

ADVANCES IN
RENEWABLE ENERGY
ENGINEERING

Volume - 5

Chief Editor

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AkiNik Publications
New Delhi

Published By: AkiNik Publications

AkiNik Publications

169, C-11, Sector - 3,

Rohini, Delhi-110085, India

Toll Free (India) – 18001234070

Chief Editor: Dr. Mahesh Chandra

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Publications Year: 2022

Pages: 109

ISBN: 978-93-5570-175-6

Book DOI: <https://doi.org/10.22271/ed.book.1690>

Price: ` 719/-

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Chapter - 1

Power System Operation in Deregulated Industry Environment

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Chapter - 1

Power System Operation in Deregulated Industry Environment

Dr. Y.V. Krishna Reddy, Dr. P. Ramesh, Dr. M. Lakshmikantha Reddy and
Ch. Narendra Kumar

Abstract

Nearly all industries in all nations are regulated to some extent. Very competitive businesses such as auto manufacturing, airlines and banking are all heavily regulated with myriad government requirements defining what they must, can, and cannot do, and what and to whom and when they must report their activities. Regulation of electric utilities is not the only way government can control the electric power industry within its jurisdiction. The other way is to own and operate the power company directly, as a government utility. As the terms suggest, they represent fundamentally opposite ideas. But neither concept is necessarily good or bad. Both regulation and deregulation make sense, and one or other is preferable under certain conditions.

Keywords: Power system operation, deregulated industry, regulation, market power, restructuring models

1.1 Introduction

Regulation refers to that the government has set down laws and rules that put limits on and define how a particular industry or a company can operate.

Need for electrical utility industry

a) Risk minimization

In initial days, for establishment of electrical industry required large capital, where governments were resistant to invest higher capitals. But some businessmen like Westinghouse, Edison know their technology was sound. So they are agreed from both sides that the businessmen would risk their money, not the government. In turn, the government guaranteed them a fair return on their investment.

b) Legitimizing of electric utility business

Regulation legitimized the electric utility business. Government franchises and regulations clearly implied to a possibly thought electricity was good thing.

c) Support from government

Regulation provided reorganization and support from the government which has necessary to solve the problems like "Right of Way"

- d) Established monopoly in building up of their systems without worry about their competitions.

1.2 Characteristics of regulated electric utility

- Monopoly franchise.
- Obligation to serve.
- Regulatory Oversight.
- Least-cost operation.
- Regulated rates.
- Assumed rate of returns.

1.3 Structure of regulated industry

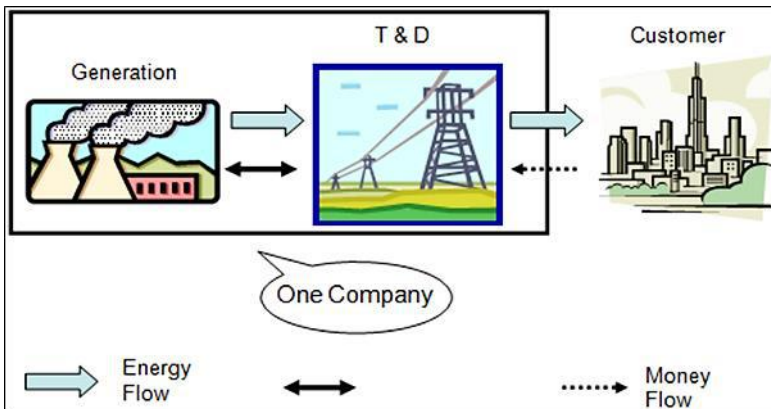


Fig 1: Basic Structure of Regulated Industry

- The electric power industry has over years been dominated by large utilities that had overall activities in generation, transmission Distribution of power within domain of operation.
- Such a utility served as only electricity provider in the region obligated to provide electricity to everyone in the region.

- A typical structure of a vertically integrated electric utility is shown in above figure.
- The Energy Flow and Money flow are presented in the diagram.

1.4 Need for deregulated power industry

Deregulation in power industry is a restructuring of the rules and economic incentives that government set up to control and drive the electric power industry.

In vertically integrated industry in which the monopoly could not provide services efficiently as competitive firms, the electric power industry plans to improve its efficiency by providing a more reliable energy at minimum cost to consumers. A competition is guaranteed by establishing a restructured environment in which customers will choose to buy from different suppliers and change suppliers as they wish in order to pay the market-based rates.

Some major reasons lead to deregulation. The following are the major factors which help in motivating the restructuring process in power system.

a) Improved technology

Technology innovation improved the efficiency of units also and proved technology, the risk involved in the investment of money is reduced. Electricity became an essential commodity, hence it should be available, which can be bought and sold in the marketplace in a competitive manner.

b) Reduce cost of power

Competition brings innovation, efficiency and lower costs, the rate of cost decline in different areas. The overall experience all over the world is that the electricity prices have declined.

c) Encourages innovation

In regulated (monopoly scheme) process and lack of competition gave electric utilities no incentive to improve on yesterday's performance or to take risks on new ideas that might increase customer value.

Innovation leads to up-gradation of new technologies and business practices. Under de-regulated environment, the electric utility will always try to innovate something for the betterment of service and it turn save its cost and maximize profit.

d) Customer focus

The monopoly franchise utilities have an obligation to serve all customers that does not promote the pro-active attention to customer needs. A monopoly franchise utility listens to its customers and then responds.

A competitive electric service company predicts the customer's requirements and responds in advance. The technological advances that will be applied under de-regulation, address customer service.

e) High tariffs

In several countries, the price of electricity is expensive on account of regulated (monopoly) power system. With the implementation of deregulation policy, the tariff is more likely to be reduced. Consumers will enjoy an improved and quality service at less tariffs as a result of restructuring. Restructuring leads to a number of power competitors in the market as a result of innovative techniques increase the efficiency and lowers the cost of electricity.

1.5 Structure of deregulated electric utility

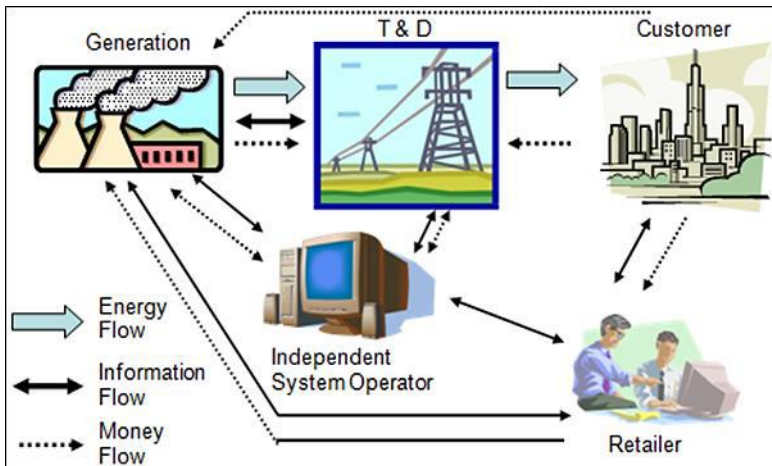


Fig 2: Basic Structure of Deregulated Industry

A system operator is appointed for the whole system and it is entrusted with the responsibility of keeping the system in balance, i.e. to ensure that the production and imports continuously match consumption and exports. Naturally, it was required to be an independent authority without involvement in the market competition nor could it own generation facilities for business. This system operator is known as Independent System Operator (ISO).

1.6 Restructuring models

Three major models of electricity markets are being discussed as alternatives to the vertically integrated monopoly. They are

- 1) Pool Co Model
- 2) Bilateral Contracts Model
- 3) Hybrid Model

1. Pool Co model

A centralized market place, where electric power sellers/ buyers to submit prices and bids for the energy they are willing to buy or sell is known as "Pool Co model". Vertical integrated transmission and distribution companies and a single and separate entity which is responsible for bidding procedures.

The main characteristic of this model is to establish independently owned whole sale power pools served by the interconnected transmission systems. For trading electricity, it acts as a centralized clearing market and forces the distribution utilities to buy power from the Pool Co model rather than trading with generation companies. These companies sell the power at the MCP i.e. Market Clearing Price (MCP), which is defined by the Pool Co instead of a price based on generation cost.

- If a provider bids too high, it may not be able to sell the power. Similarly if buyer bids too low, they are unable to get the power.
- Power pools can implement the economic dispatch and produce a single spot price for electricity by providing participants a clear idea about consumption and investment decisions.
- Winning bidders are paid the spot price i.e. equal to the price of highest bid of the winners; the spot price may exceed the actual running of selected bidders.
- Pool co does not own any generation or transmission components.
- Pool co is responsible for providing bidding procedures, scheduling and dispatching generation resources, maintenance of ancillary services.
- Pool co controls the maintenance of transmission grid and encourages an efficient operation by assessing non-discriminatory fees to generators and distributors.

2. Bilateral Contracts Model (or) Direct Access Model

This model is based on bilateral contract, also known as direct access model. As the name indicates, consumers are able to contract bilaterally (directly) with power generating companies.

- The customers are free to contract directly with power generating companies.
- The customers transfer purchased power by providing an appropriate access and pricing standards as confined to the transmission and distribution over utility or service wires.
- In this model, a single centrally transmitted power pool is not required as in the Pool Comodel.

The two important characteristic of this model are

- Role of ISO is limited.
- Direct discussion of buyers and sellers in the market place.
- The suppliers can supply incremental and decremental energy bids to prevent transmission flow congestion to maintain the reliability in real time scenario.
- The cost-based transmission pricing can provide a non-discriminatory access and pricing rules for transmission and distribution systems.
- To predict the possible constraints, load flow models are used by considering various generating units, transmission lines, transfer capability of transmission and distributionsystems.

3. Hybrid model

The hybrid model is a combination of various features of previous two models.

- This model differs from the Pool Co model, as the use of power exchange (PX) is not necessary consumers are allowed to sign bilateral (direct) contracts and choose suppliers from the pool.
- The pool would serve all those buyers and sellers, who do not sign the direct contracts.

Ex: California Model

- The advantage of this model, it provides maximum flexibility i.e. it allows end-users (customers/consumers) to buy either from the pool or directly from the suppliers.
- The presence of pool can effectively recognizes the energy requirements of individual consumers and also makes energy balancing.

- The hybrid model allows the market participants to choose between the two options based on provided prices and utility services.
- The hybrid model is very costly to set up, due to the requirement of two separate entities for operating PX and transmission systems.

1.7 Independent System Operator (ISO)

The primary role of an ISO is not dispatching or rescheduling generation sources, but matching electricity supply with demand as necessary to ensure reliability. ISO should control generation to some extent to maintain reliability and optimize the transmission efficiency. The ISO will forecast the load demand for the following day & receive bids that will satisfy the demand at the lowest cost.

The ISO has three objectives.

- Security Maintenance.
- Service Quality Assurance.
- Promotion to Economic Efficiency & Equity.

To achieve these objectives the ISO performs one or more of the following objectives.

- Power System Operations Function.
- Power Market Administration Function.
- Ancillary Services Provisions Function.
- Transmission Facilities Function.

Role of ISO

The major roles of ISO are as follows.

- 1) It maintains system security and reliability.
- 2) It provides service quality; improve in economic efficiency and Equity.
- 3) It is responsible to produce fair and reasonable transmission tariffs.
- 4) It controls the generation to the amount needed to manage reliability and enhance transmission efficiency.
- 5) It calculates the status of transmission system.
- 6) It provides a dispatch function to organize the spot market and maintains the usage of grid in pool structure.

- 7) It is responsible for executing the market such that the load and generation are balanced (or)stabilized in real time.
- 8) It provides power transportation services to the buyers and sellers.
- 9) It assures the stability of the power system and the quality of the service.
- 10) It is usually combines electricity supply with market demand for smooth operation.

1.8 Power Exchange (PX)

A market place where different participants buy and sell electricity and can-do other services in a competitive manner like by accepting certain terms such as price, availability and quality of products is known as "Power Exchange (PX)". or "Spot Price Pool". The main objective of PX is to guarantees an equal and non-discriminatory access and competitive opportunity to all market participants.

The participants in market place can be utilities, brokers, power marketers, retailers, load collectors, large industrial consumers and co-generators. Power exchange is a new independent, a non-government and non-profitable entity which acquires schedules for loads generation sources. PX provides an MCP (Market Clearing Price) for every hour of the scheduled day for trading between buyers and sellers through an on-line auction.

Services provided by PX

The following are the most important services or benefits provided by PX markets.

- It provides an automatic and internet-based market interface almost in all situations.
- It clears and settles deals.
- Correlative risk taking
- It provides auditing and billing of the products in spot market and term-market.
- It gives required information to the market participants, weather they asked.
- It does not deal with small consumers.
- It provides a day-ahead market and an hour-ahead market.

Success Factors of PX can be measured by

- 1) Number of participants
- 2) Market Liquidity
- 3) Regional progress of the market
- 4) Fee structure competitiveness

Market operations

a) Day-ahead markets

- In the day-ahead market and for each hour of 24 hrs scheduling a day, sellers bid a schedule of supply at various prices, buyers bid a schedule of demand at various prices and MCP is determined for each hour.
- Then sellers specify the resources for the sold power and buyers specify the delivery points for the purchased power.
- Power exchange schedules supply and demand with ISO for delivery.
- Supply and demand are adjusted to account for congestion and ancillary services and then power exchange finalizes the schedule.

b) Hour-ahead markets

- It is similar to day ahead, except trades are for 1 hour and the Available Transfer Capability (ATC) is reduced include may ahead trades and bids.
- Once the MCP is determined by the power exchange (Px) market participants submit additional data to the power exchange like individual schedule of generating unit, take out point for demand, adjustment of for congestion management & ancillary service.
- Then ISO and Px know the injection points of individual generating units to the transmission system.

c) Inelastic Markets and Elastic Markets

- An Elastic Market does not provide sufficient signals or incentives to a consumer to adjust its demand in response to the price, i.e. the consumers does not have any motivation to adjust its demand for the electrical energy to adapt the market conditions.
- The concept of Inelastic Market is directly related to the concept of firm load, which formed the basis of the electricity industry for many decades before the introduction of open access and energy markets.

- Customers use the "Concept of Elastic Demand" when they are exposed to and aware of the price of energy and arrange their affairs in such a fashion as to reduce their demand as the price of the next available offers exceeds a certain level.
- In the Inelastic Market, chance of imbalances occurs between the demand and supply due to unexpected demand increase, planned or forced outages in supply or transmission facilities.
- Such a situation results in a price spike (sudden change). The price tends to increase to higher levels because unusual measures need to be taken to restore the balance between supply and demand. The balance is restored by load shedding, sets MCP at the price cap, providing additional supply services.
- But, in case of Elastic Market, the problem of restoring between supply and demand is much easier. It can avoid imposing of price caps, maintains the amount of power reserves to maintain system reliability.
- The issue of transmission losses is also an important issue as it affects the production of dispatched generating units and economic operation of the system.

Market power

The ability of a firm (or) a group of firms to drive and control the market price in a competitive level for a significant period of time is known as "Market Power" or "Monopoly Power".

The main function of the market power is to maintain the total output, reduce the competition in power generation, service quality and technological introduction. The final result of studying market power is a transfer of property from buyers and sellers or a mis-allotment of sources. There are two types of market power.

- Vertical market power.
- Horizontal market power.

1.9 Conclusion

In India, the power sector was mainly under the government ownership (95-98% of total generation) under various states and central government utilities, till 1991. The remarkable growth of physical infrastructure was facilitated by four main policies:

- 1) Centralized supply and grid expansion.

- 2) Large support from government budgets.
- 3) Development of sector based on indigenous resources.
- 4) Cross subsidy.

In mid 1990s, Orissa began a process of fundamental restructuring of the state power sector. Under the World Bank (WB) loan, the state decided to adopt, what is known as WB-Orissa model of reform. This consisted of a three-pronged strategy of:

- 1) Unbundling the integrated utility in three separate sectors of generation, transmission and distribution,
- 2) Privatization of generation and distribution companies
- 3) Establishment of independent regulatory commissions to regulate these utilities.

Soon afterwards, several other states such as Andhra Pradesh, Haryana, Uttar Pradesh and Rajasthan also embarked on similar reforms and also availed loans from multilateral development banks such as WB and Asian Development bank, etc. Meanwhile, some moderate steps were taken towards reforms until the Electricity Bill 2003 was approved by Parliament in May 2003. This unified central legislation passed after 10 drafts. The Bill now replaces previous three acts on electricity of 1910, 1948 and 1998 (with their amendments).

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Chapter - 2
**Thin Film Deposition by Chemical Bath
Deposition Method**

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Chapter - 2

Thin Film Deposition by Chemical Bath Deposition Method

Dr. Rekharani Maddula and Kesava Vamsi Krishna V.

Abstract

This reviews the theory of early growth of the thin film using chemical deposition methods. In particular, it critically reviews the Chemical Bath Deposition (CBD) method for preparation of thin films. The different techniques used for characterizations of the chemically films such as Scanning electron microscopy (SEM), X-ray diffractometer (XRD), Electrical conductivity, Transmission electron microscopy (TEM) and Energy Dispersive Spectroscopy (EDS) are discussed. Survey shows the physical and chemical properties solely depend upon the time of deposition, temperature of deposition. Thin films have a great impact on the modern era of technology. Thin films are considered as backbone for advanced applications in the various fields such as optical devices, environmental applications, telecommunications devices, energy storage devices, and so on. The crucial issue for all applications of thin films depends on their morphology and the stability. The morphology of the thin films strongly hinges on deposition techniques. Thin films can be deposited by the physical and chemical routes.

Keywords: Thin films, CBD Method, deposition, Renewable energy, coatings, glass cleaning, stability, solar

1.1 Introduction

Since the industrial age, innovative energy technologies have been crucial to technological and economic progress. Readily accessible electrical and thermal energy from fossil fuels has facilitated the expansion of the production, transportation, and communications infrastructure on which our society has become dependent. This progress, however, has come at a steep environmental and social cost. Climate change, groundwater pollution and habitat destruction are all environmental consequences of the industrial culture's use of fossil fuel energy. The negative impact on society of oil and coal dependency can be seen in the political instability, health problems and

economic penalties paid for unstable energy prices. Since the oil energy crisis of the 1970s, significant resources have been directed toward developing alternative energy sources and vectors. Of all of the schemes competing for post-oil adoption, hydrogen energy systems have emerged as the most promising. The use of hydrogen as an energy vector promises several advantages over fossil fuels. Hydrogen would provide the means to store energy, move energy from location to location, and provide an on-board energy source for transportation applications. Advantages of the hydrogen energy economy include increased overall energy system efficiency, improved urban air quality, the ability to safely and effectively store energy allowing intermittent renewable energy sources to be used, and reduced greenhouse gas (carbon dioxide) emissions. As an energy vector for transportation applications, hydrogen is particularly interesting because it offers fast refueling, adequate vehicle range, and nonharmful emissions. Three potential candidates for widespread renewable energy production are solar, wind, and hydro. These sources have already begun to be exploited, with varying degrees of early market acceptance. Future expansion of large-scale hydroelectricity from both dam and tidal generators has the unfortunate potential to cause severe environmental damage. Wind power is economically viable and a very attractive source of energy but may not yield the optimum long-term economic efficiency and reliability for energy conversion and storage. Using the sun's energy directly is the most efficient and unobtrusive pathway. Currently, commercially available methods of solar energy utilization are photovoltaic (PV) electricity generation and solar-thermal water heating. There are currently no commercially viable methods of generating hydrogen using solar energy.

Chemical bath deposition (CBD) or chemical solution deposition (CSD), is a method to deposit thin films and nanomaterials, first described in 1869. It can be employed for large-area batch processing or continuous deposition. In 1933 Bruckman deposited lead (II) sulfide (PbS) thin film by chemical bath deposition, or solution growth method. This technique is extensively used to deposit buffer layers in thin film photovoltaic cells. Nowadays, most of the tools are employed for minimizing the materials into nano-size as well as nano-thickness leading to the emergence of novel and unique behaviors of such materials in optical, electrical, optoelectronic, dielectric applications, and so on. Hence, a new branch of science/materials science is called thin films or coatings. Thin film can be defined as a thin layer of material, where the thickness is varied from several nanometers to few micrometers. Like all materials, the structure of thin films is divided into amorphous and polycrystalline structure depending on the preparation conditions as well as

the material nature. Thin films comprise two parts: the layer and the substrate where the films are deposited on it. Also, thin films can be composed of different layers such as thin-film solar cells, electro-chromic cells and so on.

CdS thin films were prepared by chemical-bath-deposited method and the effect of temperature and time on the properties of CdS thin films was studied. Independent of the deposited temperature, the growth was mainly controlled by the ion-by-ion growth mechanism at the beginning of the film deposition, then the cluster-by-cluster mechanism came to be dominant. The growth rate increased faster with the increasing of temperature until the thickness reached the limitation, then thickness instead become thinner.

The scanning electron microscope results revealed that the morphology of the CdS film changed from pinholes to rough, inhomogeneous surface with increasing deposition time and deposition temperature. The X-ray diffraction results showed the film structure was a mixture of two phases: hexagonal and cubic, and it was very important to controll deposition time to the film's crystal phase. All films in depth of approximate 100 nm existed above 65% transmittance, the absorption edge became "red-shift" with temperature rising. At 60 and 70 °C, with 20 min deposited-time, the energy band gap was more than 2.42 eV and decreased with time, while at 80 and 90 °C, the energy band gap was less than 2.42 eV and increased little when the time changed from 10 min to 15 min at 80 °C.

This Global warming, environmental pollution, and impending shortage of fossil fuel sources are factors that force modern society towards an increase in the utilization of renewable sources of energy. One of the most abundant resources on the surface of the earth is sunlight. Sunlight reaches the earth in a quantity that is sufficient to supply the total global energy consumption ^[1]. The use of solar energy has many advantages such as ^[2], it is free and abundant. it has low environmental impact. It does not require large centralized supplies or expensive distribution networks. Solar energy has high public acceptance as a natural form of energy.

The conversion of solar energy into usable form like solar cell devices play vital role in converting solar energy into usable form. In this Technique generally use of thin films to convert solar energy to usable form. There are lots of thin films which are made by the researchers. There are many techniques available for researchers in the deposition of thin film of Different material on the layer ^[3], Like evaporation, sputtering, and chemical bath deposition (CBD), sol gel ^[3].

The chemical bath deposition (CBD) method is grater commercial value than either thermal evaporation or sputtering ^[4]. In the past few years, II-IV semiconductors thin films have attracted considerable attention from the research community because of their wide range of applications in the fabrication of solar cells, the cadmium Sulphide (CdS) was mostly used as a window layer ^[5, 6]. (cDs) mostly absorb bleu portion of sun light.

The fabrication and designing of low cost, high efficiency solar cell devices, selection of window material is often important. Cadmium sulphide (CdS) is a low band gap ($E_g = 2.42$ eV) n-type semiconductor and widely used as window layer material in solar cell devices. CdS absorbs blue portion of solar spectrum and decrease in the current density of solar cells ^[6, 7].

ZnO thin films with nanorod structure were deposited using Ultrasonic Spray Pyrolysis method for seed growth, and Chemical Bath Deposition (CBD) for nanorod growth. High purity Zn-hydrate and Urea are used to control Ph were dissolved in ethanol and aqua bidest in Ultrasonic Spray Pyrolysis process. Glass substrate was placed above the heater plate of reaction chamber, and subsequently sprayed with the range duration of 5, 10 and 20 minutes at the temperatures of 3500 C. As for the Chemical Bath Deposition, the glass substrate with ZnO seed on the surface was immerse to Zn-hydrate, HMTA (Hexa Methylene Tetra Amine) moreÂ Â» and deionized water solution for duration of 3, 5 and 7 hour and temperatures of 600 C, washed in distilled water, dried, and annealed at 3500 C for an hour.

The characterization of samples was carried out to reveal the surface morphology using Scanning Electron Microscopy (SEM). From the data, the combination of 5 minutes of Ultrasonic Spray Pyrolysis process and 3 hour of CBD has showed the best structure of nanorod. Meanwhile the longer Spraying process and CBD yield the bigger nanorod structure that have been made, and it makes the films more dense which make the nanorod collide each other and as a result produce unsymetric nanorod structure. The various renewable energies with different optimization techniques are presented in literature ^[8-35].

1.2 Reaction mechanism

The chemical bath deposition involves two steps, nucleation and particle growth, and is based on the formation of a solid phase from a solution. In the chemical bath deposition procedure, the substrate is immersed in a solution containing the precursors. This method depends upon parameters like bath temperature, pH of the solution, the molarity of concentration, and time. Chemical bath deposition does not cause physical damage in the substrate.

1.3 Physical deposition techniques

1.3.1 Evaporation techniques

Evaporation methods are considered as the common deposition of materials in the form of thin-layer films. The general mechanism of these methods is obtained by changing the phase of the material from solid phase to vapor phase and converting again to solid phase on the specific substrate. It takes place under vacuum or controlled atmospheric condition.

1.3.2 Vacuum thermal evaporation technique

Vacuum evaporation technique is the simplest technique used to prepare amorphous thin films especially chalcogenide films such as CdSSe ^[1], MnS ^[2], Ge-Te-Ga ^[3] and so on. In general, chalcogenide materials can be used for memory-switching applications ^[4, 5], phase-change materials ^[6, 7] and solar applications ^[8].

The technique of thermal evaporation is strongly dependent on two parameters: thermally vaporized material and applying a potential difference to the substrate under medium-or higher-vacuum level ranging from 10⁻⁵ to 10⁻⁹ mbar. The schematic diagram for thermal evaporation is shown in Figure 1 taken from elsewhere ^[9].

1.4 Chemical Bath Deposition (CBD)

Among the chemical methods of thin film depositions, Chemical Bath Deposition (CBD) is probably the simplest method. The only requirements of these methods are a vessel to contain the solution (usually an aqueous remedy of common chemicals) and the substrate on which deposition is to be carried out. In addition to this various complications such as some mechanism for stirring and a thermostatic bath to preserve a specific and constant temperature are options that may be useful. This rate control can be accomplished by generating the sulphide slowly in the deposition solution. The rate of generation of sulphide, and therefore reaction, can be controlled through a number of parameters, in particular the concentration of sulphide forming precursor, solution temperature and pH. Although CBD can be carried out both acidic and alkaline solutions, most of the CBD reactions have been carried out in alkaline solutions.

Chemical bath deposition (CBD) a low-cost growth technique capable of producing good quality thin film semiconductors over large area and at low temperature then becomes a suitable technology of choice. Heterogeneous reaction in a basic aqueous solution that is responsible for the II-VI compound film growth in CBD requires a metal complex. We have

identified the stability constant (k) of the metal complex compatible with CBD growth mechanism to be about 106.9. This value is low enough to ensure that the substrate adsorbed complex relax for subsequent reaction with the chalcogen precursor to take place. It is also high enough to minimize the metal ion concentration in the bath participating in the precipitation of the bulk compounds. Homogeneous reaction that leads to precipitation in the reaction bath takes place because the solubility products of bulk II-VI compounds are very low. This reaction quickly depletes the bath of reactants, limit the film thickness, and degrade the film quality. While ZnS thin films are still hard to grow by CBD because of lack of suitable complexing agent, the homogeneous reaction still limits quality and thickness of both US and ZnS thin films. In this study, the zinc tetraammine complex ($[\text{Zn}(\text{NH}_3)_4]^{2+}$) with $k = 108.9$ has been forced to acquire its unsaturated form $[\text{Zn}(\text{NH}_3)_3]^{2+}$ with a moderate $k = 106.6$ using hydrazine and nitrilotriacetate ion as complementary complexing agents and we have successfully grown ZnS thin films. We have also, minimized or eliminated the homogeneous reaction by using ammonium salt as a buffer and chemical bath with low reactant concentrations. These have allowed us to increase the saturation thickness of ZnS thin film by about 400% and raise that of US film.

1.5 Advantages and disadvantages

The major advantage of CBD is that it requires in its simplest form only solution containers and substrate mounting devices. One of the drawbacks of this method is the wastage of the solution after every deposition. Chemical bath deposition yields stable, adherent, uniform, and hard films with good reproducibility by a relatively simple process. The growth of thin films strongly depends on growth conditions, such as duration of deposition, composition and temperature of the solution, and topographical and chemical nature of the substrate.

1.6 Conclusion

CdS thin films, with good structural and morphological qualities, have been successfully synthesized using the CBD technique without any post annealing treatment. The band gap energy was found to be around 2.42 eV with 70 to 95% of optical transmittance in the visible range. The main finding of this work is to show experimentally that performing CBD deposition in “several runs of optimized time” allows avoiding the supersaturation solution phenomenon which constitutes the major problem uncounted when seeking to control the thickness of the deposited films. Therefore, by adopting this based CBD process, it is possible not only to

overcome any film thickness limitation but also to grow the CdS films in a single technological step at a low solution temperature (60 °C) as well. We believe that this technique paves the way to deposit thin layers on several flexible substrates requested in the embedded electronic field.

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Chapter - 3
**A Literature Review on Various Parameters of
Parabolic Trough Collector**

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Chapter - 3

A Literature Review on Various Parameters of Parabolic Trough Collector

Dr. Jignesh G. Vaghasia

Abstract

In the present era of limited sources and pollutant types, conventional sources of energy need to have energy which is abundantly available on earth and non-depletion in nature. Solar energy is best option which is available on globe on day time but greatest drawback of it that is scattered in nature so device called concentrator is required to harness and magnify intensity of solar insolation. Parabolic trough collector is a widely used collector for industrial process heat and power plants. Much research has been done for increasing efficiency and heat transfer of Solar PTC, in this review paper different parameters suggested by various researchers have reviewed for increasing efficiency of PTC.

Keywords: Solar energy, parabolic trough collector, design parameter of PTC, enhancement of heat transfer.

I. Introduction

Within last few decades, there is significant need of energy due increasing population, increasing consumption pattern of energy by mankind & Industry, increasing global pollution and limited source of fuel for conventional form of energy leads increasing to reduce the dependency on fossil fuel. Therefore we need to have non-conventional forms of energy like ocean, wind, geothermal, and solar energy. Number of countries now centring on renewable energy. Among that solar energy is widely available across the globe also having great potential, it estimated that approximately an average $1000\text{W}/\text{m}^2$ energy is available on earth surface. Solar irradiation could produce 85000TW compare to present need 15TW , there has been an increasing effort from governments, industry and academic institutions to harness scattered form of solar energy and to improve efficiency of collector. Additionally rising pressure from various segments of society to diminish CO_2 emissions, has motivates the development of state of art technologies to decrease the

dependence on fossil fuels and the optimization of existing systems in order to minimize energy consumption.

There are two ways to gain electricity from the sun's energy. First by using the concentrating solar thermal system. In this method heat from the sun is focused to produce steam. The steam will run a generator to produce electricity. This type of configuration is typically used in solar power plants. In other ways photovoltaic (PV) cells are used to convert heat to electricity.

II. Design of solar concentrator

Solar concentrator is a device that allows the collection of sunlight from a large area and focuses it on a smaller receiver or exit. For the past four decades, there have been a lot of developments involving the following designs of the solar concentrators.

They are:

- Parabolic Concentrator.
- Hyperboloid Concentrator.
- Fresnel Lens Concentrator.
- Compound Parabolic Concentrator (CPC).
- Dielectric Totally Internally Reflecting Concentrator (DTIRC).
- Flat High Concentration Devices.
- Quantum Dot Concentrator (QDC).

III. Parabolic concentrator

The surface of the parabolic concentrator is formed by 2D design of a parabola. It is extensively used as a reflecting solar collector. A distinct property that it has is that it can focus all the parallel rays from the sun to a single focus point and it is not necessary to use the whole part of the parabola curve to construct the concentrator. Most of the parabolic concentrator uses only a truncated portion of the parabola. Presently, two types of designs of parabolic concentrators are available. One is by rotating the two-dimensional design along the x-axis to produce a parabolic dish, and the other way is by having a parabolic trough. Both designs act as reflectors and are widely used in concentrating solar power systems in big solar power plants. While this concentrator can deliver a high concentration, it necessitates greater field of view to maximize the sun energy collection. To acquire maximum efficiency, it necessitates a good sun tracking system, which is rather costly. That is why this type of concentrator is not preferred in a small residential house.

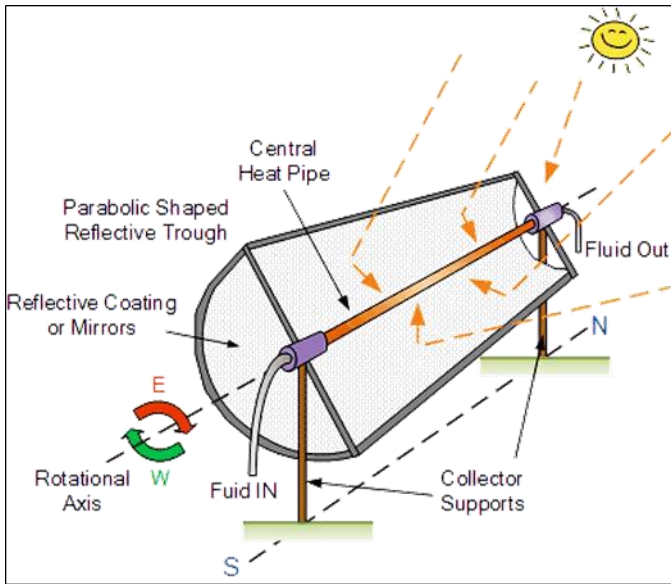


Fig 1: Schematic of parabolic trough collector

The growing need for energy and the depletion of conventional fuel has forced the man kind to think in the direction of non-conventional energy sources. One of the principal sources of non-conventional energy is the Sun. A large amount of solar energy is available in thermal form. The collection and concentration of solar thermal energy on the object is done with the help of Parabolic Trough Solar Collector (PTSC) for the temperature range 60- 600 °C. Solar flat plate collectors are available for temperature ranges lesser than 100 °C.

IV. Part of parabolic concentrator

Following are the main components of the parabolic trough collector. Assembling of all part to form PTC with providing heat transfer fluid at one end to gain concentrated heat from outer surface of absorber tube which is being reflected by reflective surface.

- 1) Parabolic Shaped Structure.
- 2) Reflective Surface.
- 3) Receiver Tube or Absorber Tube.
- 4) Support Structure or stand.

V. Literature review

Hossein Mousazadeh, *et al.* ^[1] reported that using the designed sun-tracking system, the experimental tests illustrated that 30% more energy was

collected in comparison to that of the horizontally fixed mode. Only 1.8% of all maximized energy is consumed by actuators of the designed tracking system.

Himanshu Tyagi, *et al.* [2] observed that the presence of nanoparticles increases the absorption of incident radiation by more than nine times over that of pure water. According to the results obtained from this study, under similar operating conditions, the efficiency of a direct absorption solar collector is increased by 10% in comparison with a flat plate collector while using nanoparticles in working fluid.

Accordingly Kawira M, Kinyua R., Kamau [3] the mean temperature working fluid was 150 °C whereas maximum temperature obtained was 248.3 °C. The material used for the absorber tube was copper and water is used as the heat transfer fluid. The concentration ratio of the given collectors was 128. The testing was done for different arrangements. When closed & open their efficiencies were for Aluminium sheet reflector PTSC; 55.52% & 32.38%, Car solar reflector PTSC; 54.65% & 34.45% and Aluminium foil reflector PTSC; 51.29% & 27.74% respectively.

JFM Escobar-Romero, *et al.* [4] used the reflective surface of the solar parabolic concentrator prototype with following dimensions: 200 cm of length, 100 cm in width, and 50 cm focal length. On a clear day we can achieve temperatures above 200 °C and pressures up to 12 Kg/cm².

J.K. Kaldellis, *et al.*, [5] used the concept of combining photovoltaic (PV) power stations and energy storage systems as a promising solution for small scaled autonomous electrical networks, increasing the reliability of the local network as well.

C.E. Kennedy, H. Price [6], mentioned that Improving the properties of the selective coating on the receiver represents one of the best opportunities for improving the efficiency of parabolic trough collectors and reducing the cost of solar electricity. Additionally, increasing the operating temperature above the current operating limits of 400 °C can improve power cycle efficiency and reduce the cost of thermal energy storage resulting in reductions in the cost of solar electricity. The coatings used don't have the required stability and performance, required to change to advanced working temperatures. The objective of this effort was to develop new, more-efficient selective coatings with both high solar absorptance ($\alpha \geq 0.96$) and small thermal emittance ($\epsilon \leq 0.07$ at 400 °C) that are thermally stable above 500 °C, ideally in air, with improved durability and manufacturability and reduced cost.

P. Sansoni *et al.*^[7] parabolic trough collectors were investigated, applying the study results to a plant prototype installed in Florence (Italy) for residential supply. Ray tracing simulations observed optical features and gathered performance on the base of prototype geometry and functionality. The objective was to regulate the comprehension errors and restrained the problems rising in the improvement of the solar trough plant. The study summarises the results of several studies analysing the interactions between collection efficiency, angular misalignments, mirror deformations, sun tracking and trough placement. The mirror distortions are repeated presenting a new procedure. The uncommon subject of imprecision in trough axis location is discussed.

Maria Dicorato *et al.*,^[8] noted that performances of a parabolic trough power plant of 100 kW size have been analysed. Two different types of one-axis solar tracking systems have been implemented, with horizontal and tilted rotation axes, to evaluate annual solar radiation. On the basis of simulations for analysing behaviour of sun-tracking parabolic collectors and statistical analysis of solar radiation data, annual electricity production has been calculated for both systems, showing notable advantage with respect to photovoltaic applications. Moreover, analysis on systems with inclined rotation axes on the horizontal plane has yielded better results, comparable to those from biaxial sun tracking.

The PTC as per R.M. Muthusivagami^[9], has to be oriented in one of the existing tracking modes to track the beam radiation. The concentrated solar energy from the sun is absorbed by absorber and transmitted to working fluid which flows inside the absorber tube. The sun rays instance at an angle in utmost of the tracking modes and that's why they reach to the focal line a slight after the length of the absorber tube. Hence the absorber tube should be long enough to intercept the reflected solar radiation. The study helps in calculating the increase in absorber tube length on both sides to intercept about 95% reflected solar radiation for smaller size parabolic troughs. This end effect study will be significant for pilot or small-scale set-ups in obtaining consistent test results.

Kody M. Powell *et al.*,^[10] mentioned the results of simulations show that by increasing the size of the solar field and adding 8 hours of storage capacity, the solar share (the fraction of energy provided by solar) of the power plant can be increased by over 80% to levels as high as 0.78. With enough storage capacity, it would be possible for a plant to operate 24 hours a day on only solar energy. However, economics dictate that this is not a financially optimal scenario.

E.S. Quintal *et al.* ^[11] the evaluation of the economic and technical viability for the installation of a solar air conditioning system based on parabolic solar concentrators and adsorption technology, in an existing building. A case study of the thermal system was carefully chosen for a university canteen which is placed in the centre region of Portugal. This system is used for air conditioning as well as for domestic hot water production, which permits the system to be used all over the year to make best use of the investment. Outcomes express that the operation of these systems is viable for the Portuguese climate and payback period of expenses can be realized in 84 months without any governmental monetary provision.

Yong Shuai *et al.*, ^[12] the radial stresses are very small both for uniform and concentrated heat flux dispersal circumstances due to the minute temperature across the surface of the receiver tube. The outer surface of the receiver tube faces the maximal axial stresses for uniform and concentrated solar radiation heat flux conditions. The impact of axial stress compared to radial stresses found higher on thermal stress. The temperature gradients and effective stresses of the stainless steel and Sic conditions are significantly higher than the temperature gradients and effective stresses of the aluminium and copper conditions. The stainless-steel condition has the highest stress failure ratio and the copper condition has the lowest stress failure ratio. Implementing an eccentric receiver tube for the parabolic trough concentrator system can diminish the thermal stress efficiently up to 46.6%. The oriented angle has a vast effect on the thermal stresses of the eccentric receiver tube. The thermal stress reduction of the tube receiver only occurs when the oriented angle is between 90° and 180°.

Emmanuel O. Sangotayo *et al.* ^[13] The parametric studies conducted investigating the heat transfer characteristics of fluids in the absorber in Cylindrical Parabolic Concentrating Solar Collector in Ogbomosho Climatic Conditions (lat 8°01', long 4°11'). Oil has highest heat transfer characteristics, Nusselt number values both with and without tape twist factor. It is perceived that tape twist factor increases the heat transfer characteristics of the fluids in cylindrical solar parabolic concentrating collectors. The higher value of heat transfer characteristics is obtained with the Nusselt number having a tape twist factor ($X = H/D_i$) in all the three fluids considered. In presence of high twisted tape in the absorber rises the friction factor and pressure drop leads to higher pumping power. The optimum design parameters are: length is 1.30 m, mass flow rate of fluid is 2.16 kg/min, outlet and inlet fluid temperature is 0.51 with instantaneous collector efficiency of 47.38%.

Also as per Emmanuel O. Sangotayo *et al.* [14] the energy equation for heat transfer of two dimensional fully developed fluid flow of the cylindrical parabolic trough collector have been considered and subsequently collector efficiency factor, F' , collector heat removal factor, Fr and collector overall heat loss coefficient, U_1 are used to analyse the thermal performance and to study the effect of mass flow rate \dot{m} , from 0 to 1.0 kg/s for the fixed value of incident solar absorbed flux, I_b of 186 w/m². The results revealed that the optimum design parameters are length 1.30m, mass flow rate \dot{m} of 2.16 kg/s, concentrator aperture width of 0.6 m, concentration ratio of 3.667, absorbed flux of 96.39, tilt angle of 8.2, fluid temperature of 0.05053 K and instantaneous efficiency of 47.4%. It is observed that performance of the cylindrical parabolic trough collector with twisted tape was enhanced appreciably.

S.K. Tyagi *et al.* [15] mentioned that the performance parameters such as the exergy output, exergetic and thermal efficiencies, stagnations temperature, inlet temperature, ambient temperature etc. are establish to be the increasing functions of the concentration ratio but the optimal inlet temperature and exergetic efficiency at high solar intensity are establish to be the decreasing functions of the concentration ratio. On the other hand, for low values of the solar intensity, the exergetic efficiency first increases and then decreases as the concentration ratio is increased. This happens due to the concentration ratio increases leading to collection temperature increase hence radiation losses increase. For lesser value of solar power, for a given mass flow rate there is an optimal value of concentration ratio at which the exergetic efficiency reaches its maximum value. Again it is also observed that the mass flow rate is a critical parameter for solar collectors and should be chosen carefully.

T. Yousefi *et al.* [16] has used Al₂O₃ water nanofluid, as working fluid, on the efficiency of a flat-plate solar collector was investigated experimentally. With the particle dimension of 15 nm the weight fraction of nanoparticles was 0.2% and 0.4%. They had performed the experiments with as well as without Triton X-100 as surfactant, with varied mass flow rate of nanofluid from 1 to 3 Lit/min. To calculate the efficiency the ASHRAE standard was used. The outcomes showed that as an absorption medium using the nanofluids as working fluid in comparison with water increases the efficiency. For 0.2 wt% the improved efficiency was 28.3%. From the outcomes it can be determined that the surfactant causes an improvement in heat transfer.

Balbir Singh Mahinder Singh, Fauziah Sulaiman [17] investigate that a rim angle of 90° is favoured as it provides an optimum intercept factor and allows

the depth to be the focal point. The focal point, where the rim angle is set at 90° can be calculated by using the width value alone, Simulation for various concentrations until its maximum theoretical value of 212, the model's efficiency increased until the concentration ratio stretched upto 10 for all 3 heat transfer fluids flowing in the receiver and then gradually decreased by at least 53 percent.

Tadahmun Ahmed Yassen ^[18] mentioned that the diameter was held at 0.03m so that the intercept factor γ has maximum value of unity. The rise of mass flow rate leads to high efficiency (40-65) % for the flow rate values (20.23-100) kg /hr. The efficiency starts from zero when the mass flow rate is zero because the heat removal factor is zero, and it increases quickly till it reaches about (62%) at mass flow rate of 40 kg/hr. That is, the increase of mass flow rate will decrease the absorber tube temperature so that the heat losses decrease and the heat removal factor is improved. The efficiency reaches a maximum at 40 kg/hr mass flow above which no more efficiency increase is observed.

VI. Outcomes of literature review

This include literature review of Solar Parabolic trough type collector that used for thermal and power production, analytical and experimental outcome of various researer summarized that;

- 1) Use of tracking system enhances the performance of the system however this consumes some power for it operation.
- 2) Use of Aluminum sheet as a reflecting surface will give more efficiency compare to other Car solar reflector and Aluminum foil reflector
- 3) Using proper selective coating on the receiver leads to improving the efficiency of parabolic trough collectors.
- 4) Increase in absorber tube length on both sides to intercept maximum reflected solar radiation for smaller size parabolic troughs is advisable.
- 5) Properly designed PTC used for air conditioning as well as used for domestic hot water production.
- 6) For an absorber tube the axial stress has more impact on thermal stress compared to radial stresses. The temperature gradients and effective stresses of the stainless steel and Sic conditions are significantly higher than the aluminium and copper conditions. Using copper as absorbing material is most suitable.

- 7) For lower values of solar intensity, there is an optimal value of concentration ratio for a particular mass flow rate at which the exergetic efficiency reaches its extreme value. Another time it is also perceived that the mass flow rate is a critical parameter for solar collectors and should be chosen carefully.
- 8) Comparison with water as an absorption medium using the nanofluids as working fluid increases the efficiency.

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Chapter - 4
**A Comprehensive Review of Different Types of
Solar Photovoltaic Cells**

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Chapter - 4

A Comprehensive Review of Different Types of Solar Photovoltaic Cells

Nishithendu Bikash Nandi, Shamim Ahmed Khan and Nitumoni Deka

Abstract

With increasing populations, industrialisations and economic progress, the demands for energy requirements increases day by day. To produce enough clean and low-cost energy for the future is one of the world's most important challenges. To overcome the energy crises, emphasis is placed on fabrication of solar cell/ photovoltaic cell as solar energy is the best source for renewable energy. This chapter summarizes the details description of solar cell along with working principle, types, applications etc. Among the different photovoltaic device, Dye sensitised solar cell (DSSC) is the extensively used thin film solar cell owing to its low-cost production, easy fabrication, recyclable and tunable optical properties.

Keywords: Renewable energy, solar cell, DSSC

1. Introduction

In current era Energy in different is the one of the important need of human society. Societies use energy for transportation, manufacturing, illumination, heating and air conditioning, and communication for industrial, commercial and domestic purposes. The most significant problem of this century are described below.

1.1 World energy crisis

Energy demand is rapidly increasing in the world today, particularly in the demand of electricity for households, commercial and industrial purposes. With rapid increase in population, industrialization and economical progress the energy requirement is increasing year by year. The affinity for oil, natural gas, coal and other non-renewable energy sources will increase globally by 40% by 2035 with a decrease in energy resource. Quality of life and global economy will be affected, with majority of the demand will be from countries like China and India. The possibility of a huge humanitarian crisis is evident.

The reserves of oil and gas have decreased by 40% and 70% respectively, which proves that someday the world would run out of conventional energy sources. In order to avoid this, new oil and gas fields and other conventional sources should be discovered and better cost-effective technology should be developed to utilize the un-ending source of renewable energy. Due to this, energy policy makers in European countries like Germany are investing huge amount of money on renewable energy technologies. The United States of America and the United Kingdom have also promoted bio-fuel as an alternative to fossil fuel. The current world oil and gas reserves can provide energy for a certain period of time at least 30 years. Within this period, in order to preserve the climate from drastic changes and utilizing fossil fuel efficiently, specific policies must be put into effect; energy efficiency and energy conservation, research and development of sustainable energy technologies. There should be an agreement platform for developed and developing countries to strive in CO₂ emission and global warming.

1.2 Global warming

Climate change is today's biggest threat to the human existence on earth. Planetary changes like anomalous rainfall pattern, vigorous droughts in some areas and increased rain in others, melting of ice cape and rise in sea level are signs of global warming. The world temperature is said to increase by 4°C by 2100, which will increase sea level by 30-100cm which is enough to drown islands like the United Kingdom. Major steps have to be executed in order to make the planet habitable. Global warming is simply a product of energy use. About 90% of the world energy is supplied through the combustion of fossil fuels (coal, oil, gas). When these fuels are burnt to make energy, electricity for example, a unit (kWh) of electricity used produces 0.5 kg of CO₂. For transportation, a litre of petrol burnt contributes 3kg of CO₂. Carbon dioxide which is the dominant gas in greenhouse gases including methane, nitrous oxide and fluorinated gases are responsible for global warming. In Figure 1.1, greenhouse emission by different sector is analysed. The Circle shows direct percentage share of GHG emission of five economic sectors. The extended part of electricity and heat production is related to sectors of final energy consumption. 'Other Energy' means all other minor GHG emission sources. AFOLU means emissions from Agriculture, Forestry and Other Land include land-based CO₂ emissions from forest fires and peat fires. Energy use and climate change are two sides of the same coin. [Tony Blair, 2006] As said earlier, global, economic and population growth continue to be the most important drivers of increases in CO₂ emissions from fossil fuel combustion because it leads to electricity demand. Electricity and heat production emit

more CO₂ than any other sector in an economy. Greenhouse effect, which occurs when CO₂ and other atmospheric gases (nitrogen, oxygen, water vapour, methane, nitrous oxide, and ozone) combine in large volume and form a cloud blanket over the earth surface trapping more sun light radiation which should have been freely escaped beyond the troposphere at a longer wavelength. The trapped long wavelength warms the earth beyond required temperature. These greenhouse gases act like a mirror that reflects the heat energy of the Sun's radiation back to earth instead of the radiation escaping. Currently, most of the CO₂ in the atmosphere are due to human activities and certain measures must be taken to curb such activities in order to have a habitable planet. Few countries like Denmark and Germany are stabilizing and working to reduce their CO₂ emission. Curbing and reducing CO₂ emission can not be addressed independently, but by interconnected global platform, where policies will be led in order to reduce the emission of CO₂ and one of the fastest growing means is adopting renewable energy.

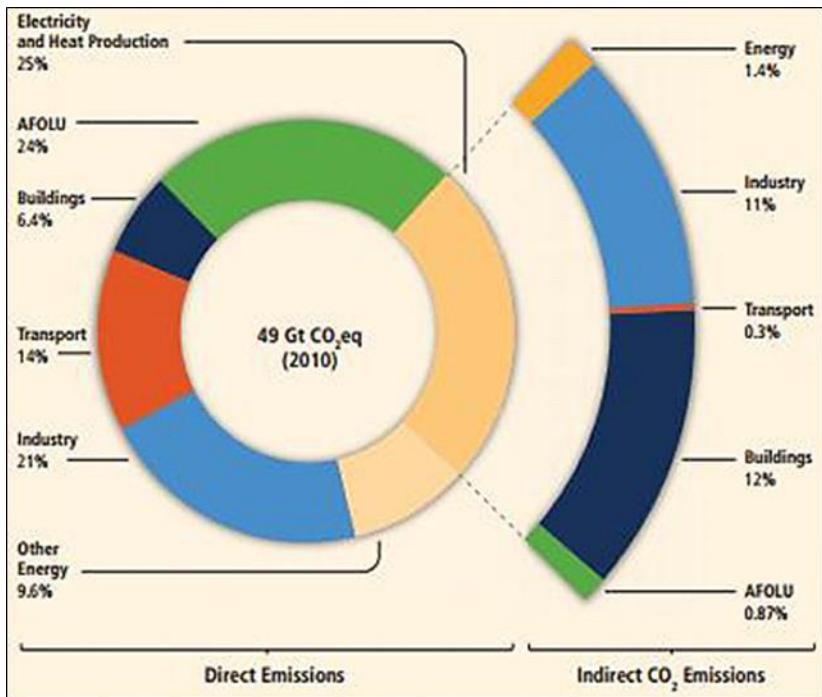


Fig 1.1: Total anthropogenic GHG (GtCO₂/ yr.) by different economic sectors

1.3 Solar energy for billions of years

The sun has been the source of energy flow for survival in the eco- system. The utilization of the sun's energy started out by concentrating the sun's heat

with glass and mirrors to light fires and today, cars, houses and electronic gadgets are solar-powered. The energy from the sun is free but device use in converting this energy isn't free. There has been so many research and developments on different technologies to harness the energy from the sun but the available technology produces about one tenth of one percent of global energy demand. The sun radiates energy in the form of electromagnetic radiation in space and the amount that reaches the earth is about $1\text{kW}/\text{m}^2$ depending on the latitude and location weather pattern. The inner and surface temperature of the sun is about $2.0 \times 10^7\text{K}$ and 6000K respectively. The huge amount of temperature and unlimited energy from the sun is produced through some fusion reaction or proton-proton reaction which occurs in core of the sun. Three quarters of the Sun consists of hydrogen, with helium being mostly the rest and smaller quantities of heavier elements like oxygen, carbon, neon and iron.

1.4 What are solar cell

Non-renewable energy sources are degrading due to the rapid population growth and development of Industrialization. Renewable energy sources are better alternative to manage human requirement and solar energy is the best source of renewable energy. The utilization of solar energy can be made possible by the fabrication of solar cells. Basically the solar cells are the electronic devices which converts solar energy to the electrical energy by the photovoltaic phenomena which is a physical and chemical phenomena. It is a device whose electrical characteristics such as electric current, voltage and resistance vary when exposed to light. The solar cells consists of different semiconducting materials as the main absorbing layer and hence working of solar cell depends on the semiconducting materials that we are choosing. The important characteristics like absorption coefficient, band gap, mobility of carriers and diffusion length are important parameters for the application of solar cell. The operation of photovoltaic cell requires three basic attributes

- i) The absorption of light and generation of electron and hole pairs i.e. formation of excitons.
- ii) The separation of charge carriers of opposite types.
- iii) The separate extraction of those carriers to an external circuit.

In 1876 British scientists Adams *et al.* found that a selenium semiconductor could produce electricity when it was radiated under sunlight. In 1954, Pearson *et al.* from US bell labs developed the first piece of crystalline silicon solar cell and achieved a conversion efficiency of 4.5% thus beginning a new era for the utilization of solar power.

1.4.1 Electronic characteristics of solar cells

Photo current and Quantum efficiency, Photocurrent J_{sc} , generated by a solar cell at short circuit condition is dependent on the photon flux. To relate the current and photon flux of a solar cell, a good understanding of the cell quantum efficiency is required. Solar cell quantum efficiency is the probability that a photon of certain energy E , can deliver an electron to an external load from the solar cell.

$$J_{sc} = q \int b_s(E) Q_E(E) dE \quad (1)$$

Where q is the electronic charge in coulombs, E is the energy of incident photon $b_s(E)$ is the incident photons flux density incident on a unit area per time having energy ranging from E to $E + dE$. Q_E is determined by the solar cell material absorptivity, it's independent of the incident spectrum. Q_E and the incident spectrum can be given as a function of either photon energy E , as in equation (4) or spectrum wavelength λ .

1.4.2 Short circuit current and open circuit voltage

The main important feature of any kind of solar cells are their open circuit voltage and short circuit current.

The open circuit voltage (V_{oc}) is the voltage between the terminals when no current is flowing through the circuit or load resistance is infinite as shown in figure 2. The short circuit current (I_{sc}), is the current when the terminals are connected to each other with no load resistance as shown in Figure 2. They are the most important characteristic of a solar cell. Short circuit current increases with concentration of photons. Increase in photons concentration means more photons on a unit square area of the cell, which in turn means more electrons and holes generated. Since the short circuit current I_{sc} is proportional to the area of the solar cell, therefore the short circuit current density can be seen as

$$J_{sc} = \frac{I_{sc}}{A} \quad (2)$$

When a voltage difference between the two terminals flows through the load is created then a dark (diode) current flows in opposite direction to the short circuit current.

$$J_{dark}(V) = J_o(e^{\frac{qV}{kT}} - 1) \quad (3)$$

Whereby J_o is the reverse saturation current of the p-n junction and it depends on the doping and on the properties of the semiconductor, K_B is Boltzmann constant, T is temperature, q is the electron charge and V_{OC} is the

voltage between the poles. The net current, J can be given as a superposition of the short circuit current and the dark current:

$$J = J_{sc} - J_o \left(e^{\frac{qV}{k_B T}} - 1 \right) \quad (4)$$

This then leads us to the open-circuit voltage, V , which is the maximum voltage available from a solar cell with no current available

$$V_{oc} = \frac{qV}{k_B T} \ln \left(\frac{J_{sc}}{J_o} + 1 \right) \quad (5)$$

1.4.3 Efficiency

The photovoltaic conversion efficiency is used to compare the performance of different kinds of solar cells. It's the ratio of output power generated from the fabricated solar cell device to the input solar radiation power. The performance of a solar cell depends intensity of the incident sunlight, air mass and the temperature of the testing location.

$$\text{Efficiency} = \frac{P_{dm}}{P_{in}} = \frac{V_{oc} J_{sc} FF}{P_{in}} \times 100 \quad (6)$$

P_{in} is the incident radiation power density which is 1 kW/m² for AM 1.5 radiation and maximum power density of the solar cell. The power density is the product of voltage V and current density J , we get power density to be

$$P = IV ; P_D = JV \quad (7)$$

The maximum power density is

$$P_{dm} = J_m V_m \quad (8)$$

Fill factor, FF is defined to be the ratio of the maximum power generated by the cell divided by open circuit voltage and short circuit current. Fill factor explains the maximum power that can be extracted from the solar cell devices.

Mathematically, it can be written as

$$FF = \frac{J_m V_m}{V_{oc} J_{sc}} \quad (9)$$

J_m and V_m are the current density and voltage respectively, at the maximum power point (MPP) as shown in Figure 1.4 but the power in the figure is in W rather than power density in W/m².

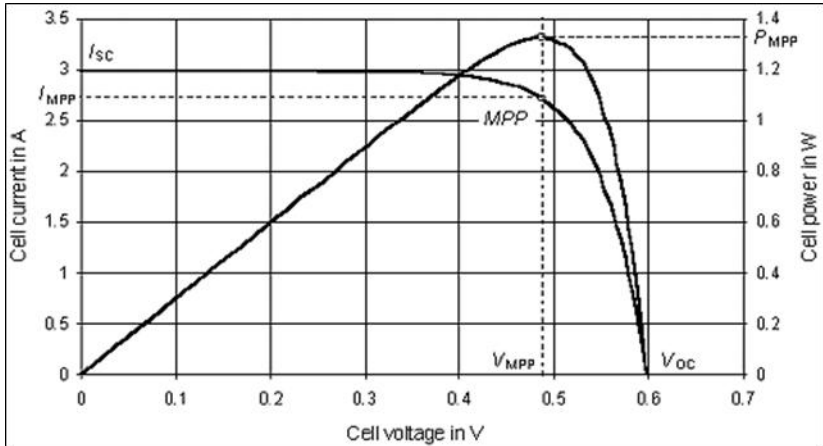


Fig 1.2: Graph showing short circuit current-open circuit voltage and power voltage solar cell characteristics, including the maximum point of both current and voltage which gives the maximum power point

In an ideal solar cell, the series resistance R_s should equal to zero and the shunt resistances, R_{sh} should be large enough or equal to infinity. Unfortunately, that isn't the case. There are manufacturing defects in silicon during production which then creates another current path for the light-generated current in the solar cell resulting into low power output. R_s and R_{sh} influence the I-V curve slope of a solar cell. The I-V equation of a non-ideal solar is given as

$$I = I_{ph} - I_{01} \left(e^{\frac{V+IR_s}{kBT}} \right) - I_{01} \left(e^{\frac{V+IR_s}{2kBT}} \right) - \frac{V+IR_s}{R_{sh}} \quad (10)$$

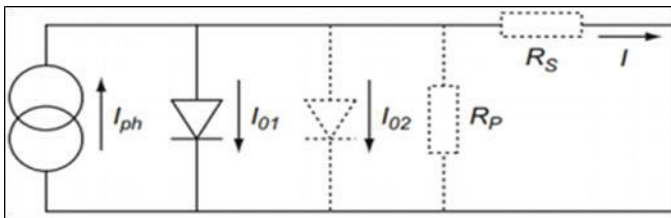


Fig 1.3: Equivalent circuit for an ideal solar cell is represented by the full line. Dotted line shows the non-ideal components

1.5 Type of solar cells

The main absorbing layer of the solar cells are semiconductor devices and hence the classifications are based on the semiconducting device that we are using for fabrication process. Solar cell can be made of one single layer of light absorbing layer or use multiple physical configurations to take

advantages of various absorption and charge carrier mechanisms. Solar can be classified into first, second and third generation solar cells. The first-generation solar cells are traditional silicon based solar cells. The second-generation solar cells basically cadmium telluride thin film solar cells. The third-generation solar cells are basically dye sensitized solar cells.

1.5.1 First generation solar cells

The Semiconducting material used for light absorbing layer in first generation solar cells are silicon and hence these are also called silicon based solar cells. Here the absorbing layer can be made up of one single crystal called mono-crystalline or cut from a block of silicon that is made up of many crystals called multi crystalline. First generation Solar cells have been commercialized due to the following reasons

- i) Silicon has an indirect band gap of 1.1 eV which explains silicon as the best candidate for solar cell applications.
- ii) Crystalline silicon is very stable material.

1.5.1.1 Monocrystalline silicon solar cell

The m-Si technology has achieved efficiencies of 24.4% ^[1]. Basically the m-Si silicon solar cells are manufactured by the Czochralski process, which consists in the growth of Si ingots from small monocrystalline silicon seeds ^[2] and subsequently cut them to obtain m-Si wafers. The process allows the production of crystals with diameters ranging from 10 up to 300 mm, and lengths from 50 cm up to 2m ^[2]. However, the Czochralski process involves a high production cost owing to several reasons

- i) It requires Si of very high purity (known as solar grade silicon) to avoid contamination by the raw materials ^[3], since it would lead to defects in the structure and worsening of the electrical properties.
- ii) Energy consumption is high, due to heat losses via conduction and radiation through the seed.
- iii) Temperature must be controlled to maintain the crystal growth during the long production time.

1.5.1.2 Polycrystalline silicon solar cell

The p-Si cells are manufactured on poly silicon wafers, which consists of small Si crystals randomly oriented. They present several advantages compared to the m-Si ones: they involve less energy their production and less associated greenhouse effects. However, this type of PVCs can only the efficiencies of 19.9% ^[4], smaller than m-Si based cells.

The main reason for this smaller efficiency is the lower material quality due to grain boundaries and defects, and the higher concentration of impurities. Therefore, the influence of recombination in p-Si solar cells is more than in m-Si cells, which leads to a slightly lower voltage. Current is also lower due to incomplete carrier collection in these devices.

P-Si can be obtained at an industrial scale by the Siemens process, initially developed for electronic applications in the 1950s^[5]. In general, the process consists in a gasification of the metallurgical grade Si, a distillation of the product and a final deposition to obtain ultra-pure silicon.

1.5.2 Second generation solar cells

The second generation focuses on thin-film technologies with the aim of reducing the high costs associated with the first generation by using lower amount of material and poorer quality, deposited on cheap substrates. It is based on material identified as potentially useful during the development of first generation and was extended to include amorphous-Si, CdTe, copper-indium selenide (CIS), Copper-Indium-Gallium-diselenide (CIGS). The second-generation solar cells have following advantages^[6].

- i) Cheaper compared to Si-based solar cells.
- ii) Drastic reduction in the amount of materials needed. Sometimes only one-micron thick layer is required.
- iii) High absorption coefficient
- iv) Can be used in both vacuum and non-vacuum process.
- v) Most of technologies allow direct integration into a higher voltage module (i.e., a-Si), which reduces the no of production stages compared to the first generation-PVCs.

However they show disadvantages^[6]

- i) Light-induced degradation in first stages of outdoor usage. Higher degradation in outdoor uses; the semiconductor deposited onto glass can generate a flow of ions in the glass. In the case of amorphous silicon, this problem can occur even if the substrate is not glass. Environment contamination starts from fabrication process.
- ii) In some technologies, the availability of manufacturing materials may not be abundant.

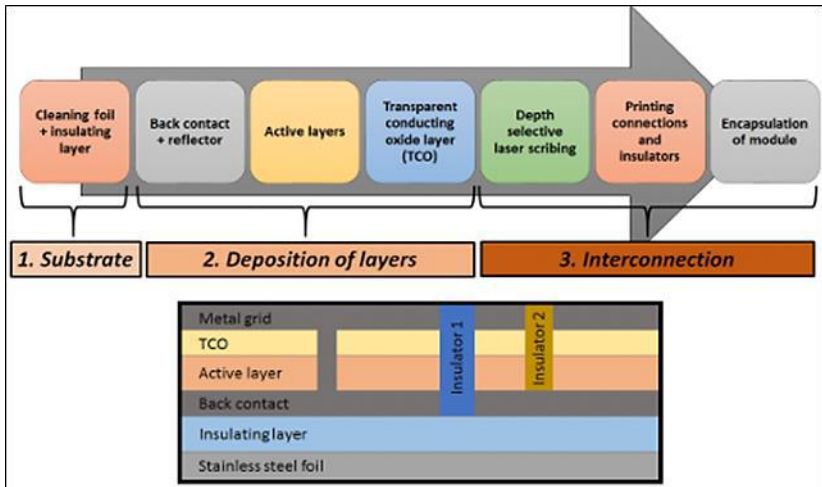


Fig 1.4: Schematic representation of a-Si based solar cell ^[7]

The most commonly used third generation solar cells are Cadmium Telluride thin film solar cells. Cadmium Telluride (CdTe) is a semiconductor compound with a band gap of 1.45 eV, which makes it a good candidate for converting sunlight into electricity in single junction cells ^[8].

1.5.3 Third generation solar cells

The third-generation solar cell arises from the idea of increasing device efficiency and reducing the distance to the Carnot limit, which is nearly 60% above the Shockley-Queisser limit ^[9]. Its aim to develop devices with high efficiencies using the thin layer deposition techniques employed for the second Generation and/or new architectures or materials; this may lead to an increment in the area cost, but the cost per watt peak would be reduced. In addition, Si based cells third generation PVCs use non-toxic and very abundant materials, hence are suitable for the large-scale implementation of Photovoltaic cells ^[6]. Further, they may employ new nanostructured or organic materials that could achieve high efficiencies (greater than 60%) using phenomena such as the hot carriers collection ^[10], the generation of multiple carriers (impact ionization) ^[11] or new semiconductor architectures that contain multiple energy levels. Considerable attention is paid to charge and energy transferable process and routes to optimize charge collection and improve the energy capture within the solar spectrum ^[12].

The main advantages of 3 generation solar cells are

- i) Solution process able technologies.
- ii) Suitable for large scale production.

- iii) Mechanical robustness.
- iv) High efficiencies at high temperature.

In recent days, development of clean and renewable energy, Dye sensitised solar cells are the strong contender as a next generation solar cell technology^[13]. Dye Sensitized solar cells (DSSC), also sometimes referred to as dye sensitised cells (DSC), are a third generation photovoltaic (solar) cell that converts any visible light into electrical energy. This new class of advanced solar cell can be likened to artificial photosynthesis due to the way in which it mimics nature's absorption of light energy. It is a low-cost solar cell belonging to the group of thin film solar cells. Dye Sensitized solar cells (DSSC) were invented in 1991, which is the first developed solar cell by the successful combination of nanostructured electrodes and organic/natural dyes^[14]. Oxides such as TiO₂, zinc oxide, tin oxide, niobium oxide or chalcogenides such as cadmium selenide are the preferred electrodes. Among them, TiO₂ have good chemical stability under visible irradiation in solution^[15] and stable photo electro-chemical system even under extreme operating conditions. It is cheap, readily available and non-toxic. In DSSC, Chemical dye is employed to capture photons from solar energy and using captured photons, electrons are ejected from the surface of the metal nanoparticles which is chemically attached to the dye molecule^[4]. Various organic dyes have been employed for this purpose owing to its Low cost, ease of synthesis, materials abundance etc.^[16]. For a better efficiency, dye molecules must have some following requirement's^[17]:

- a) It should have strong absorption in the visible region.
- b) It should strongly adsorbed on the semiconducting surface. For that, dye molecule must possess =O or -OH groups (anchoring group) which is capable is chelating to the Ti(IV) sites of the TiO₂ surface.

DSSC is a disruptive technology that can be used to produce electricity in a wide range of light conditions, indoors and outdoors, enabling the user to convert both artificial and natural light into energy to power a broad range of electronic devices. The DSSC has a number of attractive features; it is simple to make using conventional roll-printing techniques, is semi-flexible and semi-transparent which offers a variety of uses not applicable to glass-based systems and most of the materials used are low-cost. In practice it has proven difficult to eliminate a number of expensive materials, notably platinum and ruthenium and the liquid electrolyte presents a serious challenge to making a cell suitable for use in all weather. Although its conversion efficiency is less than the best thin-film cells, in theory its price/performance ratio should be

good enough to allow them to compete with fossil fuel electrical generation by achieving grid parity.

The overall chemical reaction that involved in DSSC are as follows ^[24]:

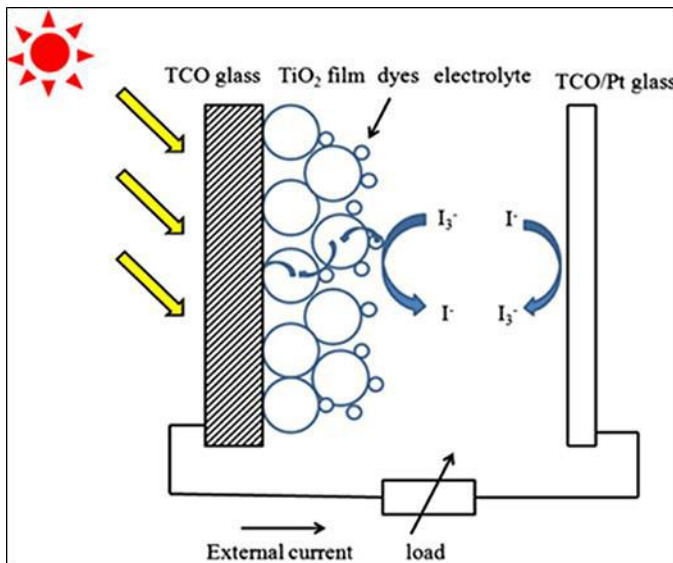
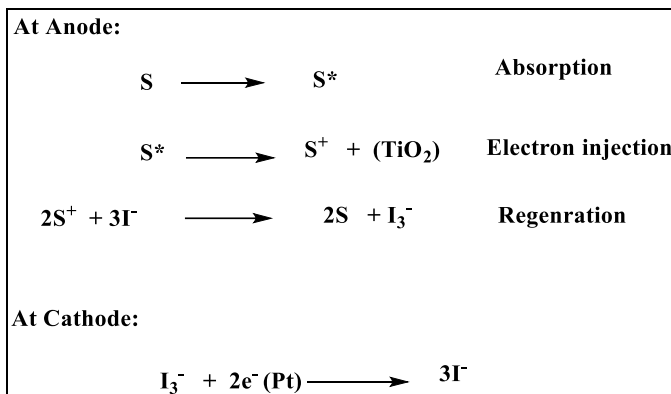


Fig 1.5: Schematic representation of a DSSC ^[18]

However, the main disadvantages of this dye sensitized solar cells are the use of liquid electrolytes which are not very stable at varying temperatures. Therefore, a significant effort has been taken in order to replace the liquid electrolyte by the p-type conducting polymer material ^[19].

In general, there are various different types of photosensitiser have been used to improve the efficiency viz. simple organic dye molecule, natural sensitizer and metal complex. In 2009, Japanese scientists Kojima *et al.* found

that the organic metal halide perovskite was similar to dyes and can absorb sunlight [20]. Despite of perovskite-based photosensitiser [21], the majority of the metal complex used in DSSC are ruthenium compounds [19, 22]. The novel properties like high absorption coefficient, longer diffusion length, lower recombination rate and high mobility rate have attracted researchers worldwide to carry research on this photovoltaic technology.

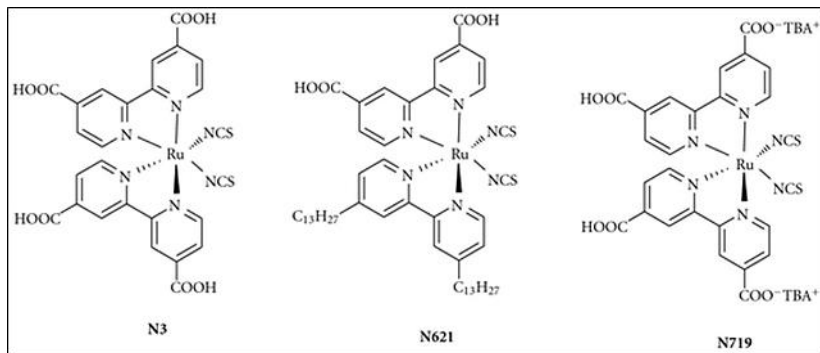


Fig 1.6: Chemical structures of some Ru-based photosensitiser [23]

1.6 Conclusion

In recent days, demands for renewable energy sources have gain considerable interest because of continuous increase of World's population together with development of industry. To overcome the energy crises, the various renewable energy technologies have been used which converts solar energy into electricity. Among the different photovoltaic device, Dye sensitised solar cell is belonging to thin film solar cell, extensively used because of low cost production, easy fabrication, lighter weight, recyclable and tunable optical properties.

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Chapter - 5
Adsorption Based Greenhouse Systems for
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Chapter - 5

Adsorption Based Greenhouse Systems for Sustainable Agriculture

Suresh Kannan V and Lenin V.R

Abstract

Greenhouse systems gaining importance nowadays for optimal growth conditions of fruits and vegetable. The covers used in Greenhouse safeguards inside-plants from hostile climates and, with the suitable additional systems, provides the crop microclimate, thus results in high yields with good quality. Sustainable greenhouse agriculture could be achieved by having varied techniques for cultivation, with suitable equipment aimed to lessen pesticides and energy use, and water requirement. Desiccant systems assisted with evaporative cooling technology seems better solution for providing optimal micro climate inside the greenhouse systems. Solar thermal systems could be used as an additional system for regeneration purpose of saturated desiccant and thus minimizing energy cost associated with continuous operation. The chapter presents the importance of greenhouse farming, types of greenhouse system, and inside-climate control strategies. In addition, it considers economic analysis of medium and high-cost greenhouse systems.

Keywords: Greenhouse farming, sustainability development, desiccant systems, evaporative cooling

1. Introduction

By 2050, the world will have almost 10 billion mouths to feed. Agricultural production will need to grow by 50%. By 2050 there will be 20% less arable land and 50% less available water. Over 70% of our freshwater is consumed by agriculture. The average person's daily water footprint is 5500 litres. Precision irrigation saves upto 50% water compared to flood irrigation, increases average productivity by 30-50%, improves fertilizer use efficiency by 30%, reduces grower dependency on rainfall and manpower and operational costs and reduces greenhouse gas emissions by upto 90% compared to flood irrigation and reduces energy consumption by 35%. Therefore, sustainable agriculture is need of hour to meet the growing demand

of food. Greenhouse farming will address the challenges in sustainable agriculture. Greenhouse farming uses enclosed space made of structure with transparent walls and roof to grow plants. Enclosed space protects the plants from extreme climates pertaining to sudden variation of temperature and humidity. Due to optimal climate conditions, the increase in yield is witnessed. Greenhouses is useful in preventing pest problems and related diseases. The plants can be cultivated year-round since it uses climate-controlled environment since the outside climate does not influences the inside one.

A desiccant cooling system based on solar energy seems very attractive due to its adaptation in phase with high required cooling demand [1-4]. The conventional vapour compression system for air conditioning is energy consuming and in contrast to that the desiccant cooling system with solar energy is promising one to provide suitable climatic conditions. It is most suitable in terms of energy since it uses free energy for its regeneration of saturated desiccant [5]. Lee *et al.* (2013) [6] conducted experiments to compare conventional vapour system with desiccant assisted system. The test results confirmed that the desiccant systems assisted with solar energy helps in reduction of carbon-di-oxide emissions by 13%. Hirunlabh *et al.* [7] performed investigation to study the applicability of desiccant system and results showed that it is most suitable for hot and humid climate by helping to save 24% of electrical energy. Hourani *et al.* [8] investigated the system with evaporative cooling in two stages. The test results concluded that a reduction of 16% and 27% is achieved on energy consumption and water consumption respectively when compared to an evaporative cooling system.



Fig 1: Photographic view of greenhouse systems

This chapter exposes the results obtained from the study of a adsorption based greenhouse system for sustainable agriculture.

2. Materials and Methods

Variety of greenhouse structure based on shape, construction method, material and method of ventilation are used for crop production. Each type of

green house has its own advantages. All are designed according to specific needs. In India, greenhouse of sawtooth natural ventilation type is mostly used for vegetable and cut flower cultivation purpose. The components of greenhouse are shown in Fig. 2.

Based on shape, green house systems are categorized as Gable, flat arch, tunnel, dome, tri-penta, saw tooth, skillion green house, uneven green house, A-frame green house, ridge & furrow green house, gothic green house, shaded green house, lean-to type green house and Igloo type systems. The schematic diagram of these types of systems are shown in Fig. 3.

Fig. 4 shows the schematic diagram of greenhouse farming elements. The hot and humid process air flows through the adsorption section of desiccant wheel and the water vapour is adsorbed by desiccant wheel from the process air (1-2). At this stage, the temperature of dehumidified air increases and in turn humidity ratio decreases due to heat of adsorption. Then process air temperature is lowered by passing through heat exchanger (2-3), to precool the process air stream and in the pad cooling system (3-4). The return air from the greenhouse is used to cool the process air stream in the heat exchanger (5-6). Then its temperature is raised to regeneration temperature of saturated desiccant by an auxiliary heater of solar energy (6-7) to ease to get continuous dehumidified air that is needed for the greenhouse systems.

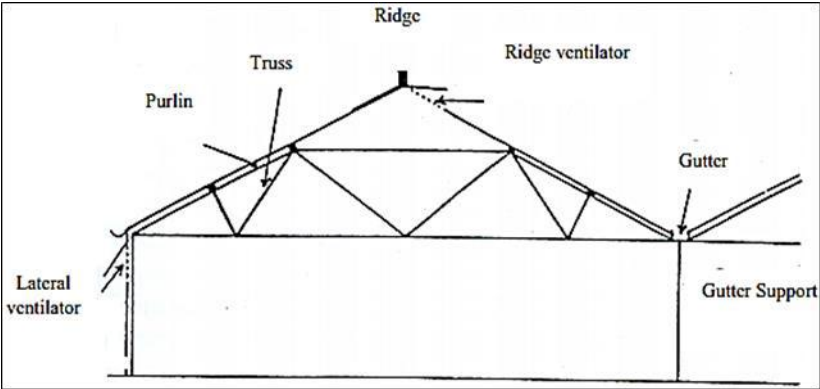


Fig 2: Components of greenhouse

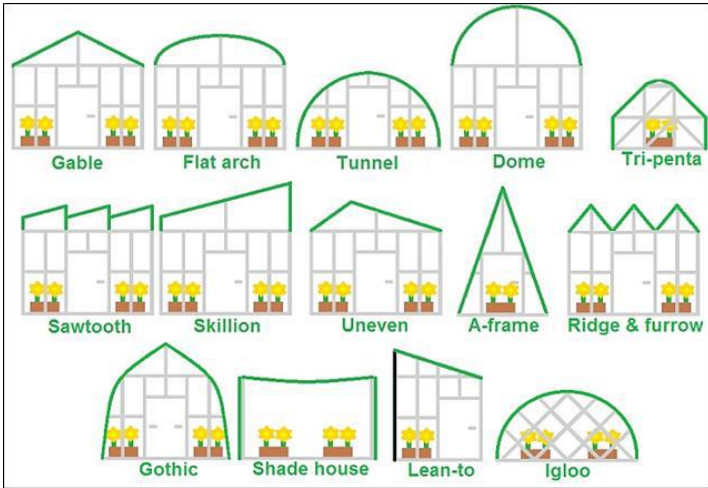


Fig 3: Greenhouse system based on shape

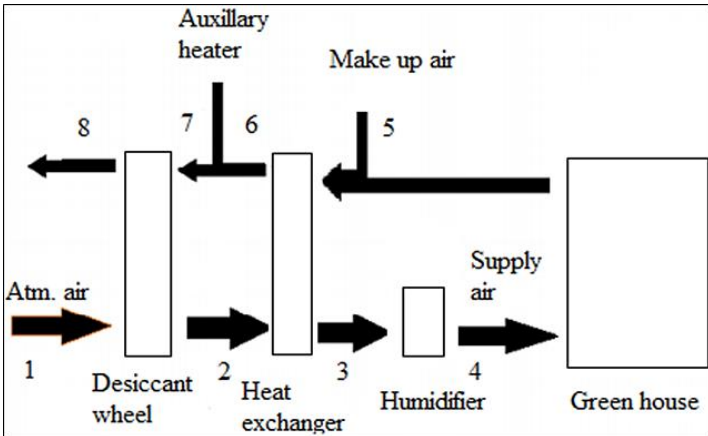


Fig 4: Schematic diagram of greenhouse farming elements

3. Results and discussion

3.1 Dehumidifier energy consumption

The total energy consumption of the dehumidifier is calculated from the summation of electrical energy consumption, the sensible heat load of the motor and the latent heat load by the condensate.

3.2 Dehumidifier energy factor

The energy factor is used to evaluate the performance of dehumidifier and is calculated from the ratio of total water quantity removed per unit of electricity used by the dehumidifier at standard conditions.

3.3 Adsorption capacity of desiccant wheel

Fig. 5 shows the variation of adsorption capacity of desiccant wheel with respect to varied air flow rate during adsorption. It is noted that the adsorption capacity decreases with rise in mass flow rate of process air. When flow rate is increased, there was lesser contact of air with the desiccant honeycomb structure and thus results in decrease in adsorption capacity. At 0.4 kg/s air flow rate, the desiccant wheel performs better in adsorbing the water vapour from the process air.

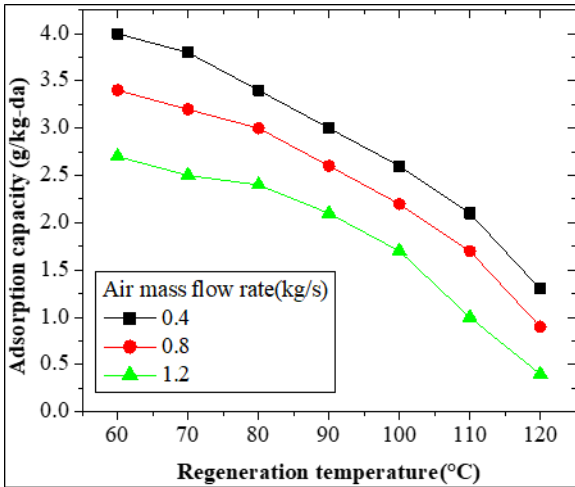


Fig 5: Variation of adsorption capacity of desiccant wheel with respect to air flow rate

3.4 Desorption capacity of desiccant wheel

Fig.6 shows the variation of desorption capacity of desiccant wheel with respect to varied air flow rate during adsorption. It is noted that the desorption capacity decreases with fall in mass flow rate of process air. When flow rate is decreased, there was lesser contact of air with the small portion of desorption area in desiccant honeycomb structure and thus results in decrease in desorption capacity. At 1.2 kg/s air flow rate and at 120 °C regeneration temperature, the desiccant wheel performs better in adsorbing the water vapour from the process air.

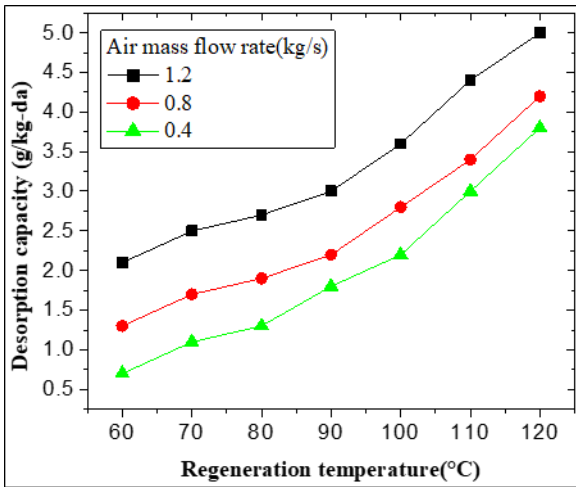


Fig 6: Variation of desorption capacity of desiccant wheel with respect to air flow rate

3.5 Variation of temperature in the elements of greenhouse farming stages

Fig. 7 shows the variation of different elements' temperature in the stages of elements of greenhouse farming. The ambient air moisture (T_1) is adsorbed by the solid desiccant wheel, and thus leads to raise in temperature due to heat of adsorption (T_2). The increased temperature is lowered down in heat exchanger (T_3) with the return air from greenhouse for precooling. Then the air is cooled in a humidifier (T_4)^[9-16].

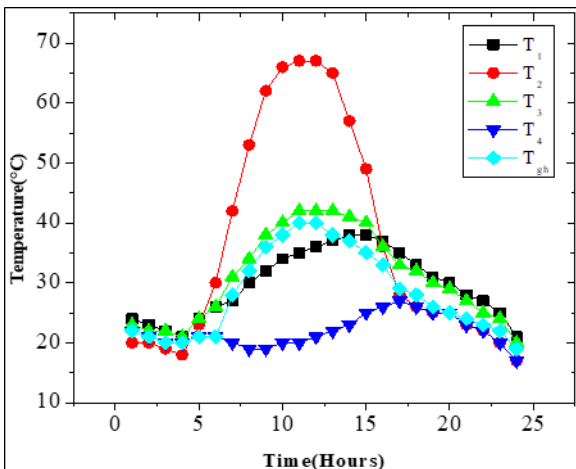


Fig 7: Variation of temperature in the greenhouse system

3.6 Economic analysis

Table 1 shows the economics of multispan structure greenhouse. The given cost estimation may vary slightly according to the crop variety, material used for cladding, the system used for environment control.

Table 1: Economics of medium cost greenhouse

S. No.	Specifications	Cost per square metre
1.	Multilayer polyethylene cover	150
2.	Evaporative cooling system	300
3.	Carbon di oxide distribution	225
4.	Heating and humidification system	300
5.	Lighting	300
6.	Shading system	225
7.	Drip system	30
8.	Nutrient supply system	150
9.	Flooring	600
10.	Construction	450
11.	Other expenses	300
Total cost per square metre		3030

4. Conclusion

This chapter aims to through some light on the performance of elements of greenhouse system assisted with desiccant wheel and pad cooling system. In this study, the dehumidification system coupled for greenhouse insulation to maintain optimum range of temperature to get maximum crop yield. The test results showed that environment temperature inside the greenhouse system coupled with adsorption wheel is maintained at 33 °C in average which was most suitable for plants growth. During summer season the process air is 10 °C cooler that surrounding ambient conditions. The cost analysis also showed that the greenhouse system assisted with adsorption wheel is found attractive and can be rented since the payback period is 1.02 years.

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Chapter - 6
Production of Energy Efficient Bio Fuel by the
Addition of Metal and Metal Oxide Nanoparticle:
An Overview

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Chapter - 6

Production of Energy Efficient Bio Fuel by the Addition of Metal and Metal Oxide Nanoparticle: An Overview

Srinivasan Periasamy Manikandan, Dharmakkan Nesakumar and Natarajan Deepapriya

Abstract

In recent days, varieties of applications were derived from novel nano materials. One among them is the addition of nanomaterial in biofuel. “Biofuel” is a renewable and bio degradable liquid fuel mainly produced from domestic vegetable oil, plant oils and recycled cooking oils. It is an alternative fuel used as a blend in CI engines, which reduces green house gas emissions also. Recent research proved that the blend of biodiesel perform well in cold temperatures. Recently, nanosized metal/metal oxide particles were suspended in a bio fuel (base fluid), by which the properties of the base fluid gets enhanced significantly. By changing its thermo physical properties it is possible to produce energy efficient bio fuel. Based on the number of experimental investigations from literature, it is noted that with a wide variety of nano additives the fuel properties and the engine performance could be significantly improved. In this chapter, an overview on the Production of Bio fuel by the addition of metal and metal oxide nanoparticle was discussed. This chapter initially explains about the studies on thermal conductivity, viscosity, specific heat capacity, heat transfer and rheological properties performed with nano particle addition in different base fluids. Then provides the detail on improvement made in bio fuel production by the metal/metal oxide nanoparticle addition. Finally, the chapter concludes with possible further research aspects of bio fuel production using nanoparticle.

Keywords: Bio fuel, energy, heat transfer, nanoparticle, rheological, thermo physical

Introduction

“Nanotechnology” is the field applies in the study of matters on an atomic, supra molecular and molecular scale. Based on the National Nanotechnology Initiative the nano materials is a matter sized from 1 to 100 nano meters ^[1]. Different applications were derived from researchers to

produce variety of novel nano materials ^[2]. The recent experiments by the researchers show that the solids with nanosize possess very good thermo physical and heat transfer properties like higher thermal conductivity, Viscosity, Density, Specific heat capacity etc., which could be utilized for many industrial applications ^[3]. Metals, Metal oxides, CNTs and carbides were used in the preparation of nanofluid ^[4].

The following areas are some major areas in which nanofluids are utilized, because of its significant thermo physical and heat transfer properties ^[5-7].

- Catalysis
- Microelectronics
- Hybrid-powered engines
- Heat and mass transfer
- Fuel cells
- Pharmaceutical processes
- Engine cooling/vehicle thermal management
- CO₂ sequestration
- Solar collectors
- Domestic refrigerator
- Bio fuels

Among the above applications, nanofluid addition in Biofuel is a latest area identified by the researchers. Since Bio fuel is an alternative fuel source to extend the value to conventional or fossil fuels. Due to its closed carbon cycle, this bio fuel mainly reduces the greenhouse gas emissions, which safe guard our environment.

Figure 1 represents the overall layout of the chapter which includes the distribution of chapter topics with respect to energy efficient bio fuel production by mixing nanomaterials.

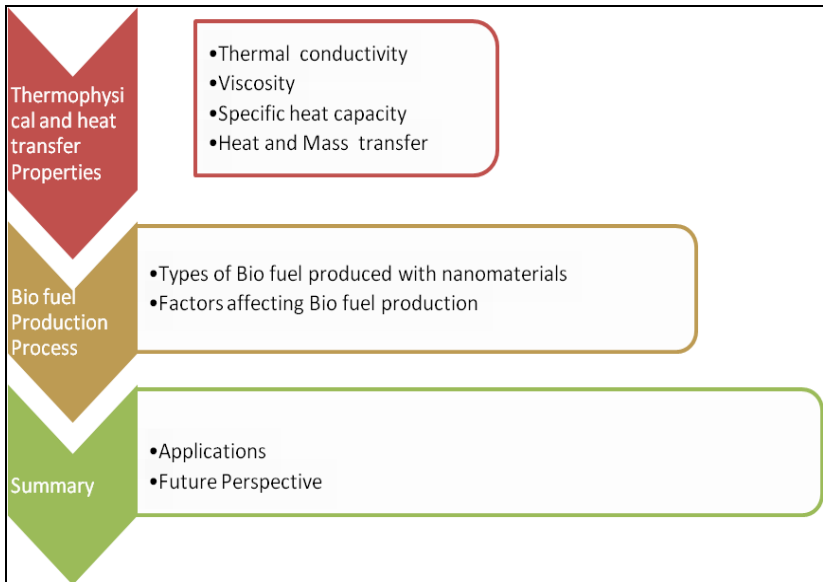


Fig 1: Overall Layout on Energy Efficient Bio fuel production by mixing Nano material

Studies on thermo physical and heat transfer by nanomaterials

From the literatures it was noted that solids of metals/ metal oxides have high thermal conductivity than conventional heat transfer fluids such as propylene glycol, ethylene glycol, water, engine oil etc. From the inception of a concept “Nanofluid”, many research publications have arrived to explore the unique properties and capabilities shown by this new engineering fluid. An innovative idea was initiated by Choi *et al.* [8] to enhance the thermal conductivity of conventional fluids by mixing nanoparticle in it. This initial idea of nanoparticle mixing in base fluid provides opportunities and challenges for process and thermal engineers.

Thermal conductivity

Thermal conductivity plays a major role in altering the properties of base fluids. This section deals with the literatures related with Thermal conductivity studies conducted with nanomaterials.

Lee *et al.* [9] conducted study on thermal conductivity behaviour of metal oxide suspended nanoparticle and observed significant enhancement in thermal conductivities of nanofluid than the conventional liquids without nanoparticle. They have used CuO/water, CuO/ethylene glycol, Al₂O₃/water and Al₂O₃/ethylene glycol nanofluid for their study. They have reported the

linear behaviour of thermal conductivity ratios with respect to volume fraction (up to 0.05); however the rate of increase changes for each system. From the study, it was clear that the thermal conductivity ratio of nanofluid to base fluid are always higher than those of conventional heat transfer fluids.

Nie *et al.* ^[10] proposed different possible mechanisms for the significant enhancement of thermal conductivity ratio reported by many researchers. According to their study, thermal conductivity is enhanced due to the Brownian motion. They also reported that at a given nanoparticle size, the thermal conductivity enhancement is proportional to the ratio of thermal conductivity to the viscosity (T/μ). They also listed the other possible mechanisms such as the phonon transport speed in nanofluid, micro convection, and the phonon mean free path.

Multi-walled carbon nano-tube (MWCNTs) was used by Aravind & Ramaprabhu¹¹ to study the thermal conductivity effect of graphene nanoparticle dispersed in DI water and ethylene glycol. They observed that there is an increase in thermal conductivity of nanofluid with respect to the nanoparticle volume fraction. For DI water, the percentage increase was 73% at temperature of 50 °C. For ethylene glycol, the percentage increase was 20% at the same temperature.

The copper oxide nanoparticle was prepared by Patel *et al.* ¹² in a water and Ethylene Glycol base fluid. Their objective was to study the effect of thermal conductivity on nanoparticle addition. They reported enhancement of 11.5 and 14% of thermal conductivity with water and Ethylene Glycol respectively at a temperature of 50 °C. According to their study, the reason for the enhancement in thermal conductivity is due to the finer particle and uniform dispersion of nano particles in the base liquid.

Periasamy *et al.* ^[13-15] used copper, SiO₂ and graphene nanoparticles in water-ethylene glycol mixture for their study, to evaluate the thermo physical property variations and reported that the nanoparticle has significant contribution in enhancing thermo physical properties of conventional heat transfer fluids.

The magnetic Fe₃O₄ nanoparticle was suspended by Sundar *et al.* ^[16] to conduct experimental investigation on thermal conductivity with water as a base fluid. The nanoparticle volume fraction range for their study was from 0 to 2% and the temperature range from 20 °C to 60 °C. Similar to many researchers, they also observed a significant enhancement in thermal conductivity of suspension and their results are 17 and 9% at the temperatures of 60 °C and 20 °C respectively.

The graphene nanoparticle was suspended in water and used by Ahammed *et al.* [17] to study the effect of nanoparticle suspension on thermal conductivities of graphene-water nanofluid. They prepared different volume fractions of nanofluids such as 0.05, 0.1 and 0.15%. The study was performed at the temperature ranges from 10 to 50 °C. Their result for the two temperatures are about 7% and 19% increase in the thermal conductivity ratio at 10 °C and 50 °C respectively for the volume fraction of 0.05%.

Periasamy *et al.* [18-20] prepared graphene nanoparticle and studied the effect of nanoparticle addition on thermal conductivity of ethylene glycol-water base fluid in a plate heat exchanger. They have reported the thermal conductivity was enhanced significantly with respect to hot fluid temperature as well as nanoparticle concentration.

Rheological properties

Barbés *et al.* [21] prepared two types of nanoparticle suspension, one with Al₂O₃/water and the other with Al₂O₃/ethylene glycol. Their objective was to measure thermal conductivities and specific heat capacities for the above suspensions. The temperature range from 298 to 338 K was used with a nanoparticle concentration of 1.0 to 10.0% for their study. The study reveals that the thermal conductivity increased with respect to the concentration of nanoparticle, but the specific heat capacity decreases with respect to the nanoparticle concentration.

Yiamsawasd *et al.* [22] studied the effect of specific heat capacity of Titanium dioxide and Aluminium oxide metal nanoparticle mixed in two solutions (water and a mixture of EG/water (20/80 wt %)). They have used differential thermal analysis technique for measuring specific heat capacity at the temperature ranges from 15 and 65 °C with 8.0% volume fraction of suspensions. They have proposed a correlation equation for the prediction of the specific heat capacity of suspended nanofluid in a form of specific heat capacity ratio.

Heat and mass transfer studies

The experimental study performed by Xuan & Roetzel²³ also proposed an empirical correlation equation for determining convective heat transfer coefficient for nanofluid. They have derived equation by considering the nanofluid as the conventional single-phase fluid and the multiphase fluid.

The study conducted by Mare *et al.* [24] by dispersing alumina and carbon nanotubes nanoparticle in water under laminar flow condition in plate heat exchanger. Their objective was to find the viscosity effect and the

pressure drop effect at low temperature. The result of the study was viscosity and pressure drop increased, hence optimization is needed before concluding the effects of nanoparticle addition.

The heat transfer performance of Al_2O_3 /water was studied by Pandey *et al.* [25] in a counter flow corrugated plate heat exchanger. The objective of their study was to find the effects of nanofluid on heat transfer, frictional and exergy losses. The results revealed that the rate of heat transfer was improved with optimum concentration of nanofluid. It was also noted from their study that the heat transfer increases with the increase in Peclet-number and Reynolds number.

The heat transfer study was conducted in U-tube heat exchanger with helical tape inserts by Prasad *et al.* [26]. They have suspended aluminium oxide nanoparticle in water. According to their study report, the Nusselt number was improved at different Reynolds number as well as nanoparticle concentrations. They have concluded that the maximum enhancement in heat transfer was observed in terms of Nusselt number with higher Reynolds number and nanoparticle concentrations.

Heat transfer behaviour of Al_2O_3 and Copper nanoparticle suspended ethylene glycol-water mixture was analysed by Periasamy and Baskar [27-29]. Their analysis results reveal that the heat transfer coefficient is directly enhanced with nanoparticle volume fraction. Kim *et al.* [30] conducted the heat and mass transfer study by the addition of SiO_2 nanoparticle in a water. Their study result shows significant enhancement in the heat transfer and mass transfer coefficient. Their result was 18% improvement in mass transfer coefficient and 47% improvement in heat transfer coefficient.

The mass transfer study performed in packed bed absorption column by Periasamy *et al.* [31-33]. They have prepared oxides of Titanium and aluminium nanoparticle in water mixture. Their objective was to study the absorption efficiency of a nanoparticle suspended water solvent. They have reported significant improvement in the CO_2 absorption rate. They have also reported the highest enhancement at 0.6 volume fraction of aluminium nanoparticle.

Torres Pineda *et al.* [34] performed the mass transfer study in a tray column with SiO_2 /water nanoparticle suspension and reported 10% improvement in CO_2 absorption rate.

Bio fuel production processes

Types of bio fuels

Due to environmental friendliness and easy availability, “biofuels” attracted many researchers for their production. Based on the properties and applications, Some of the bio fuels ^[35] identified in this chapter are;

- 1) Bio Diesel
- 2) Bio gas
- 3) Bio Hydrogen
- 4) Bio Ethanol

In order to identify and extract the potential benefits of these bio fuels, the detailed literature studies are given below.

Bio diesel

Because of environmental friendliness, less CO₂ emission, degradability the “Biodiesel” was produced by many researchers from edible and non-edible oils ^[36]. The raw materials used for producing this bio diesel is highly abundant and waste materials (plant, microalgal and animal oils, hence the economic production of bio diesel is a needed one to safe guard our nation ^[37]. In order to obtain an energy efficient bio diesel, Mixing of nanoparticle can be used to maximize the yield of biodiesel production ^[38]. It is noted that that the metal/metal oxide nanoparticle addition enhances the efficiency of a catalyst in the transesterification process.

The experimental study was made by Chen *et al.* ^[39] to assess the effect of Fe₃O₄/ZnMg (Al)O (magnetic) nanoparticle addition to produce biodiesel. They have used the feedstock as micro algal oil. Based on the study, they reported that the activity of catalyst increased significantly because of its large surface-area-to-volume-ratio and magnetic responsivity. Study reports the bio diesel produced with high yield of 94%. They also observed that the conversion of bio diesel is around 82% (after 7 cycles) and the recoverability of nanocatalyst is simple.

Baskar *et al.* ^[40] used nickel doped ZnO nanocatalyst to optimize the process conditions for the bio diesel production process. They have used castor oil as a feedstock for their study. Study concludes with a maximum of 95.2% biodiesel yield at a catalyst weight fraction of 11.07% (w/w), methanol-to-oil-ratio of 8 mol/mol, reaction time of 60 min and a temperature of 55 °C.

From the feed material as cooking oil, Tahvildari *et al.* [41] prepared CaO and MgO nanocatalysts to study the effects of prepared nanocatalyst on biodiesel production. From the experimental study, they reported that the mixing of nanocatalysts favours the bio diesel production and helps to achieve its maximum yield. Study shows the maximum yield of around 99% of bio diesel with 7:1 ratio of methanol-to-oil-ratio, 0.7 g of Calcium Oxide and 0.5 g of Magnesium Oxide at a reaction time of 6 hours.

From soyabeans oil Dantas *et al.* [42] produced bio diesel with the addition of Cu²⁺ doped magnetic nanoferrites (Ni_{0.5}Zn_{0.5}Fe₂O₄). They have assessed the effects of prepared nanocatalysts during the methyl transesterification process. They observed significant enhancement in the bio diesel yield and reported the maximum yield of 85% bio diesel production.

Variety of feedstocks was used by Wang *et al.* [43] to assess the effect of addition of acid/base-functionalized magnetic nanoparticle in the production of biodiesel. The acid-functionalized nanoparticles consists of sulfamic and sulfonic silica-coated crystalline Fe/Fe₃O₄ magnetic nanoparticle (MNP) were prepared and applied in the transesterification process of glyceryl trioleate. The addition of nanoparticle in these feedstock showed high catalytic activity as well as high yield (95%) of bio diesel.

Bio gas

Bio gas is one of the main type of bio fuel, which is produced usually from anaerobic digestion process [44].

The main steps involved in anaerobic digestion process [45] are

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

Nanoparticle addition in feedstock has shown promising results in enhancing anaerobic processes particularly in relation to electron donors/acceptors [46].

In bio gas production, nanoparticle addition increases the hydrolysis of organic matter, which increases in substrate conversion (hydrolysis). Since the nanoparticle provide a large surface-area-to-volume-ratio, the activity of microorganisms gets improved, which stimulates their biochemical processes [47].

Table. 1 provides some of the significant nano materials reported in literatures for the production of bio diesel using anaerobic digestion processes with different feed materials. Zero-valent metals, metal oxides and carbon-based nanomaterials were reported [48] in the table. 1.

Table 1: Different Nano Material and Feed Material Used in the Production of Bio Diesel

Feed material	Nanomaterial	Operating conditions	Percentage Yield	Reference
Soy bean oil	Cu	180°C, MOR*-1:20, 4% wt, 1 h	85	[35]
Sun flower oil	MgO	110°C, MOR-1:12, 3% wt, 3 h	95.7	[49]
Palm oil	TiO ₂ -ZnO	50-80°C, palm oil=21.86 g, methanol=12.23 mL, 5 h	98	[50]
Microalgae oil	CaO	70°C, MOR - 10:1, 1.7% wt, 3.6 h	86.5	[51]
Waste cooking oil	ZnO	60°C, MOR - 6:1, 1.5% wt, 15 min	96	[52]
Rapeseed oil	Na ₂ Si ₂ O ₅	65°C, MOR - 30:1, 0.4% wt, 120 min	97.8	[53]
Rice bran oil	CaO	65°C, MOR - 30:1, 0.4% wt, 120 min	93.5	[54]
Bombax ceiba oil	CaO	65°C, MOR – 30.37:1, 1.5% wt, 70.52 min	96.2	[55]
Castor oil	Ni doped ZnO	55°C, MOR-1:8, 11% wt, 1 h	95.2	[33]
Tricaprylin	Ca ₂ Fe ₂ O ₅	180°C, MOR-1:6, 4% wt, 1 h	100	[56]

*MOR: Methanol to Oil ratio.

Wang *et al.* [57] conducted several studies to assess the effects of nanoparticle on microbial communities (during anaerobic digestion processes). For the study, four nanoparticles such as Fe₂O₃, ZVI, MgO and Ag were prepared for producing biogas with waste activated sludge. Study reported that Fe₂O₃ and ZVI nanoparticle shows a positive effect on the methanogenic archaea activity. They concluded that Fe₂O₃, nanoparticles (100 mg/g TSS) increased the biogas production 117% and ZVI nanoparticles (10 mg/gTSS) increased the biogas production 120%.

Koenig *et al.* [58] used combination of ZVI nanoparticles and organochlorine-respiring bacteria (ORB) for their experimental study on bio gas production. Study reports that the mixing of nanoparticle has enhanced the methane-generating pathways by favoring the formation of intermediates (butyrate, formate, hydrogen, acetate, etc.) [59].

Koenig *et al.*^[60] reported that the ZVI nanoparticles and organochlorine-respiring bacteria (ORB) combination could be applied to detoxify chlorine containing compounds. It was noted from this study that below 0.05 g/L concentration, ZVI improves the growth of ORB, and this reduces the concentration of chlorine during the bio gas production process.

Addition of nanoparticle in anaerobic digestion process offers a symbiotic relationship and it allows microorganisms to act as catalytic agents. Hence the oxidation state of the nanoparticle elements could be altered. This promotes the electrons transfer and improves the reaction rate^[61]. The nanoparticle also provides a large surface-area-to-volume and physiological changes for microorganisms to bind in active sites of molecules and stimulates their microbial activities^[62].

Biohydrogen

“Biohydrogen” is produced by a diverse group of anaerobic bacteria by using different metabolic routes. One of the environmentally friendly and cost-effective method for Bio hydrogen production is Dark fermentative process. Using renewable feedstocks and microorganisms Bio hydrogen can be produced under mild fermentation conditions.

Zhang and Shen^[63] prepared gold nanoparticles for their studies on bio hydrogen production. The results showed that the addition of 5 nm gold nanoparticle improved 56% substrate utilization efficiency during dark fermentation process. Study also concludes that the yield of bio hydrogen was achieved with 46%.

Zhao *et al.*^[64] prepared silver nanoparticles and used in the enrichment of dark fermentative biohydrogen-production process. They have carried out their studies in anaerobic batch reactors. They reported that the addition of nanoparticle improves the activity of micro organism and bio hydrogen yield.

Different metallic nanoparticles and FeO nanoparticle were used by Beckers *et al.*^[65] to examine the role of nanoparticles in biohydrogen production. The metallic nanoparticles of Pb, Ag and Cu were chosen for the study. The selected nanoparticles were immobilized on SiO₂ (porous silica) at a concentration of 10–6 mol/L. Report shows that FeO nanoparticle suspended microorganisms increased the yield of biohydrogen by 38% compared with cultures without the addition of FeO nanoparticle. The enhancement is due to improved hydrogenase activity in the production process of bio hydrogen.

Studies on the effect of Ni and Ni-graphene nanocomposite catalyst on dark fermentative biohydrogen production was performed by Elreedy *et al.* [66]. In their study, the impact of Ni nanoparticles and Ni-graphene nanocomposite addition on the enhancement on biohydrogen production in dark fermentative process was made industrial wastewater as a feed material. Based on the research they reported that at nanoparticle concentration of 60 mg/L, maximum biohydrogen production yield of 24.73% was observed using Ni nanoparticle, where as 42% yield with Ni-graphene nanocomposite material.

From the literatures it was observed that the newly synthesized $\text{Fe}_3\text{O}_4@\text{SiO}_2$ nanoparticle are suitable material in dark fermentation process because of their stability and a high catalytic performance [67].

Bio ethanol

Because of non-polluting performance, “Bioethanol” is one of the significant bio fuels in specific to the transport sector [68], this advantage made the industries to produce maximum quantity of bio-ethanol in recent years.

The following properties highlights the benefits of bio ethanol [69], such as

- High octane number.
- High evaporation enthalpy.
- Wide range of flammability.
- Environmental friendly.
- Easy availability.

The above characteristics made bio ethanol to be blended with conventional hydrocarbon fuels derived from crude oil.

Some of the literature supports on bio ethanol production using nanoparticle suspended microorganisms immobilized is discussed below.

Magnetic nanoparticle was used by Ivanova *et al.* [70] to produce bio ethanol. They prepared immobilized cells of *S. cerevisiae* with magnetic nanoparticles. Result shows that the prepared immobilized cells showed a high yield of bioethanol production with a production rate of 264 g/L.h during the bio fermentation process.

Cherian *et al.* [71] prepared nano catalyst using MnO_2 nanoparticle suspended immobilized cellulose. They have used feedstock as sugarcane

leaves in the production of bio ethanol. Study observes that the performance of immobilized cellulose was improved to hydrolyze cellulosic materials and reported the bioethanol yield of 75% even after five cycles.

Galazzo and Bailey ^[72] used magnetic nanoparticles in the production of bio ethanol and observed that cells cultivated in an alginate matrix yields 50% greater than bio ethanol production that of cells without nanoparticles. From the Researchers work, it was noted that mixing bacterium-based nanoparticle improves the large-scale production of bioethanol ^[73].

Factors affecting the performance of nanoparticles in biofuel production processes

From the collected literatures the several factors, which influence the performance of nanoparticle in bio fuel production processes are summarized below:

- The type of synthesis of bio fuel.
- Operating Temperature.
- Nanoparticle synthesis pressure.
- Nanoparticle synthesis P_H .
- Size of nanoparticle.
- Concentration of nanoparticle.

Future perspective on nanomaterials in bio fuel production

Bio fuels are advanced alternative sources of renewable energy due to their non-polluting features and cost-competitiveness in comparison to fossil fuels. Because of the high reactivity nature of some nanoparticle, they have a tendency to form agglomeration, which limits its application and create a threat for settling or sedimentation in the equipment itself.

Overall, this chapter demonstrates the potential benefits of nano sized materials addition towards the advancement of bio fuel production methods. From the survey it is true that nanoparticle could play a significant role towards the advancement in bio fuel production processes.

The following considerations may be taken to produce cost effective energy efficient bio fuel by the addition of nano materials. They are

- Preparation of bio fuel using non-reactive and non-toxic nanoparticle.
- Selection of easily available and less expensive nanomaterial.
- Synthesize bio fuel using environmental friendly nanomaterials.

Acknowledgment

The authors thank the management of Kongu Engineering College and department of Chemical Engineering for the facility provided.

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Chapter - 7

Semiconductor Solar Cell

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Chapter - 7

Semiconductor Solar Cell

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Abstract

The photovoltaic device is the conversion of electromagnetic radiation into electrical energy. Solar cells are the most common photovoltaic device. Solar cells are an essential technology for addressing global energy and environmental issues. The most important part of a photovoltaic device is semiconductor junctions. In this chapter, we are describing fundamental topics about photovoltaic devices, which include the semiconductor bandgap, intrinsic and extrinsic semiconductor, the concept of the p-n junction, band bending, p-n junction applied bias, photo-generation, direct and indirect bandgap. Also, it describes the basic structure, working, and characteristics of a photovoltaic cell.

Keywords: Semiconductor basic, p-n junction, direct and indirect band gap, PV devices

Introduction

The bandgap of a semiconductor is defined as the minimum energy required carrying an electron from its valence band into a free state, contributing to conduction current. In a "band diagram", which illustrates the band structure, the energy of the electrons is represented on the y-axis. The lower energy level is the "valence band", whereas the higher energy level is the "conduction band", where an electron can be treated free.

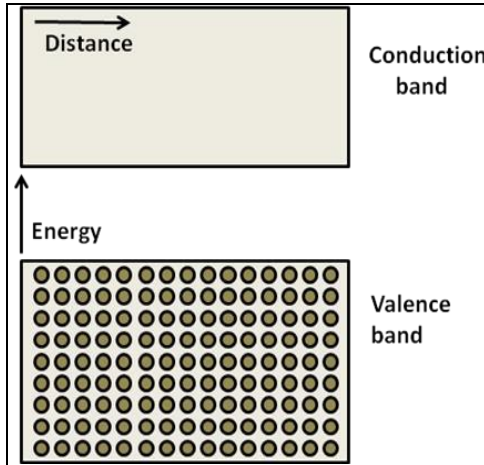


Fig 1: Energy Band diagram for electrons in a solid

Based on the energy band gap of materials, there are three broad classes of materials: an insulator, semiconductors and conductor. Bandgap (E_g) is also called the forbidden gap^[1], where there are no permissible energy levels for the electrons. The valence and conduction bands overlap entirely at equilibrium inter-atomic distances in a metal (Conductor). Fig. 2 shows the energy gap diagram for different materials. In metal electrons are partially filled, and many energy levels are empty. So that if we apply a small external field, then the electron can easily contribute to the conduction current and the material can exhibit a substantial electrical conductivity. The fundamental difference between insulators and semiconductors is it depends on the energy bandgap of the materials. If the material bandgap exists in the order of 1 eV, then it is referred to as a semiconductor. In which relatively few electrons are available in the conduction band at room temperature. When we start to supply sufficient external field, this electron will contribute to the conduction current. In the insulator case, the material bandgap exists more than 3.5 eV^[2]. So that at room temperature, there are essentially no electrons in the conduction band, and the valence band remains full. If an external field is applied, no electron moves to the next energy level and essentially no charged particles can contribute to a drift current^[3].

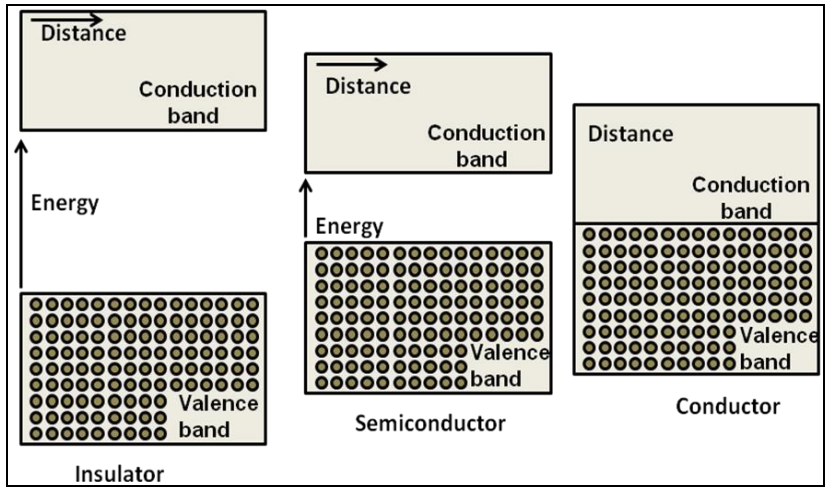


Fig 2: Energy band diagram of different materials insulator, semiconductor and metal

Intrinsic semiconductor

An intrinsic semiconductor is a semiconductor that is entirely free of impurities, and its conductivity (or charge carrier concentration) is ultimately temperature dependant. There will be no charge carriers at 0 Kelvin, and this material has no essential electrical properties. As a result, the charge carrier concentration is only affected by temperature. The electron carrier concentration in the conduction band is equal to the holes carrier in the valence band, and it denoted n_i and p_i as electron and hole concentration, respectively. In general, group four A elements are good examples of intrinsic semiconductors. Intrinsic semiconductor material exists in both an elemental and a compound form. We can use silicon and germanium for elemental semiconductors, and compound semiconductors are prepared from two (or) three different elements with an equimolar ratio. For example, group two elements combine with group six; we can form II-VI compound semiconductors like cadmium sulfide, cadmium selenide, zinc sulfide, zinc selenide, zinc telluride, and cadmium telluride.

Similarly, group three elements combine with group five; we can form an III-V compound semiconductor. For example, gallium arsenide, indium phosphide, gallium nitride, gallium phosphide. The "Fermi level" in an intrinsic semiconductor is positioned halfway between the valence band and the conduction band, as seen in Fig. 3. If the $h\nu$ frequency of that radiation is allowed to reach the material, the electron captures the energy and then it will get the transition from the "valence band" to the conduction band. There is an electron in the conduction band (at the lowest energy level) and a hole

in the valence band⁴. Because this electron is cited at the lowest energy level, it will easily recombine with the hole. Even if we provide additional radiation, the electron still has a probability of recombination. As a result, electricity generation is a more complex process using these intrinsic-based semiconductor materials. So for a solar cell application, we preparedly used only extrinsic semiconductor materials.

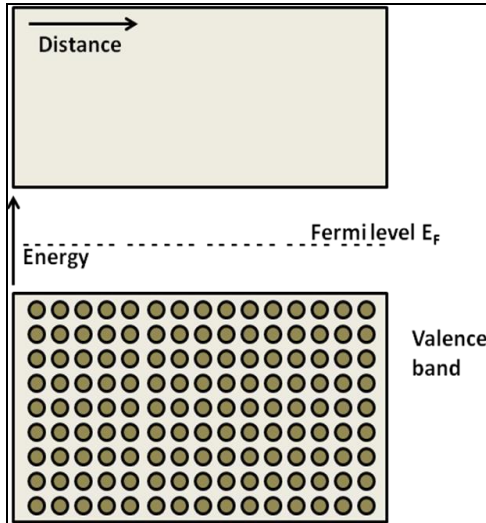


Fig 3: Fermi level in intrinsic semiconductor

Extrinsic semiconductor

In the process of adding dopant with pure semiconductor crystal one can get extrinsic semiconductor materials. In general, trace elements or chemicals are used as a doping agent, which has been incorporated chemically into the crystal. These dopant atoms provide charge carriers that convey electric current through the crystal. There are two types of doping agents utilized, resulting in two types of extrinsic semiconductors. One is an n-type semiconductor in which an electron donor dopant is introduced into a crystal; it gives a mobile conduction electron into the lattice. For example, group five elements in a periodic table like nitrogen (N), phosphorus (P), arsenic (As), antimony (Sb) and bismuth (Bi) are doped with pure intrinsic semiconductors we can create n-type extrinsic semiconductors. So in an n-type semiconductor, one valence electron is available for free movement within the crystal and it is captured in the band diagram by donor level, which stays very close to the conduction band. Fermi level (E_F) is lined up above the donor level, and it is shown in Fig. 4.

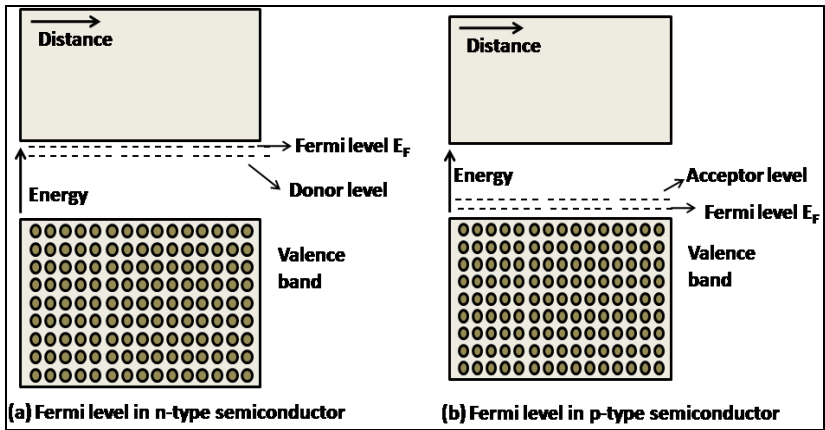


Fig 4: Fermi level in extrinsic semiconductor

When a small amount of external energy is applied to the system, it can get into a higher energy level (conduction band) and then carry out the conduction processes. Another extrinsic semiconductor is the p-type in which acceptor dopant is added with pure intrinsic semiconductor. For example, group three elements in a periodic table like boron (B), aluminum (Al), gallium (Ga), indium (In), and thallium (Ti) are doped with silicon; we obtain a p-type semiconductor. So in a p-type semiconductor, the hole is readily accepting one electron from the system, so it is called an acceptor dopant. The acceptor energy level is available very close to the top of the valence band and the Fermi energy level is lined up below the acceptor energy level ^[5].

p-n junction

The p region is produced by doping acceptor impurity atoms in one part of a single crystal (silicon) and another side, the n region, is formed by doping donor atoms. Such a semiconductor junction produced within a single semiconductor is called a homojunction. The metallurgical junction is the point where the n and p regions meet. Before metallurgical junction formation, the energy band diagram is well separated, as shown in Fig 4. The electron-hole concentration level has a significant density gradient in the metallurgical junction. As a result, most electron carriers in the n-side start diffusing into the p region, while most carrier holes in the p-side start diffusing into the n-side. This charge transfer process could not continue permanently unless an external field was applied to the semiconductor. The electrons diffuse from the n-side to the p-side, it leaves positively charged ions in the n-region. Similarly, as the hole diffuses from the p-side to the n-

side, it leaves the negatively charged ions in the p-region. The potential difference (electric field) in the metallurgical junction is produced by the net negative and positive charges in the p and n regions. Such a build-up of oppositely charged regions results in the formation of the junction potential, which effectively prevents further migration of free carriers. The net negative and positively charged regions are referred to as space-charge (or) depletion regions. The electric field essentially sweeps all electrons and holes out of the space charge region). The diffusion and electric field forces are perfectly balanced in thermal equilibrium [6].

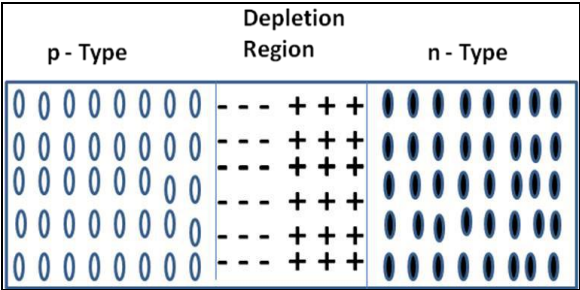


Fig 5: p-n junction formation

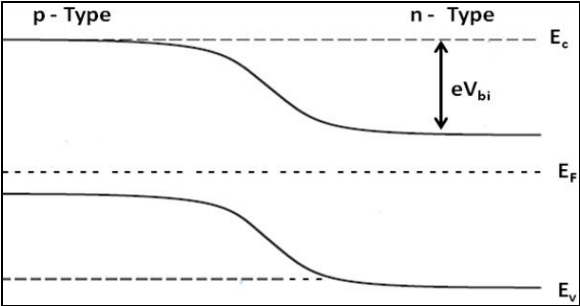


Fig 6: PN junction energy band diagram at thermal equilibrium

Band bending

The internal built-in potential is essentially formed due to the Fermi energy difference between the n and p type regions. If no voltage is injected across the p-n junction, the Fermi level (E_F) remains constant throughout the system. Figure 6 shows the bandgap structure of a p-n junction in thermal equilibrium. The valence and conduction band energies must bend when we pass through the depletion area. The actual position of the valence and conduction bands related to the Fermi level modification is obtained between both the p and n regions. When electrons in the n region of the conduction band try to travel into the p region of the conduction band, they encounter an

energy difference (move uphill-potential barrier). The opposite is true for holes [6]. This potential barrier is indicated as the built-in potential barrier symbolized by V_{bi} . The amount of potential energy is measured using the given equation:

$$= V_t \ln \left(\frac{N_a N_d}{n_i^2} \right)$$

Where V_t stands for thermal voltage, N_a acceptor dopant concentration, N_d donor dopant concentration and n_i is concentration of intrinsic carrier.

The space charge width (depletion width) is referred to as the range seen between the metallurgical interface and the space charge region that extends into the n and p regions. The width of space charge region calculated using the given equation:

$$W = \frac{V_{bi}}{e} \left(\frac{N_a + N_d}{N_a N_d} \right)$$

ϵ_s is the permittivity of the semiconductor material.

Forward-bias applied voltage

A forward voltage is provided to the p-n junction, as shown in Fig. 7. That means the positive voltage is applied to p region. The free electrons and holes are directed towards the junction in this scenario. In contrast, electrons in the n region recombine with stationary positive ions (+), offering additional energy to traverse the junction. Similarly, holes in the p region recombine with immobile negative ions. Because of this, the width of the depletion region decrease until the fluid of the electron passes through the junction. This indicates that the forward bias is reduced the potential barrier. The carriers (electron and hole) injection across the space charge region will continue as long as the bias V_F is applied.

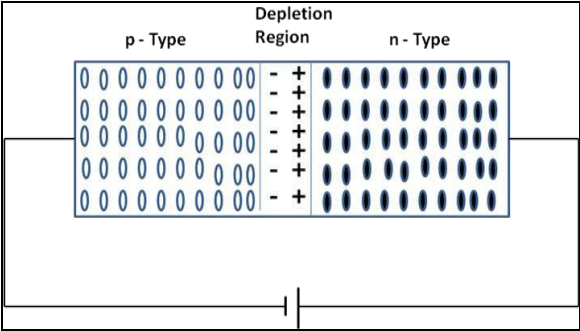


Fig 7: p-n junctions forward biasing conditions

The depletion width in forward bias is given by:

$$W = \left(\frac{(V_{bi} - V_f)}{e} \left(\frac{N_a + N_d}{N_a N_d} \right) \right)^{\frac{1}{2}}$$

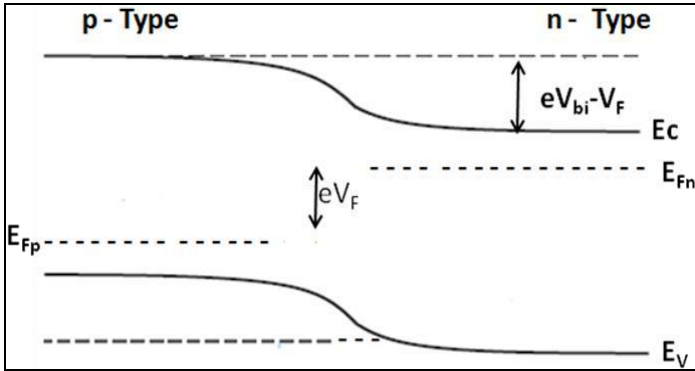


Fig 8: PN junction energy band diagram for forward bias condition

Reverse bias applied voltage

In reverse applied voltage, the n region is connected to negative terminal and p region is connected to positive terminal of the battery (Fig. 9). The positive end of the terminal attracts electrons, while in the p region, the negative terminal draws holes. Because electrons and holes are forced away from the junction, the depletion area is made even more difficult to traverse in a pn junction. In the reverse applied voltage p-n junction energy band structure, the built-in potential seems to be downhill, and the Fermi level on the n side is lower than the Fermi level on the p side (Fig. 10). This means that the potential barrier height is increased in reverse bias applied voltage.

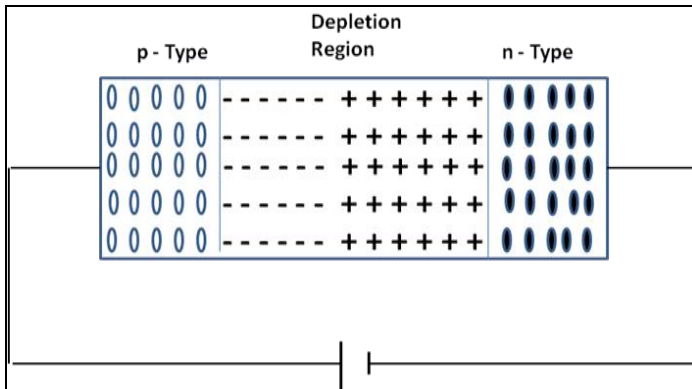


Fig 9: p-n junctions reverse biasing conditions

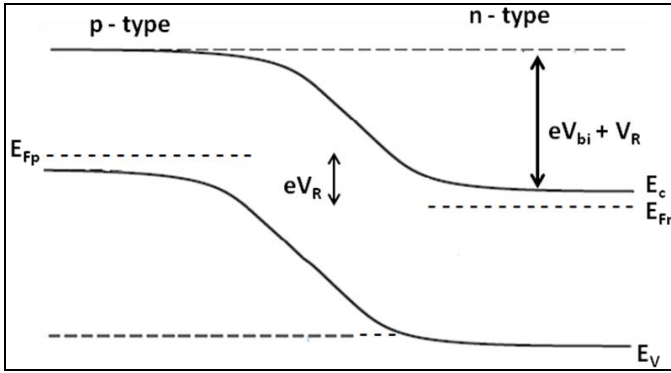


Fig 10: pn-junction energy band diagram for reverse bias condition

The depletion width of reverse bias is given by:

$$W = W = \frac{(V_{bi} + V_R)}{e} \left(\frac{N_a + N_d}{N_a N_d} \right)^{\frac{1}{2}}$$

Such a reverse and forward bias performance of the p-n junction is employed in many electronic device applications. Note that the actual method of formation of p-n junction which include diffusion [7], ion implantation [8] or epitaxial growth [9]. In diffusion process the suitable dopant with sufficient concentration is diffused using heat in the appropriate regions. In ion beam implantation dopant impurity is added with semiconductor materials using the high energy ions source, resulting in form sharp junctions. But the heavy ion beam implantation processes induced various defects in crystal lattice. The process of junction formation is also possible to implement the epitaxial deposition process, which allows the production of different semiconductor layer with required dopants included during the growth.

Concept of direct and indirect band gap

The valence band and conduction band edge appear at the same value of wave vector k in the case of a direct bandgap, and no phonon process takes place during the transition (Fig. 11a). During most optical emission and absorption processes, the momentum and energy must be conserved for direct band gaps materials. GaN, GaAs, InGaAs, AlN, CdS, CdSe, CdTe, PbS and PbSe, are direct bandgap semiconductor materials. The top of the valence band edge does not coincide with the bottom of the conduction band edge in an indirect band semiconductor (Silicon), and the wave vectors do not occur at the same value of k (Fig. 11b). This means that an electron-hole pair can only be formed with the participation of a phonon process. As a

result, indirect bandgap semiconductor materials such as silicon and germanium have a poor absorption coefficient value. The photon absorption occurs for direct bandgap semiconductor materials when the electron is turned out of its bonds without any oscillation changes. As a result, absorption is more probable for direct band material; as a result, it acts as high absorption coefficient material. We concluded that the bandgap of semiconductor materials has a significant impact on the absorption coefficient of materials ^[10, 11].

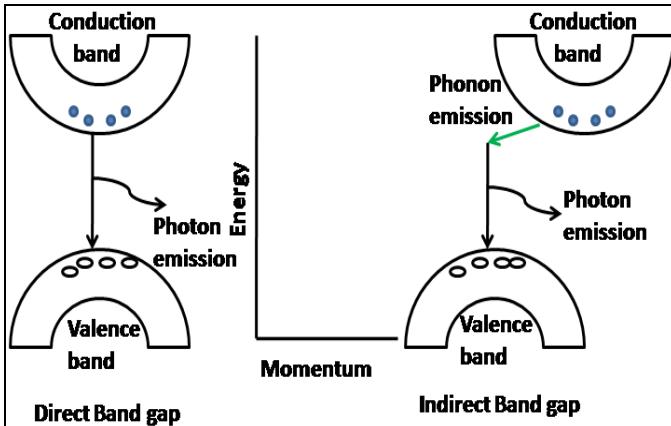


Fig 11: Energy band diagram for direct and indirect band gap materials

Concept of photo-generation

The incident photon of solar radiation energy is sufficiently higher than the bandgap of the semiconductor material, and then it creates electron-hole pairs in a semiconductor (Fig. 12). In other words, valence band electrons absorb light energy, prompting electrons to transfer from the valence band edge to the conduction band edge and it creating a hole in the valence band ^[12].

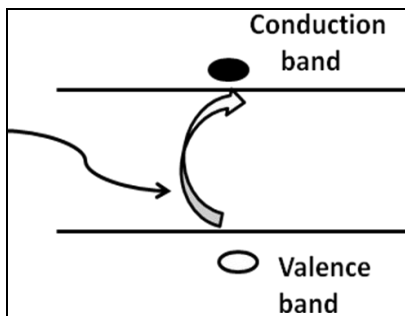


Fig 12: Schematic diagram for photo-generation

Photo-generation rate is dependent on the number of incident photons per sec, and it is generally measured by photon flux Φ (photons/sec). The rate of generation G is represented by the following equation.

$$G = \alpha \Phi \eta$$

Where α is absorption coefficient and η is Quantum efficiency

Basic of photovoltaic devices

The production of solar radiation into electrical energy (voltage and current) from electromagnetic light is known as photovoltaic devices. Practically all photovoltaic devices incorporate a pn junction in a semiconductor across which the photovoltage is developed. The photovoltaic effect was first reported in 1839, and it provides the basis for solar energy. The solar cell is a renewable energy source, and we produce electricity without the emission of CO_2 or the greenhouse effect ^[13]. A Photovoltaic device consists of a p-n junction that generates a voltage from solar energy. The electricity produced throughout the junction is determined by the semiconductor material properties and the diffusion constant. A wide range of methods and materials can satisfy the criteria for PV solar conversion, although, in practice, almost all photovoltaic power processing is done with semiconductor materials.

The basic four fundamental processes required to photovoltaic energy conversion are:

- 1) Absorption of light that produces a transition of an electron from a ground state to an excited state in the material of PV devices.
- 2) Transition of an electron to excited state, create electron-hole pairs in a semiconductor (Exciton).
- 3) Electrons and holes are separated because of the asymmetry of the band structure of semiconductor materials (n and p-type). So that recombination does not occur. The charge carriers move in separate directions. The electron traversed the n-side, while the hole traversed the p region of semiconductors. After that, the electrons and holes are separated by front and back contact.
- 4) Finally, the photogenerated negative-charge carriers flow through the external circuit.

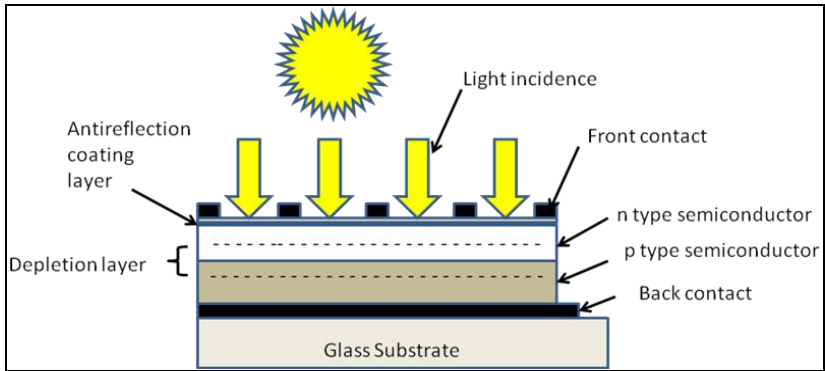


Fig 13: Schematic representation diagram of solar cell

Structure of solar cell

The diagrammatic diagram of a p-n photovoltaic cell is shown in Fig. 13. The basic structure of a solar cell seems to be a p-n junction, with a p-base at the bottom and a highly doped n-type semiconductor on top. Front metal contact is placed on the top of the n layer and above the layer coated by antireflection materials such as silicon oxide or silicon nitrides. Back ohmic contact that extends all the way around the back surface ^[14].

Characteristic of solar cell

When a solar cell is exposed to different wavelengths of a light source, the electrical properties of the cells will influence the spectrum responses. The electrical characteristic of solar cells is mainly dependent on diffusion time, junction depth, open-circuit voltage, and short-circuit current of solar cells. A typical solar cell equivalent circuit is shown in Fig 13. In an ideal solar cell the total current is given by ^[15].

$$I = I_{ph} - I_d - I_{sh}$$

I_{sh} is shunt current

I_{ph} Photocurrent (that every absorbed photon also leads to an electron

– hole pair and therefore makes a contribution to the photocurrent

I_d diode current

$$I_d = I_0 (e^{qV / K T} - 1)$$

where I_0 is reverse saturation current, $K T / q = V_t$ thermal voltage

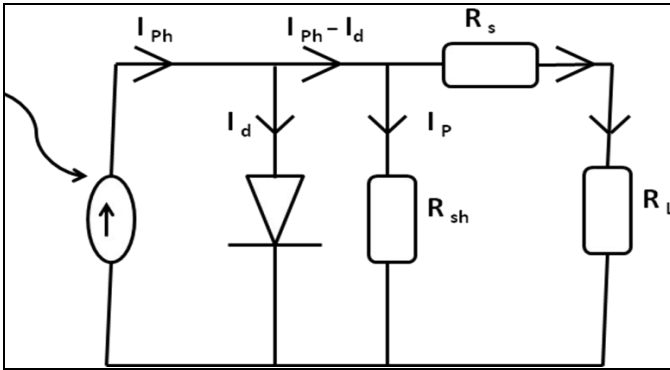


Fig 13: Schematic diagram of solar cell equivalent circuit

Open circuit voltage

In solar cell applications, open circuit voltage is a popular word, and it stands for VOC. Open circuit voltage is the most significant voltage obtained from a solar cell when the current is zero.

$$V_{oc} = \frac{\gamma KT}{q} \ln \left\{ \frac{I_{ph}}{I_0} + 1 \right\}$$

Short circuit current I_{sc}

Short circuit current is the highest current obtained from a solar cell when the voltage is zero. I_{sc} occurs where there is no voltage across the circuit I (at $V = 0$) = I_{sc} . Short circuit current is equal to the photocurrent I_{ph} .

Conversion efficiency

The ratio of electrical energy output P_{out} to solar energy input P_{in} into is known as PV conversion efficiency ^[16].

$$\eta = \frac{P_{out}}{P_{in}}$$

The quantity P_{out} seems to have its best value at the maximum power point denoted by the current density I_{max} and voltage V_{max} , measured from the I-V characteristic curve (Fig. 14). The P_{in} is taken as the product of the irradiance of the incident light, measured in W/m^2 with the surface area of the solar cell.

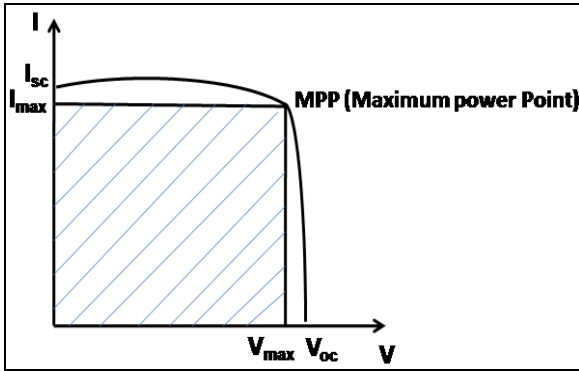


Fig 14: I-V characteristic curve for photovoltaic cell

Fill factor

The relationship between MPP power and the product of open circuit voltage and short circuit current is described by the fill factor FF.

$$FF = \frac{I_{Max}V_{Max}}{V_{oc}I_{sc}}$$

The fill factor (FF) was established to determine how closely a given feature is to the ideal rectangular I-V shape. The potentially different fill factor for different solar cells. The FF is close to one PV cell has more conversion efficiency. The efficiency of the solar cell can be improved through the following point ^[17, 18].

- i) Improve the carrier's lifetime by reducing the recombination process.
- ii) Increase the generation of electron-hole pairs by improving the incident solar influx.
- iii) Antireflective coating and textures.
- iv) Keep the solar panel at the optimum temperature to avoid thermal degradation.

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