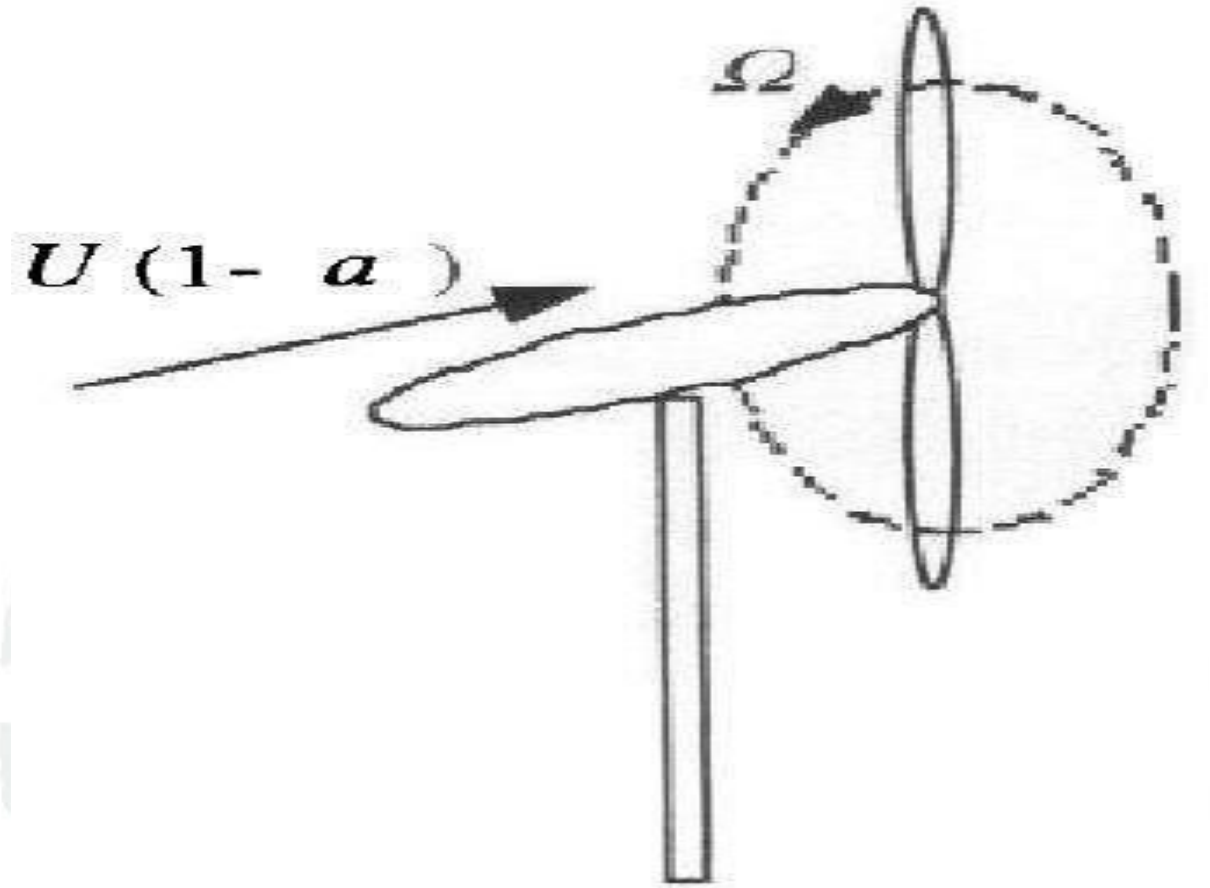


Diagram of blade elements

c = airfoil chord length; d*r* = radial length of element

r = radius; *R* = rotor radius; Ω = rotor angular velocity



Overall geometry for a downwind HAWT analysis;

U = velocity of undisturbed flow;

Ω = angular velocity of rotor;

a = axial induction factor

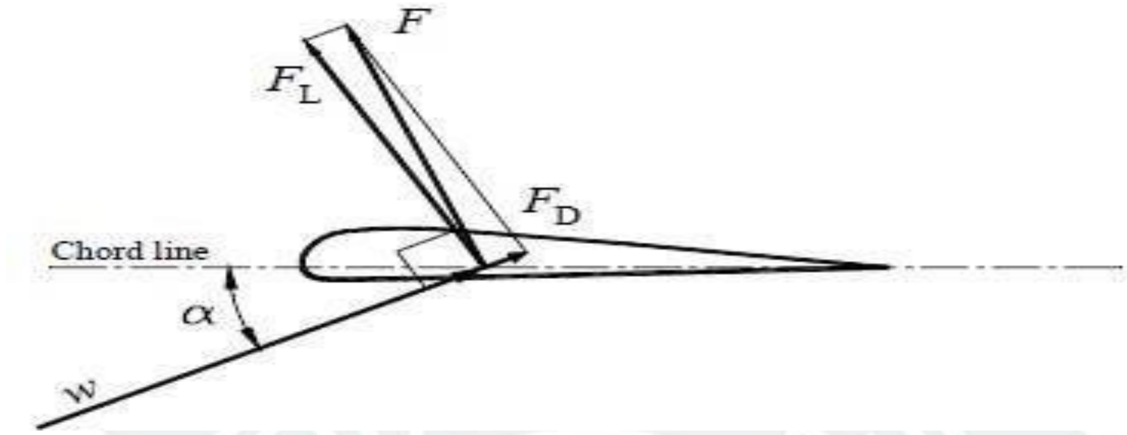
Note:

- Lift and drag forces are perpendicular and parallel, respectively, to an effective, or relative, wind.
- The relative wind is the vector sum of the wind velocity at the rotor, *U (1 - a)*, and the wind velocity due to rotation of the blade.

- This rotational component is the vector sum of the blade section velocity, $\Omega\, r$, and the induced angular velocity at the blades from conservation of angular momentum, $\omega\, r$ / 2, or:

$$\Omega \mathbf{r} + (\omega/\mathbf{2})\mathbf{r} = \Omega \mathbf{r} + \Omega \mathbf{a}'\mathbf{r} = \Omega \mathbf{r}(\mathbf{1} + \mathbf{a}')$$

Rotor Design
(Blade element theory)



- The air hits the blade in an angle α which is called the "angle of attack". The reference line" for the angle on the blade is most often "the chord line" .
- The force on the blade *F can be divided into two components – the lift force F $_L$ and the drag force F $_D$ and the* lift force is – per definition – perpendicular to the wind direction.

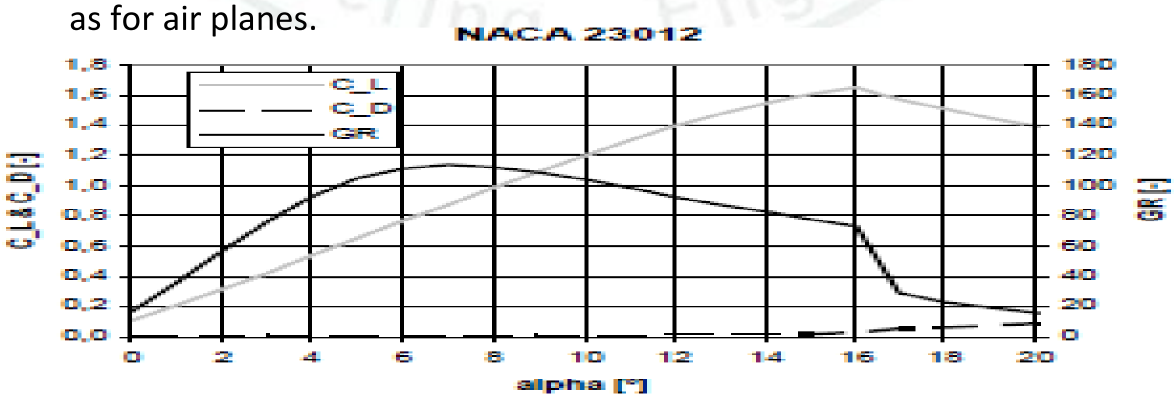
The lift force is given as

$$F_L = C_L \frac{1}{2} \rho W^2 (bc)$$

And the drag force

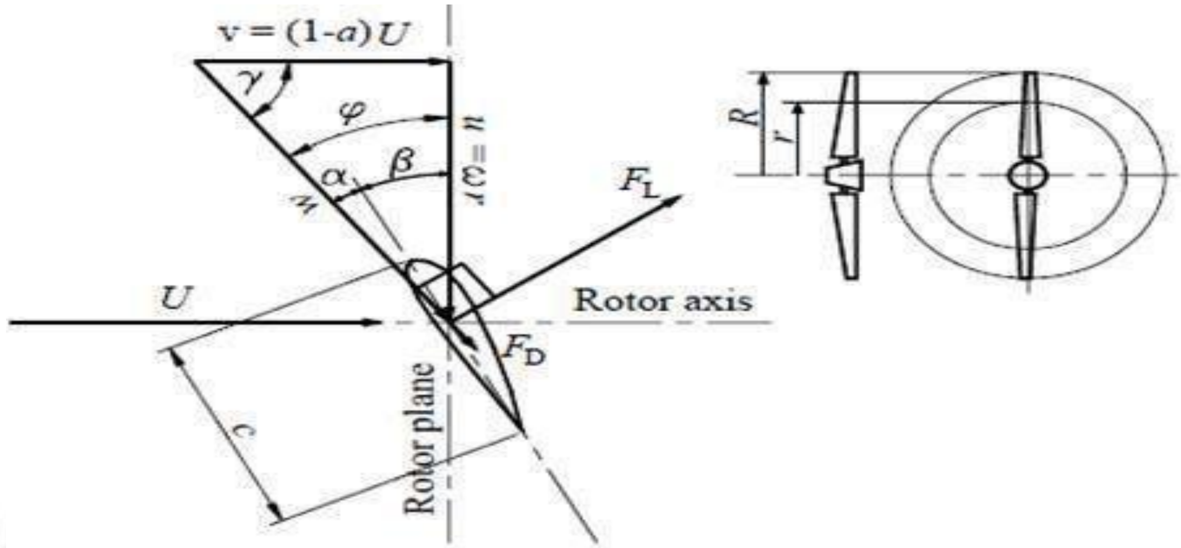
$$F_D = C_D \frac{1}{2} \rho W^2 (bc)$$

- The ratio *GR=C_L / C_D is called the "glide ratio",*
- *Normally we are interested in at high* glide ratio for wind turbines as well as for air planes.



Pitch angle, β, and chord length, c, after Betz

To design the rotor we have to define the pitch angle β and the chord length c. Both of them depend on the given radius, that we are looking at therefore we sometimes write β(r) and c(r).

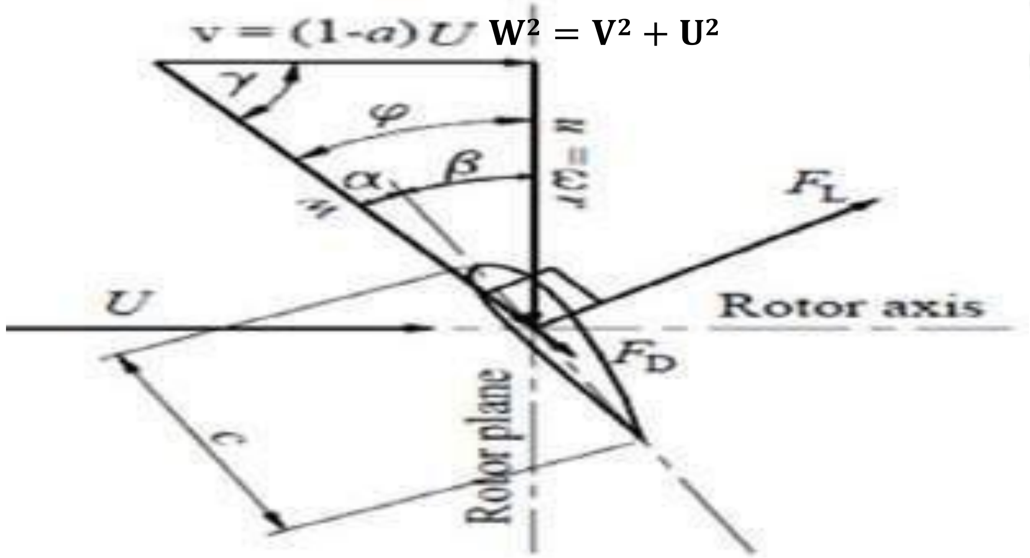


Angles, that all depends on the given radius

- γ(r) = angle of relative wind to rotor axis
- ϕ(r) = angle of relative wind to rotor plane
- β(r) = pitch angle of the blade

The blade is moving up wards, thus the wind speed, seen from the blade, is moving down wards with a speed of *u.*

$$\mathbf{W}^2 = \mathbf{V}^2 + \mathbf{U}^2$$



Betz does not include rotation of the wind (No Wakes). Therefore

$$\mathbf{U} = \Omega\mathbf{r}$$

Here ω is the angular speed of the rotor

$$\lambda = \frac{\Omega R}{U}$$

$$\emptyset(\boldsymbol{r}) = a + Q$$

$$(\boldsymbol{r}) = \mathbf{tan}^{-1} \frac{\boldsymbol{\Omega R}}{(\mathbf{1} - \boldsymbol{a})\boldsymbol{u}}$$

For *a=1/3*

$$(\boldsymbol{r}) = \mathbf{tan}^{-1} \frac{\mathbf{3}\lambda r}{\mathbf{2}\boldsymbol{R}}$$

And

$$\emptyset(\boldsymbol{r}) = \mathbf{tan}^{-1} \frac{\mathbf{2}\boldsymbol{R}}{\mathbf{3}\lambda r}$$

The pitch angle

$$Q(\boldsymbol{r}) = \mathbf{tan}^{-1} \frac{\mathbf{2}\boldsymbol{R}}{\mathbf{3}\lambda r} - a$$

Most often the angle is chosen to be close to the angle, that gives maximum glide ration that means in the range from 5 to 10° but near the tip of the blade the angle is sometimes reduced.

Chord length, c(r):

For one blade element in the distance r from the rotor axis with the thickness *dr* the lift force is

$$dF_L = \frac{1}{2}\rho W^2 c\,dr\,C_L$$

And the drag force

$$dF_D = \frac{1}{2}\rho W^2 c\,dr\,C_D$$

For the rotor plane (torque) we have

$$dQ = \left(dF_L \sin\emptyset - dF_D \cos\emptyset\right) r = \frac{\rho}{2}\Omega^2 c\,(r)\,(C_L \sin\emptyset - C_D \cos\emptyset) r$$

$$= \frac{\rho}{2}\Omega^2 (r) r\,dr\,C_X$$

The thrust

$$dT = \frac{1}{2}\rho W^2 c\,dr\,C_Y$$

AND

$$C_Y = C_L \cos\emptyset + C_D \sin\emptyset$$

Now, in the design situation, we have $C_L >> C_D$

$$dQ = \frac{\rho}{2}\Omega^2 C\,(r)\,dr\,C_L r \sin\emptyset$$

For *N blades*

$$dP = N\frac{\rho}{2}\Omega^2 c\,(r)\,dr\,C_L r\Omega \sin\emptyset$$

According to Betz, the blade element would also give

$$dP = 2(1-a)^2 \quad U^3 A = \frac{16}{27} N \frac{\rho U^3}{2} (2\pi r dr)$$

Using

$$U = \frac{3}{2} W \cos\gamma \;, \quad u = \Omega r \sin\gamma$$

$$(r) = \frac{16}{9N}\,\frac{\pi R}{C_L D}\,\frac{1}{\sqrt{\lambda^2 \left(\frac{r}{R}\right)^2 + \frac{4}{9}}}$$

Note:

- Effect of drag is to decrease torque and, hence, power, but to increase the thrust loading.
- Thus, blade element theory gives 2 equations: normal force (thrust) and tangential force (torque), on the annular rotor section as a function of the flow angles at the blades and airfoil characteristics.
- These equations will be used to get blade shapes for optimum performance and to find rotor performance for an arbitrary shape.
- These equations may be used to find the chord and twist distribution of the Betz optimum blade.

Example: Given λ = 7, *R* = 5m, C_L= 1, C_D/C_L is minimum at α = 7, and there are 3 blades (*N* = 3) we can use:

$$\emptyset(r) = \tan^{-1}\frac{2R}{3\lambda r}$$

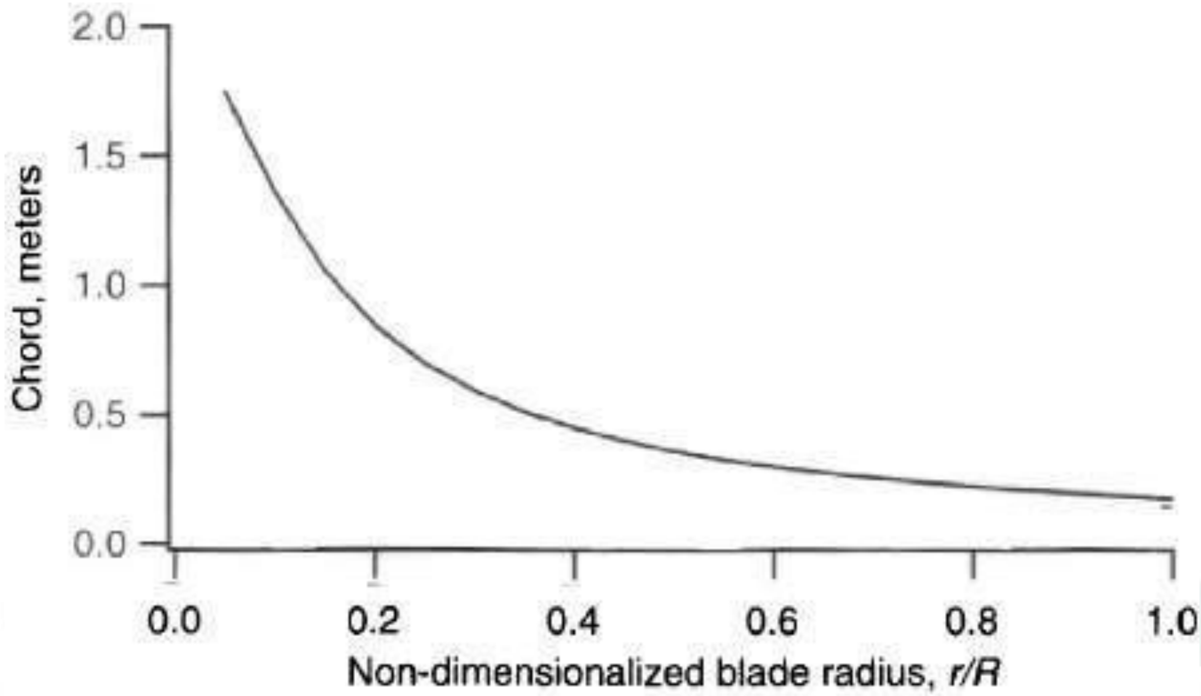
$$(r) = \frac{16}{9N}\,\frac{\pi R}{C_L D}\,\frac{1}{\sqrt{\lambda^2 \left(\frac{r}{R}\right)^2 + \frac{4}{9}}}$$

Together with $\emptyset(r) = \alpha + \beta$ to obtain the changes in chord, twist angle (= 0 at tip), angle of relative wind, and section pitch, with radial distance, *r/R*, along the blade:

r/R	Chord, m	Twist Angle	Angle of Rel. Wind	Section Pitch
0.1	1.375	38.2	43.6	36.6
[illegible]	0.858	20.0	25.5	18.5
0.3	0.604	12.2	17.6	10.6
0.4	0.462	8.0	13.4	6.4
0.5	0.373	5.3	10.8	3.8
0.6	0.313	3.6	9.0	2.0
0.7	0.269	2.3	7.7	0.7
0.8	0.236	1.3	6.8	-0.2
0.9	0.210	0.6	6.0	-1.0
1	0.189	0	5.4	-1.6

Twist and chord distribution for a Betz optimum blade
(r/ R = fraction of rotor radius)

- Hence, blades with optimized power production have increasingly larger chord and twist angle on approaching the blade root ($r \to 0$). Actual shape depends on difficulty/cost of manufacturing it.



Blade chord for example Betz optimum blade