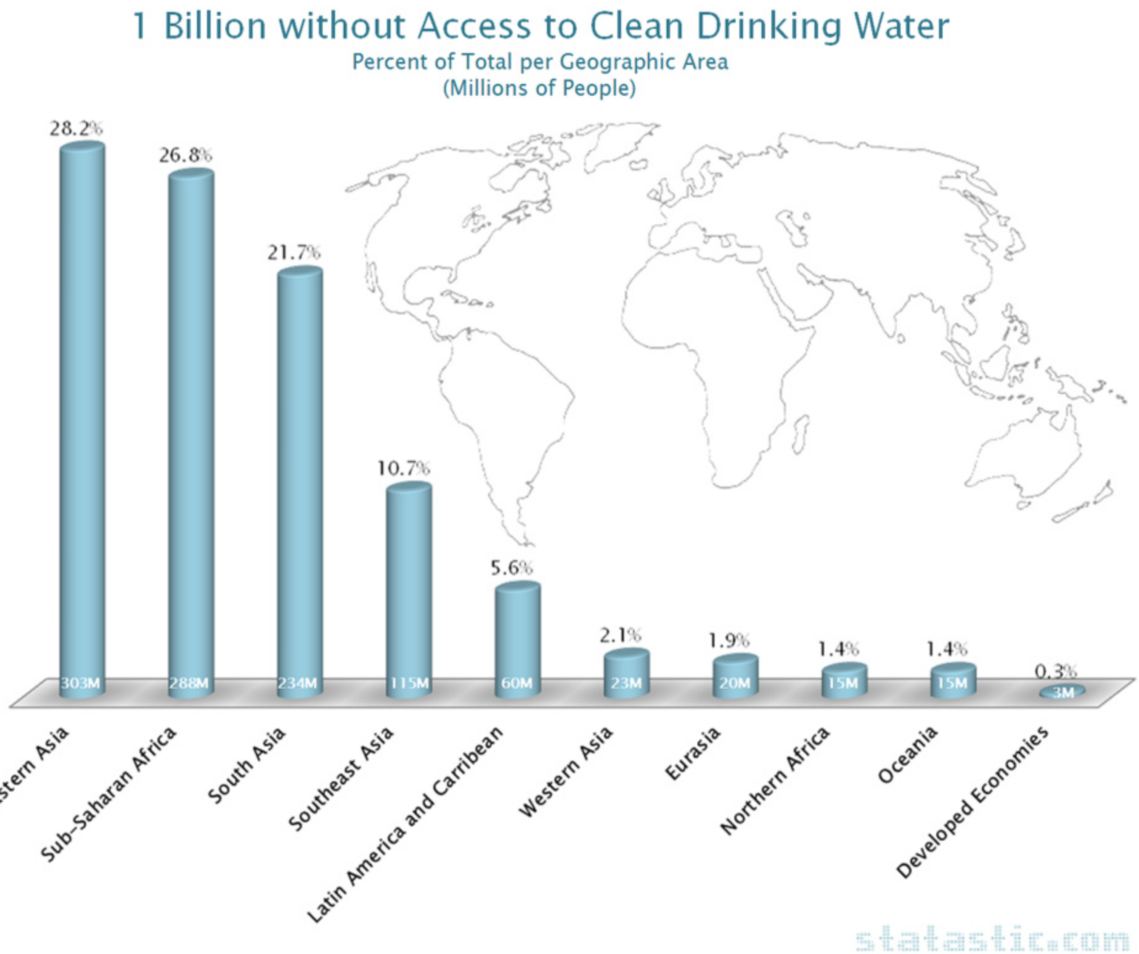
CHAPTER-1

INTRODUCTION

Many parts of the India do not have clean drinking water. Most of the water available in streams, lakes, rivers, sea, etc. carries parasites or diseases, or is simply not fit for drinking and therefore it causes significant health hazard. Poverty stricken areas do not have the infrastructure necessary to develop and support large scale water purification plants. Thus, there is need for a small scale, affordable water purification system for individual families or villages. A few of the negative results of this water crisis are:

- Inadequate amount of water for sanitation and waste disposal.
- Groundwater over drafting (excessive use) affects the agricultural quality.
- Excess use and over pollution of the country hurt the biodiversity.

Our motive is to attain this goal by harnessing and converting the solar power into heat and distill brackish and undrinkable water, change it into fresh drinkable water. Portable Solar distillation system is a comparatively simple treatment for brackish (i.e. contain dissolved salts) water. Distillation is done for water purification and can use natural source like sun or traditional heating source like hydro- electric power and fossils fuels. Solar energy is easily available and natural option for everybody. In this phenomenon, water is converted into vapours by utilizing the energy of the sun the water vapors condenses into pure drinkable water. This process removes salts and other hazardous impurities not fit for health associated with the water.



[Figure-1.1 Clean water access around the world]

Solar water distillation technology has very long and old history and installations were done around 2000 years before, although this technique was used to produce salt rather than fresh drinking water. Large number of solar distillation system was built in 1872 century to supply fresh drinking water for mining community in Chile. Large amount of water produced by solar distillation in first time during the Second World War when 200,000 inflatable plastic stills were made to be kept in life-crafts for the US Navy. The main motive of this project is to design a system that can purify the brackish water from nearly available source of water, this system that is very cheap in cost, easy to carry, and works only on solar energy. This system is very useful for those places where the availability of fresh or drinkable water is very less. This is very useful and economical for rural areas of Himalayan region.

Water form	Relative proportion (%)
Oceans	97.39
Glaciers(polar-icecaps)	2.09
Underground water, soil moisture	0.58
Lakes and rivers	0.02
Atmospheric water vapour	0.001
Total hydrosphere	100

[Table-1.1 Water Distribution]

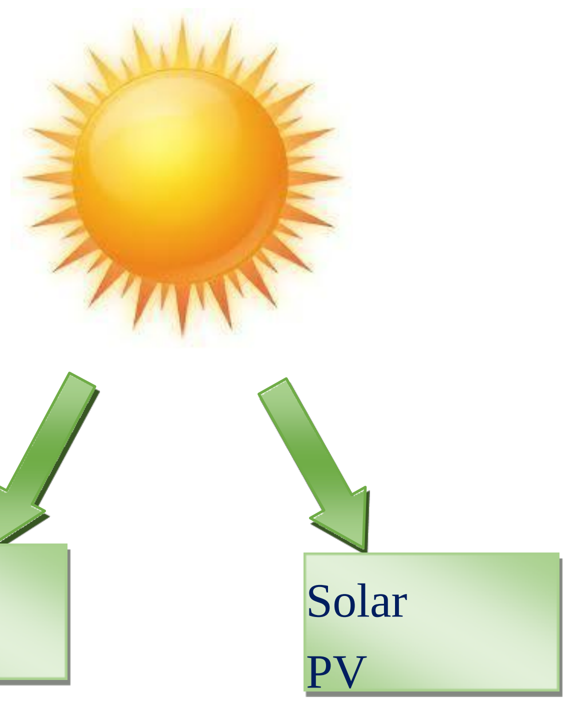
The sun is an enormous sphere of extremely hot gaseous mater and it is situated about 1.5×10^{11}m away from the earth. It is 1.39×10^{9} m in diameter (about 109 times the earth), and it continuously generating heat by thermonuclear fusion reaction, four hydrogen atoms (i.e. four proton) combine to form one helium atom. The mass of single helium is less than that of the combine mass of four protons. This loss in mass in reaction is converted into energy and that is known as Solar Energy.

It is estimated that about 90 % of energy is produced in the interior regions which is within 23 % of the sun's radius, and that contains 40 % of the mass of the Sun. This energy is radiated from the surface of the sun in all direction, and a very small fraction of its reached the earth.

Solar energy is considered to be the predominant source of all forms of energy on the earth. Almost every part of the earth receives some amount of solar energy. Heating of the air also influences of global evaporation and precipitation process. Even the energy in fossil fuel is actually solar energy that was first stored as chemical energy in bio-mass and transformed into coal, oil or gas over millions of years ago.

The energy collected by 1 m^2 of solar collector in a day is approximately equal to that release by burning 1 kg coal or we can say burning of 0.5 liters of kerosene. Thus the solar energy is a dilute source and large areas are needed for its collection. Man has been harnessing the sun's energy and using it to meet energy requirements for ages. Solar energy received on the earth in the form of heat and light can used as thermal as well as electrical energy. On the basis of utilization pattern, technology to harness solar energy can be divided into two as seen in fig.1;

1.0 SOLAR POWER:



[Figure-1.2 Technologies of solar energy]

1 1 TECHNOLOGY OF SOLAR THERMAL

Solar collectors are used in solar thermal technology to store solar thermal energy and transfer it to the fluid or space to be heated. The different types of solar collectors include the Evacuated Tubular Collector (ETC), Flat Plate Collector (FPC), Compound Parabolic Concentrator (CPC), Parabolic Trough Collector (PTC) and Linear Fresnel Reflector (LFR).

Solar thermal technology can be used for producing thermal energy and generating electricity. Solar Cooking, solar water and space heating, solar process heating for industrial applications, solar drying, solar refrigeration and air conditioning, solar desalination and solar thermal power generation are different types of applications of solar thermal based technology.

1.2 SOLAR PHOTOVOLTAIC TECHNOLOGY

Solar Photovoltaic is a semiconductor – based technology used to convert solar radiation directly into electricity using a solar cell. A solar cell is semi-conducting device, which when exposed to sunlight generates electricity. Solar cells are made of silicon. The magnitude of the electric current generated is dependent on many factors. These include intensity of radiation, exposed area of the cell and type of material used in making the cell. Solar cell can be conducted in series or parallel to form modules to obtain the desired power. A basic SPV system comprises the balance of systems and PV modules. The electricity generated can be used for lighting, water pumping, communications and power supply.

1.3 SOLAR ENERGY IN INDIAN SCENARIO

Most part of the India (above 70%) in the country receives solar energy of 4-7 kWh/m^2/day for 200-250 sunny days per year. Over the last three decades, many systems and device like the solar water heating system, solar driers, and solar air heating system, solar cookers, solar lighting systems, solar pumps, and SPV power plants have been developed and installed in the country. The designing of energy-efficient building based on solar passive architecture concept is also an upcoming field. These systems are getting popularity in India and have large scope to expand, and attained commercial status. Moreover, many remote villages in the country have been electrified through Solar Photo Voltaic route.

1.4 DIFFERENT TYPES OF SOLAR COLLECTORS

1.4.1 FLAT PLATE COLLECTOR (FPCS)

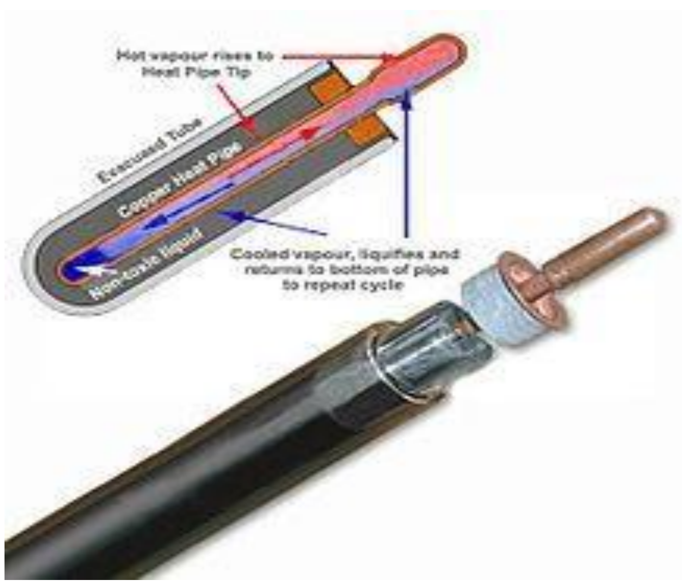
Hottel and Whillier have developed the flat plate collectors in the 1950s, are the most basic type collectors. Flat plate collectors consist of (1) a deep dark flat-plate absorber, (2) a transparent cover which reduces heat losses, (3) a heat-transport fluid (air, antifreeze or water) to remove heat from the absorber, and (4) a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminium, steel or copper, to which a matte black or selective coating is applied) often supported by a mesh or coil of fluid tubing placed in an insulated shell with a glass or polycarbonate cover. In water heat panels, fluid is usually circulated through tubing to transfer heat from the absorber to an insulated water tank. This may be attained directly or through a heat exchanger [1].

[Figure- 1.3 Flat plate collectors]

1.4.2 EVACUATED TUBULAR COLLECTOR (ETCS)

Evacuated heat pipe tubes (EHPTs) are consist of multiple evacuated glass tubes each containing an absorber plate joined to a heat pipe. The heat is given to the transfer fluid (water or an antifreeze mix— typically propylene glycol) of a domestic hot water or hydronic space heating system in a heat exchanger called a "manifold". The manifold is enclosed in insulation and covered by a protective sheet metal or plastic case. The evacuated tube collectors have been trusted from last more than 25 years, the reflective coating for the design is confined in the vacuum inside of the tube, which will not demean until the vacuum is lost. The vacuum that surrounds the outside of the tube efficiently reduces heat loss due to convection and conduction phenomenon [2].

[Figure-1.4 Evacuated Tubular Collectors (NISE)]

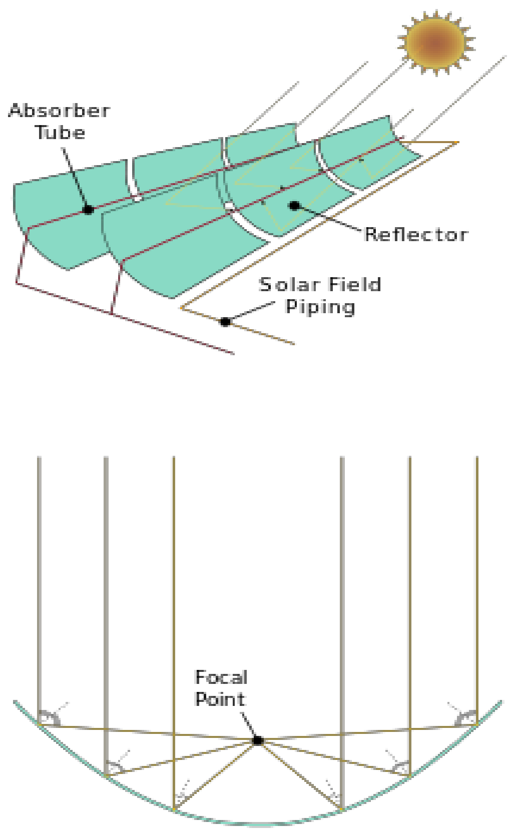


[Figure-1.4.1 Detailed views of ETCs]

1.4.3 PARABOLIC TROUGH COLLECTOR (PTCS)

In this section, parabolic troughs, dishes and towers are explained which are used widely and almost unrestrictedly in solar power generating stations or for research purposes. Although simple, the performances of these solar concentrators are quite different from the theoretical maximum concentration. For example, the parabolic trough concentration is about 1/3 of the theoretical maximum for the same acceptance angle. Approaching the theoretical maximum performance may be achieved by using more efficient concentrators based on non-imaging optics. Solar thermal collectors may also be used in conjunction with photovoltaic collectors to obtain more and combined heat and power from solar energy [3].

[Figure-1.5 parabolic trough collectors (NISE)]



[Figure-1.5.1 Concepts of PTCs]

1.4.4 PARABOLIC DISH COLLECTOR

In a parabolic dish collector, one or more parabolic dishes concentrate solar energy at a single focal point, like reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This design may be used for solar furnaces and solar based power plants.

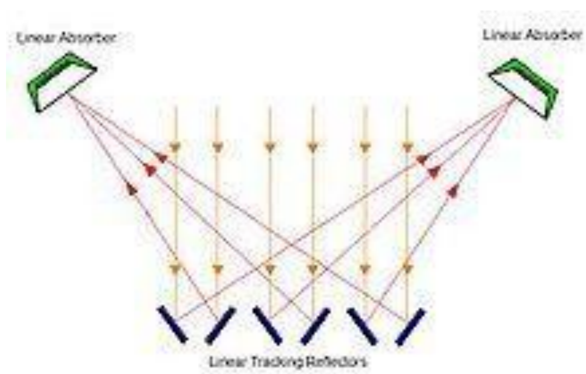
The shape of a parabola means that incoming light rays coming from the sun which are parallel to the dish's axis will be concentrated at the focal point of the dish after reflection. The sun rays coming from the sun are almost parallel to the Earth's surface. So that the alignment of dish is axis pointing towards the sun, allowing almost all incoming sun radiation to be reflected towards the focal point of the dish. Imperfections in parabolic geometry lead to the major losses in such type of collectors.

Losses due to atmospheric scattering are generally minimal. The cloudy or foggy day, light is diffused and scattered in all directions through the atmospheric suspended particles, which decrease the efficiency of a parabolic dish significantly [4].

[Figure-1.6 Parabolic Dish collectors (NISE)]

1.4.5 LINEAR FRESNEL REFLECTOR (LFRS)

Long and thin segments of mirrors are used in Linear Fresnel reflectors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors. These mirrors having ability to concentrate the sun's light to approximately 30 times to its calculated intensity. This concentrated energy is transferred through the absorber into required thermal fluid (this is typically oil capable of maintaining liquid state at very high temperatures). The fluid then moves through a heat exchanger to a stream operated power plant. As opposed to traditional LFR's, the concentrating linear Fresnel reflector (CLFR) utilizes multiple absorbers within the vicinity of the mirrors [5].



[Figure-1.7 Concepts of LFRs]

[Figure-1.7.1 Field view of Fresnel Reflector]

1.5 PYRANOMETER

A Pyranometer is a device which is used to measure broadband of solar irradiance on a planar surface and having a sensor which is designed to measure the solar radiation intensity (W/m^2) from a field of view of 180 degrees. The name pyranometer stems from Greek, “pyr – πῦρ” meaning “fire” and “ano - ἄνω” meaning “above, sky”. A typical pyranometer does not require any power to operate.

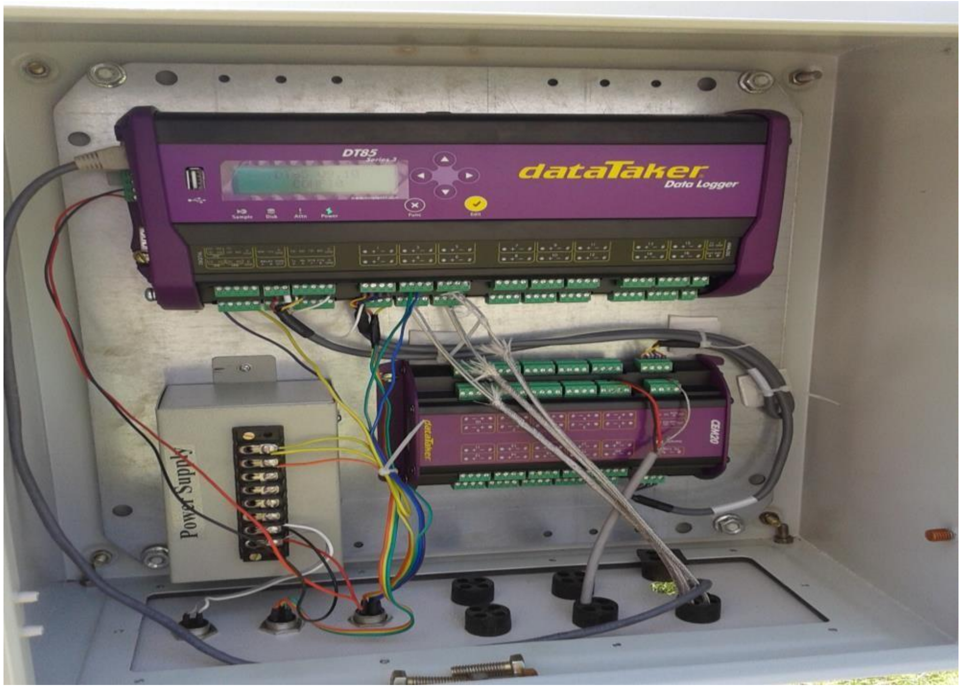
[Figure-1.8 Field Pyranometer (NISE)]

1.6 DATA LOGGER

A data logger (also data logger or data recorder) is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. The working of data logger is based on a digital processor (or computer). They are small in size, battery powered, portable, and provided with a microprocessor, internal memory for data storage, and sensors. Some data loggers interface with a personal computer and uses software to activate the data logger and analyze the collected data, while others have a local intermediate device (keypad, LCD) and can be used as a stand-alone device.

Data logger records the following parameters

- Wind speed
- Wind direction
- Global radiation
- Temperatures with thermocouples (j-type)
- Ambient wind temperature



[Figure-1.9 Channels of Data Logger]

datalake

Full screen

List all channels

Update

Show hidden channels

Manual

Below is a list of all channels in the current job.

Auto

Run	Name	Value	Units	Alarm	Time stamp	Log	Input	Schedule
✓	AIR TEMP	24.730835	0C		2015-04-09, 09:06:20	✓	2*R	(A) Schedule_1
✓	PYRO METER	469.77966	W/m2		2015-04-09, 09:06:20	✓	101V	(A) Schedule_1
✓	Temp1	55.043316	degC		2015-04-09, 09:06:20	✓	4TJ	(A) Schedule_1
✓	Temp2	68.033577	degC		2015-04-09, 09:06:20	✓	5TJ	(A) Schedule_1
✓	Temp3	69.060364	degC		2015-04-09, 09:06:20	✓	6TJ	(A) Schedule_1
✓	WD	70.984329	Degree		2015-04-09, 09:06:20	✓	3R	(A) Schedule_1
✓	WS (m/s)	1.4098877			2015-04-09, 09:06:20	✓	1HSC	(A) Schedule_1

[Table-1.2 Data taken by Data Logger]

[Figure-1.10 Field Data Logger (NISE)]

CHAPTER-2

LITERATURE REVIEW

2.0 INTRODUCTION

The abundance of solar energy available in India is an untapped renewable resource that can be used for the proposed device. Traditional sources of energy such as fossil fuels are expensive, limited, and not available in many parts of India. India's abundant solar radiation is a highly effective and completely renewable resource. The goal of the solar distillation system is to minimize size while maximizing the output of clean drinking water. In addition, the device must be portable and moveable by a maximum of single person. The amount of solar energy available in a region, along with the desired output, will theoretically dictate the overall size of the device. However, the size of the device could be minimized by experimentally testing and optimizing specific design factors incorporated into the solar distillation system. A lot of research has been done by various researchers, after exhaustive effort some conclusion has been drawn by researchers.

2.1 LITERATURE

Wang Geun Shim et. al. (2015) Development of a solar assisted direct contact membrane distillation (DCMD) system for seawater desalination and an improved mathematical model to predict the permeate flux for unsteady state conditions were investigated. Different types of commercially available polytetrafluoroethylene (PTFE) membranes were used in a solar-DCMD system for seawater desalination. Membrane properties, such as the liquid entry pressure (LEP), pore diameter, effective porosity and pore size distribution, were characterized for each membrane. A two dimensional (2D) flat-plate dynamic model with heat and mass transfer mechanisms was used to predict the permeate flux under different operating conditions. Good agreement between the numerical simulation and experimental results were found. Long-term fouling phenomenon in the DCMD system was experimentally and theoretically examined. The experimental heat energy consumption ranged from 896 kW h/m3 to 1433 kW h/m3, and the gained output ratio (GOR) ranged from 0.44 to 0.70. The solar-DCMD system was run continually for more than 150 days for seawater desalination in Korea [6].

Pang Wang et. al. (2015) Membrane distillation is a separation process based on the vapor transport across the hydrophobic micro porous membrane driven by the vapor pressure gradient across membrane. This process can be used for various applications such as sea water desalination, waste water treatment, separation of volatile compounds, concentration of non-volatile compounds and processing of dairy fluids [7].

Achmad Chafidz et. al. (2014) They have developed an integrated solar-driven desalination system that uses membrane distillation process to produce potable water. The system encompasses the sources of both water and energy. The system is an integrated (self-contained) system that utilizes solar energy for its operation by combining solar photovoltaic (PV) and solar thermal collectors. The system is intended for autonomous operation in arid remote areas of Saudi Arabia where electricity and potable water are not readily available. Due to its portability, the system can be used in emergency situations in which potable water is essential for survival, such as natural disasters. The system has three major components: the solar-thermal system, solar-PV system, and membrane distillation system [8].

R. Schwantes B. et. al. (2013) The development of small to medium size, autonomous and robust desalination units is needed to establish an independent water supply in remote areas. This is the motivation for research on alternative desalination processes. Membrane distillation (MD) seems to meet the specific requirements very well. This work is focused on experimental studies on full scale demonstration systems, utilizing a parallel multi MD-module setup. Three different plant concepts are introduced, one of them is waste heat driven and two of them are powered by solar thermal collectors. Design parameters and system design are presented. After the analysis of plant operation a comparison among the plants as well as a comparison with laboratory experiments is carried out and discussed. Impact of different feed flow rates, salinities, operating hours and process temperatures are taken into consideration and put into relation [9].

Young-Deuk Kim et. al. (2013) This paper presents a solar-assisted direct contact membrane distillation (DCMD) system with novel energy recovery concepts for a continuous 24-h-a-day operation. A temperature modulating scheme is introduced to the solar–thermal system that supplies feed seawater to the DCMD modules. This scheme attenuates extreme temperature fluctuations of the feed water by storing the collected energy during solar-peak hours and reutilizing it throughout the day. Thus, the energy savings is realized yet the feed seawater temperature is maintained within the desired range. Additionally, the system employs heat recovery from the permeate and brine streams to the feed seawater. The simulations for such a system with a shell-and-tube type DCMD modules are carried out to examine the spatial property variations and the sensitivity of system performance (i.e., Trans membrane pressure, permeate flux and performance ratio) to the operating conditions (inlet temperature and flow rate) and the fiber dimensions (fiber length and packing density) [10].

Edward K. Summers et. al. (2012) Compared to solar water heaters, high-temperature solar air heaters have received relatively little investigation and have resulted in few commercial products. However, in the context of a humidification–dehumidification (HD) desalination cycle, air heating offers significant performance gains for the cycle. Heating at a constant temperature and constant heat output is also important for HD cycle performance. The use of built in phase change material (PCM) storage is found to produce consistent air outlet temperatures throughout the day or night. In this study, the PCM has been implemented directly below the absorber plate. Using a two dimensional transient finite element model, it is found that a PCM layer of 8 cm below the absorber plate is sufficient to produce a consistent output temperature close to the PCM melting temperature with a time-averaged collector thermal efficiency of 35%. An experimental energy storage collector with an 8 cm thick PCM layer was built and tested in a variety of weather and operating conditions [11].

Guofeng Yuan A. et. al. (2011) In this paper, an experimental investigation of a 1000 L/day solar humidification–dehumidification system was presented. The system has been designed and constructed by the Chinese Academy of Sciences and HIMIN Solar Co., Ltd, based on a series of researches since the year 2007. This system was composed of a 100 m2 solar air heater field, a 12 m2 solar water collector, a humidifier–dehumidifier unit, a pre-treatment and post-treatment system and other subsystems. Performance of the solar air heater field and the humidifier was investigated by experimental tests and analyses. Water production tests were carried out on several typical days, and the results showed that water production of the system could reach 1200 L/day, when the average intensity of solar radiation got to 550 W/m2 [12].

M. Zamena et. al. (2009) The performance of the humidification–dehumidification (HD) desalination process was optimized through mathematical programming. In this paper, by adding a solar system to the model, the total solar HD system is optimized. The main purpose of this optimization is the reduction of fresh water production costs. By using special operational and geographical constraints the model can be used for any region to determine optimum operation point of system. Results show that solution obtained by cost objective function has a cost 7–28% lower than other objective functions. Also recycling, in spite of the increase of productivity and decrease of specific thermal energy consumption of the HD process, increases the cost of production [13].

Majed M. Alhazmy et. al. (2007) This paper presents a theoretical analysis based on the second law of thermodynamics for estimating the minimum work required for air dehumidification process to produce potable water in a humidification-dehumidification (HD) desalination cycle. The general air dehumidification process is analyzed through an equivalent path consisting of an isothermal dehumidification followed by a sensible cooling Dehumidification is treated as separation process of an ideal mixture consisting of two components, namely air and water vapor. The present analysis assumes the dead state to be the dry ambient and the final state for complete dehumidification to be saturated air at 0.01EC. Contours of the minimum work are plotted on psychometric chart and presented as a handy engineering tool to estimate the power requirement for complete and incomplete dehumidification process independent of the devices used [14].

J. Orfia et. al. (2007) This paper presents a theoretical study of a solar desalination system with humidification–dehumidification which is a promising technique of production of fresh water at small scale (few m3/d). A general model based on heat and mass transfer balances in each component of the system was developed and used to optimize the system's non dimensional characteristics. The daily production of fresh water depends on the ratio between the salt water and the air mass flow rates. It was shown that, if this ratio is continuously adjusted for optimum performance, it is possible to produce more than 40 L of fresh water daily per square meter of solar collector surface on a typical July day in Tunisia [15].

Said Al-Hallaja et. al. (2006) Major desalination processes consume a large amount of energy derived from oil and natural gas as heat and electricity, while emitting harmful CO2. Solar desalination has emerged as a promising renewable energy-powered technology for producing fresh water. Combining the principle of humidification-dehumidification with solar desalination results in an increase in the overall efficiency of the desalination plant, and therefore appears to be the best method of water desalination with solar energy. A detailed study of the mechanism of this process is presented in this report, along with an economical evaluation of the process. Comparison of the costs of currently available solar desalination processes presented in this report leads to the conclusion that a better understanding of this method of solar desalination is highly desirable. Simulation verification and design optimization by varying the three major components (humidifier, condenser and collector surface areas) of the unit is perhaps a critical step in the commercialization of a solar desalination process based on the humidification–dehumidification principle [16].

Shaobo Houa et. al. (2005) This paper presents a method of performance optimization of solar humidification–dehumidification desalination (HDD) process using Pinch technology. Pinch technology is used in the humidification process to determine the maximum possible saturated air temperature and the temperature of water rejected from the unit, and then in dehumidification process to determine the temperature of water leaving from heat exchanger. From pinch chart, all the thermal energy rejected, supplied and recovered are determined easily. Both the optimum mass flow rate ratio of water to dry air and maximum thermal energy recovery rate is obtained by adjusting mass flow rate ratio of water to dry air. The curve of optimum mass flow rate ratio of water to dry air at a different spraying water temperature is acquired by changing spraying water temperature follow the above steps. The analysis method using Pinch technology in HDD process proves a very simple, visual and efficient [17].

Henry Shih et. al. (2005) This paper compares the effectiveness of thermal schematics, thermal efficiency, and performance ratio. A sulfuric acid plant located at the coastal line of Morocco was identified as an example for comparison because it utilizes low-grade heat to produce desalinated water needed at the facility from the large volumes of cooling water used in current processes. Currently the acid cooling is performed in the shell-and-tube heat exchanger used for cooling hot sulfuric acid. The heat is then ‘‘rejected’’ to the sea. Both multi-effect distillation (MED) and multi-stage flushing (MSF) systems have advantages in that low grade heat can be used for evaporation and subsequent production of freshwater. The MED process is designed for utilization of low-grade thermal heat as a heat source in the form of hot water in the range of 0.8–3 bar, which is supplied to the first effect of the desalination unit. It operates with lower top brine temperatures in the range of 64–70_C. The thermal performance, operational and capital cost are directly proportional to the number of effects in the MED system [18].

Sandeep Parekh et. al. (2004) Major desalination processes consume a large amount of energy derived from oil and natural gas as heat and electricity. Solar desalination, although researched for over two decades, has only recently emerged as a promising renewable energy-powered technology for producing fresh water. Solar desalination based on the humidification dehumidification cycle presents the best method of solar desalination due to overall high-energy efficiency. This paper provides a comprehensive technical review of solar desalination with a multi-effect cycle providing a better understanding of the process. Discussion on methods to improve system performance and efficiency paves the way towards possible commercialization of such units in the future [19].

S. Al-Kharabsheh et. al. (2003) This paper presents a theoretical analysis and preliminary experimental results for an innovative water desalination system using low-grade solar heat. The system utilizes natural means (gravity and atmospheric pressure) to create a vacuum under which water can be rapidly evaporated at much lower temperatures and with less energy than conventional techniques. The system consists of an evaporator connected to a condenser. The vapor produced in the evaporator is driven to the condenser where it condenses and is collected as a product. The effect of various operating conditions, namely, withdrawal rate, depth of water body in the evaporator, temperature of the heat source, and condenser temperature, on the system performance was studied. Numerical simulations and preliminary experimental results show that the performance of this system is superior to a flat-basin solar still, and the output may be twice that of a flat-basin solar still for the same input [20].

Hassan E. S. Fath et. al. (2002) A numerical study has been carried out to investigate the performance of a simple solar desalination system using humidification-dehumidification processes. The desalination system consists of a solar air heater, humidifier, dehumidifier and a circulating air-driving component. The study covers the influence of different environmental, design, and operational parameters on the desalination system productivity. Environmental parameters include solar intensity, ambient temperature and wind speed. Design parameters include the solar heater base insulation, the humidifier and the dehumidifier effectiveness. Operational parameters include air circulation flow rate, feed water rate and temperature. The results indicated that the solar air heater (energy source) efficiency significantly influences system productivity. Increasing the solar intensity, ambient temperature and decreased wind velocity increases system productivity. Increasing the air flow rate up to 0.6 kg/s increases the productivity, after which it has no significant effect. The feed water flow rate has an insignificant influence on system productivity [21].

Naser K. Nawayseh et. al. (1997) Solar desalination with a humidification-dehumidification process has proven to be an efficient method of utilizing solar energy for obtaining fresh water from saline water. The reason behind the success of this method is the use of latent heat of condensed water vapor. With proper use, this process efficiency could be high. A simulation program was written to describe the performance of such units. It was found to predict the performance of a desalination unit constructed in Jordan in 1993. The simulation program was then used to optimize the unit performance by studying the effect of different parameters such as the condenser and humidifier area, as well as the effect of some of the operating conditions such as the feed water flow rate to the unit [22].

2.3 RESEARCH GAP

Solar distillation system are often ignored and overlooked as a method of producing of clean water. Many superior research techniques have been developed to maximize production of potable water. These techniques are more widespread and applied in developed countries. But it is not practical to build a multimillion dollar distillation plant in an underdeveloped and rural region that cannot afford the high cost. A number of solutions have been put forward to address the daunting trouble facing roughly a billion people due to lack of clean, safe drinking water. Portable Solar distillation system is an affordable, economical and reliable source for clean drinking water that is often ignored and underutilized.

CHAPTER-3

EXPERIMENTAL SETUP

3.0 SOLAR DISTILLATION

There is an urgent required for clean, pure drinking water in many countries. Most of the water sources are brackish (i.e., containing dissolved salts) or contain harmful salts and therefore cannot be used directly for drinking. There are number of coastal areas where seawater is available in large amount but fresh drinkable water is not available. Pure water is not only required for drinking but it is needed in some industries, hospitals, and school. Solar distillation system is one of the cheap and best processes that can be used for water purification. In solar distillation process, water is evaporated and separated water vapor from dissolved impurities, and is then condensed as pure distilled water.

Solar distillation process is a natural phenomenon available on earth. Solar radiation heats water in the seas and lakes, evaporates it, and condenses it as clouds and return to earth surface as rainwater. Basin-type solar still systems is a replication of solar distillation phenomenon on a small scale for producing the fresh water, and are the most common and general method for solar water distillation. Porous radiation-absorbing pad (the wick) absorbs slowly the feed water in basin-type solar wick still. Two advantages are declared over basin stills. First, the wick can be tilted, so that the feed water presents a more suitable angle to the sun (reducing reflection and presenting a large effective area). Second, less feed water is in the still at any time, and thus the water is heated more quickly and to a higher temperature. Simple basin-type solar wick stills are more efficient than common basin type solar stills, and some designs are insist to be less costly than a basin-type solar still of the same output.

The inclined wick type solar still is of academic interest only since no commercial or large plant has been installed. The only advantage of the inclined wick type solar still is that due to its very low thermal capacity and exactly parallel and very nearly transparent cover, solar radiation absorption is high thus resulting higher output. The main problems are in the chocking of the pores of the wick with salt in due course of time, deterioration of the wick cloth, discoloring of the wick cloth and maintaining uniform flow of water. Saline water is supplied from the top side of the still to the entire width of black cloth wick with the help of a distributor at a very slow flow rate such that the entire area of the wick remains wet all the time. A water proof liner is positioned between the insulation and the wick. Solar radiation is absorbed by the water present in the wick which gets evaporated and after that condensed into water inside of the glass and finally collected in the condensate channel fixed on the lower side of the glass. Twenty such solar stills each of 1 m wide and 2.32 m long with a total wick area of 46.4 m^2 were installed at Daytona Beach, USA. In 12 units, glass cover was used. In 4 units weatherable Mylar film was used. In the remaining 4 units Tedlar film was used. Initially wick of black terrycloth was used which was later replaced by sailcloth and glass fibers pressed into black plastic. The stills were tilted 30^o towards south and have given an output of 4.48 l/m^2 day at 22.72 MJ/m^2 input solar radiations per day.

3.1 Types of Solar Distillation System

3.1.1 Thermal based desalination processes,

Those employ thermal energy to evaporate water with following condensation to get fresh water.

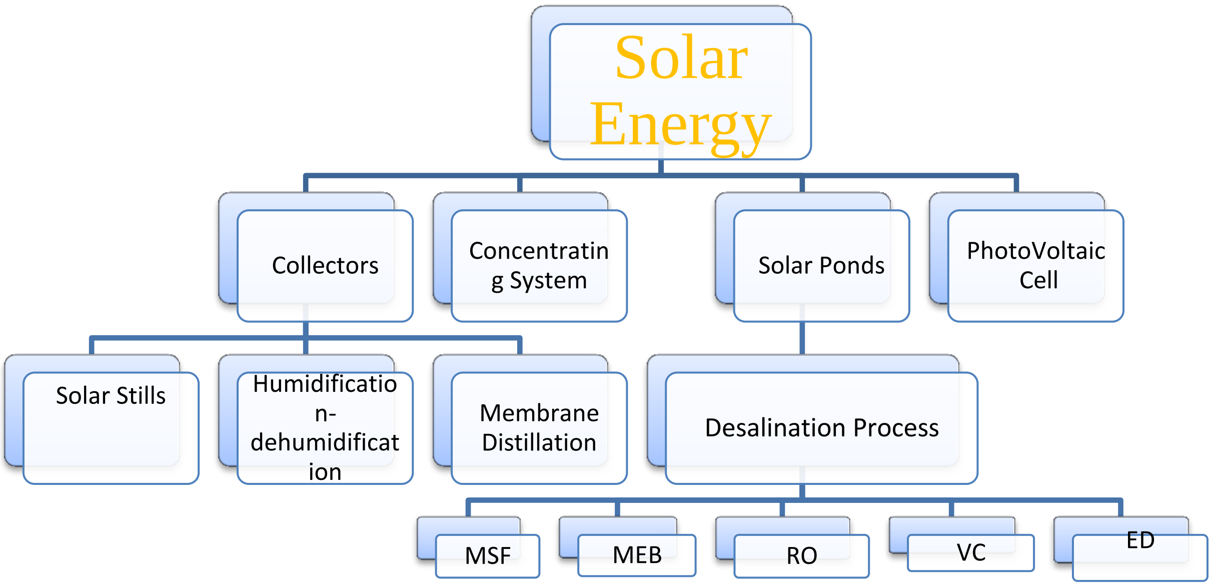
The major process comes under this category are

- Multiple stage flash process with brine circulation (MSF-BR)
- Multiple stage flash process as the once through process (MSF-OT)
- Multiple effect boiling process (MEB)

3.1.2 Membrane based processes

This is based on a particular flow of water through semipermeable membranes.

- Pressure : Reverse Osmosis (RO), Filtration
- Electrical Potential : Electro-dialysis (ED), Membrane Electrolysis
- Concentration : Membrane Extraction and Dialysis



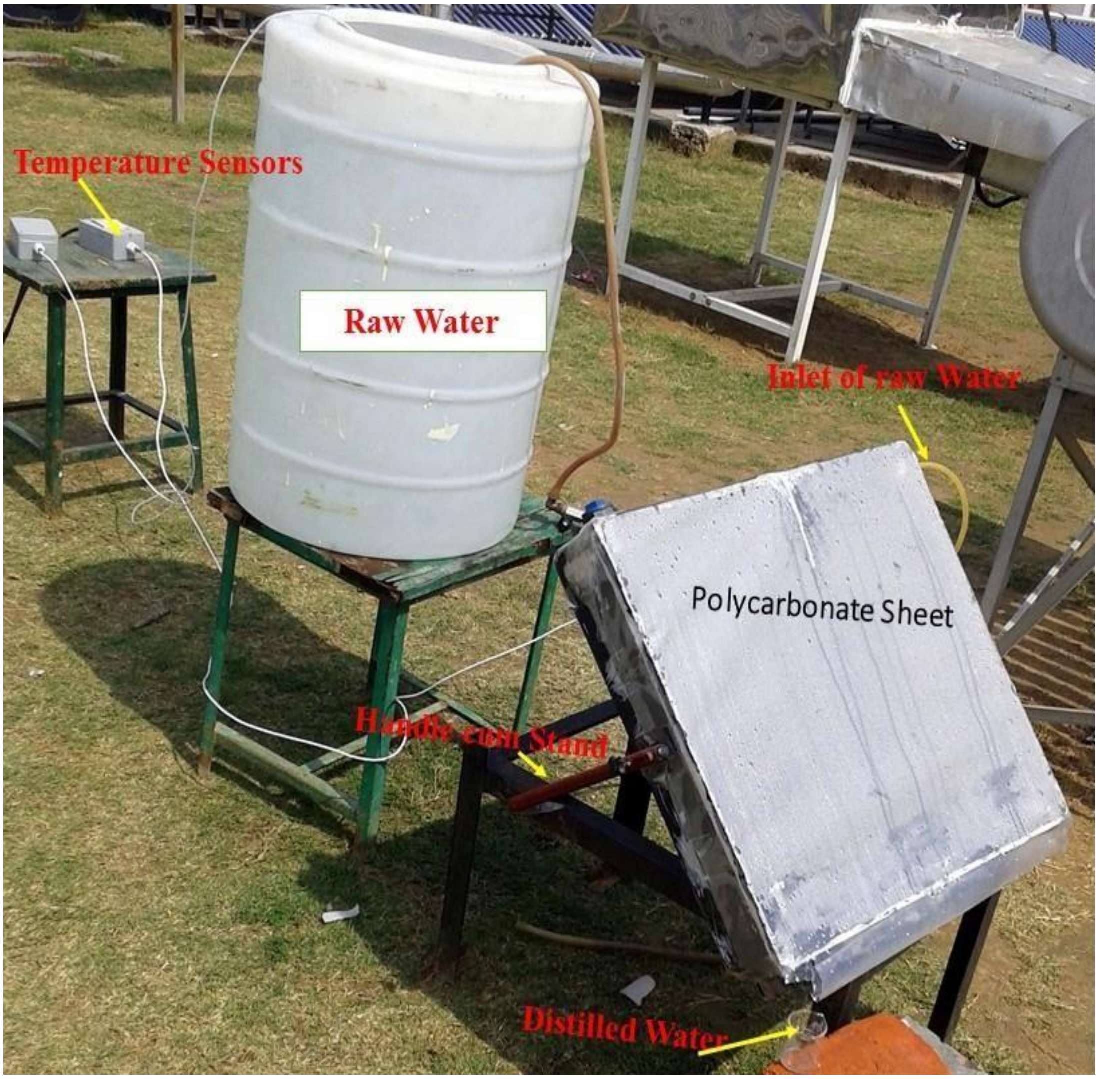
[Figure-3.1 Types of Distillation Process]

3.2 PORTABLE SOLAR WATER DISTILLATION SYSTEM (PSWDS)

Portable Solar Water Distillation system (PSWDs) having an importance for providing hot water and drinking water simultaneously to households. It uses sun radiation to heat the water and produce fresh distilled water out of the saline or brackish water & also produce hot water. The paper is focused on field performance of a new design of PSWD for domestic applications in remote areas and hilly areas. Field Performance data of (PSWDs) has been recorded during summer and winter. It observed that on Solar Global Radiation 6.2 kWh/m^2, maximum output of distilled water generation is achieved 1.2 liters/day per 0.25 m^2 and average temperature of hot brackish water has reached 40^0C at ambient temperature of 23^0C within 8 hours. This system is a most efficient and cost effective. It can produce pure, clean fresh water on any scale from any water sources and gives hot water (brackish water), which gives more advantages and additional efficiency.

3.3 SYSTEM DESCRIPTION

The PSWDS system is design with a glazed area of 0.25 m^2, weight 6 kg and having a thin black cloth of 0.2 mm for absorbing the input water. The front glazing is of polycarbonate thin sheet (0.18 mm), which is tough, dimensionally stable, high impact resistance, low reflectivity, good temperature capability and expected life of 8-10 years. The inlet raw water is located at the top of the system and outlet of distilled water, hot brackish water at the bottom of the system. However, all metal parts of the system that come into contact with water are preferably made of stainless steel, copper, or brass because of better resistance to corrosion. A black-wick is placed on the absorber plate in order to spread water evenly on the plate and to increase the thickness of the water film. The absorber plate is shield from the bottom to stop heat losses. The glazing surface is inclined to an angle of 45 ° in order to make to condensed to water run down on the glazing plate and to increase the amount of sun radiation reaching the surface aperture more efficiently during the day. The feed water comes from a brackish tank and goes into a distribution pipe (diameter of 2 mm) which has a longitudinal slot of 0.2 mm. The water then falls through this slot onto the black absorber plate or onto the black wick, spread all over the absorber plate. Solar radiation heats the absorber plate. Some of the water evaporates and condenses as it reaches the cool cover. The condensate flows into a condensate channel and is separated out from the brackish water and collected. The rest of the feed water, which is hot water, flows into another channel and collected, called the remaining water channel. The hot water is taken out from the bottom of the remaining water channel. In this way the fresh water and hot water are separated and collected in separate storage tanks.



[Figure-3.2Experimental setup of PSWDs]

The input water first absorbed the black cloth sheet and slowly runs down. Solar energy heats the absorbed water (cloth) causing it to vaporize at the temperature of 65-75^{0}C and vapors will condense on the inside of the composite plastic (polycarbonate) panel enclosure due to wind speed outer side of the sheet. The vaporized water (distilled) started dropping and by drop wise condensation it run down in to fresh water with two Total Dissolved Solid (TDS) out let at the bottom of the panel. And the remaining waste water or hot brackish water at the temperature of 45-50 ^{0}C runs down at the bottom of the system. The performance of PSWDs has been designed and installing the system at the Out –Door Test Bed of National Institute of Solar Energy (formerly solar energy center), MNRE (latitude: 28^0 25$^/$ 31.2$^{//}$N & longitude: 77^0 9$^/$ 18.8$^{//}$E). This system has been evaluated and observations were recorded on the basis of field data collected (sunshine hours).

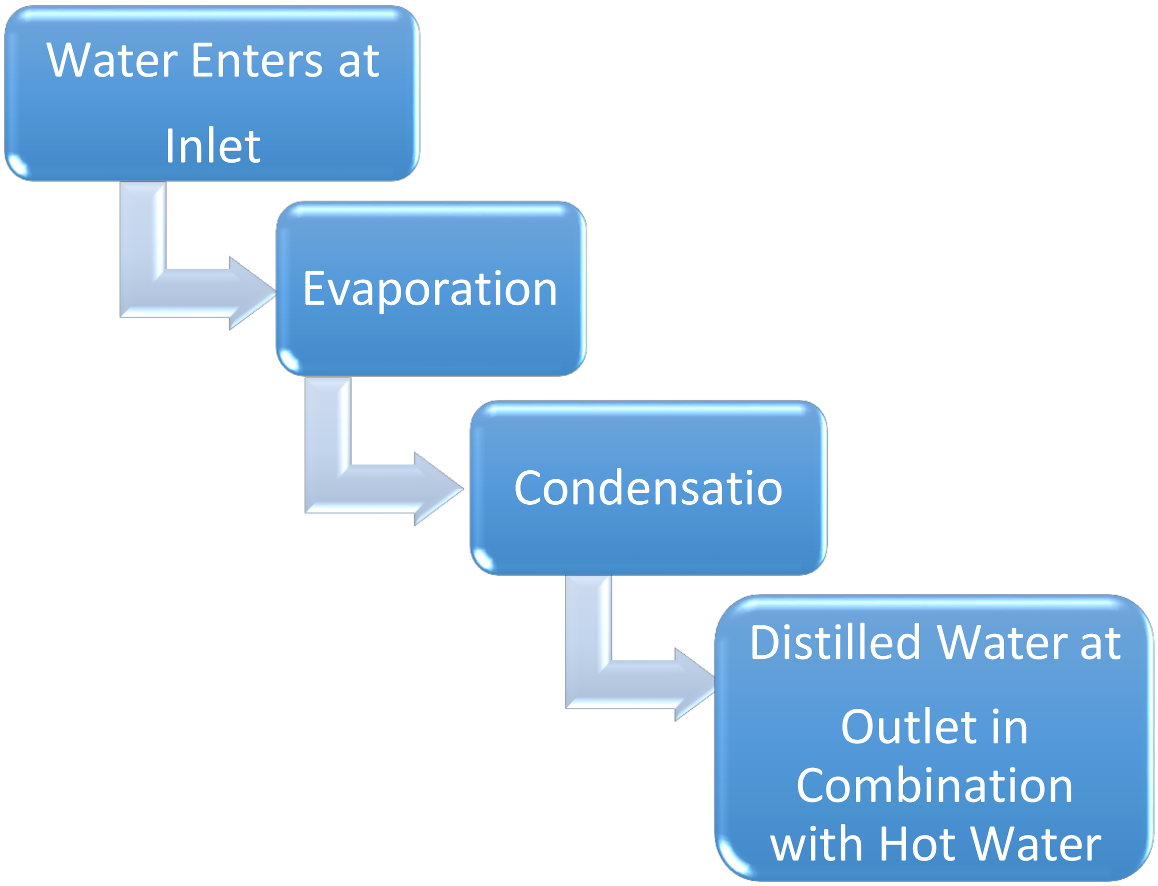
3.3.1 TECHNICAL SYSTEM SPECIFICATION

Weight	6 kg
Collector area	540 * 540 mm^2
Absorber area	500 * 500 mm^2
Membrane thickness	0.2 mm (approx.)
Glazing thickness	0.18 mm (approx.)
Space between membrane and sheet	25 mm
Paint below membrane	Black acrylic spray paint
Water sprayer	Copper pipe diameter 2 mm having 4

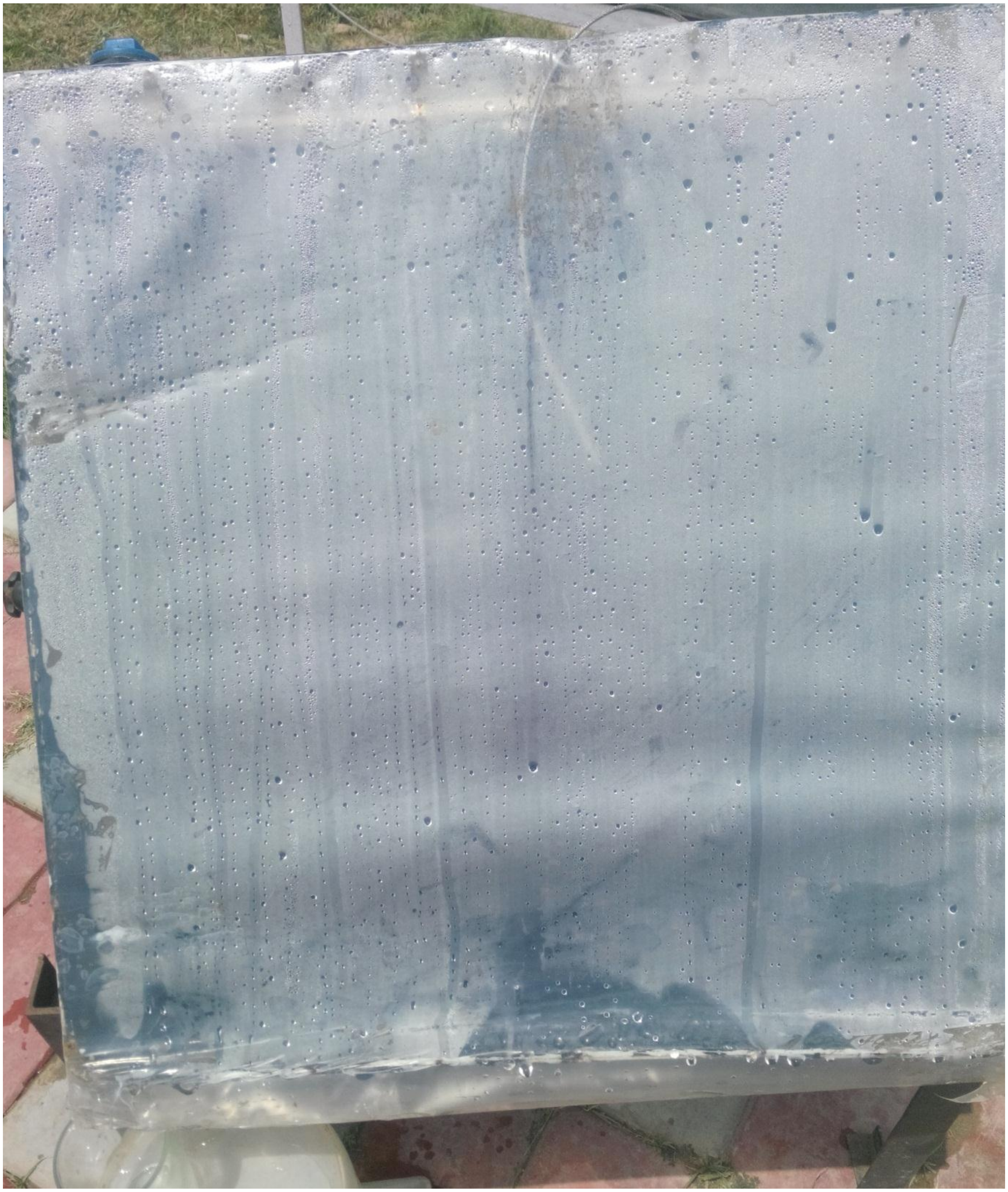
[Table-3.1 Specification of set-up]

[Figure-3.3Black Membrane of PSWDs]

3.4 PROCESS INVOLVED IN PSWD SYSTEM

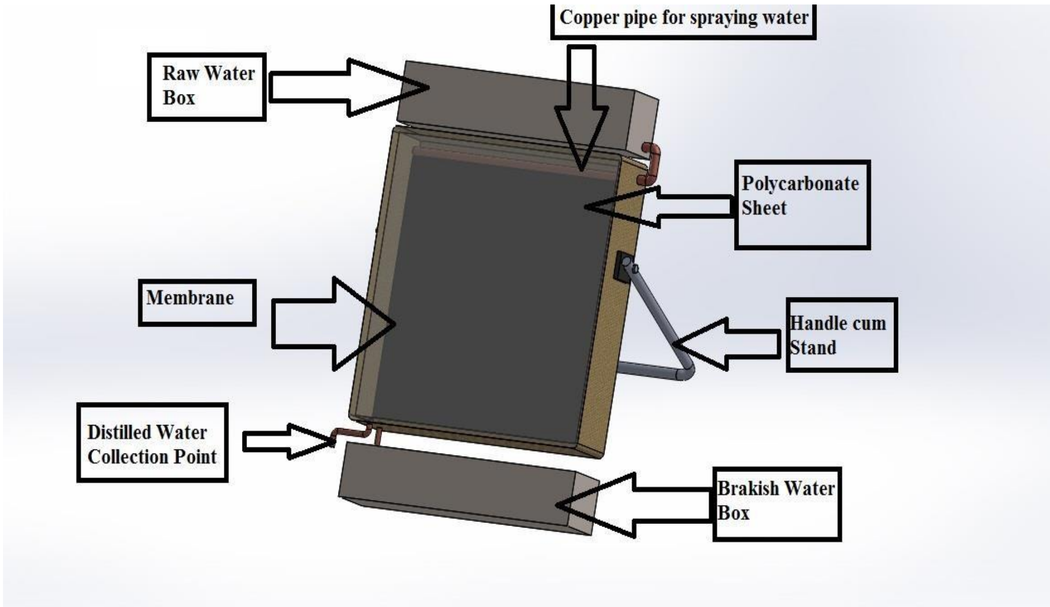


[Figure-3.4 Block diagram of PSWDs processes]



[Figure-3.5 Glazing Sheet of PSWDs]

3.5 SYSTEM DESIGN



[Figure-3.6 Design of PSWDs]

The above figure shows the cheap & robust design of Portable Solar Water Distillation System having tanks made up of aluminium sheet which is cheaply available and easily formable into a box with some minor adjustments even in rural, coastal & areas away from man's approach like in defence applications.

The glazing sheet can easily be replaced by another one as it is cheaply available. Its handle has removable bolts which can easily be tightened to place it at any angle desirable according to the favorable conditions. Its membrane is a simply a black cloth, if any debris may deposit on the cloth it can easily be washed and used again & again.

CHAPTER-4

RESULTS AND DISCUSSIONS

In this experimental study, a portable solar water distillation (PSWD) system is designed and tested. The PSWD system consists of an inclined flat solar absorber plate covered with polycarbonate sheet. Water spread on the absorber plate creates a continuous thin film of water. The heating and evaporating processes take place on the absorber plate, and then the condensing process takes place on the glazing sheet. The most important feature of the system is the fact that the system produces hot and fresh drinking water simultaneously. The heated water can be used for domestic purpose if it is not too brackish. To increase evaporation a porous medium is used.

The Experimental analysis involves analysis of a collection of data collected by testing the experimental setup. The set-up was assembled from existing, nearly available components. It was fixed at an angle of 45°. The system is under test every day for two months about 7 to 8 hours approximately. It is supplied with 700 ppm raw water at the inlet and 1 ppm distilled/potable water is obtained at the outlet with a lump amount of hot water at 40^0c to 50^0c. The total water involved in the test of which 30 % water is converted to distilled water and rest 70 % is brackish water.

To simplify the analysis/performance, some assumptions/standard conditions are made.

- Solar irradiance with ±50 W/m².
- Wind speed up to 1.2-5 m/s with ±1.2 m/s.
- Ambient air temperature with accuracy of ±0.1ºC.
- Collector temperature with ±0.1ºC

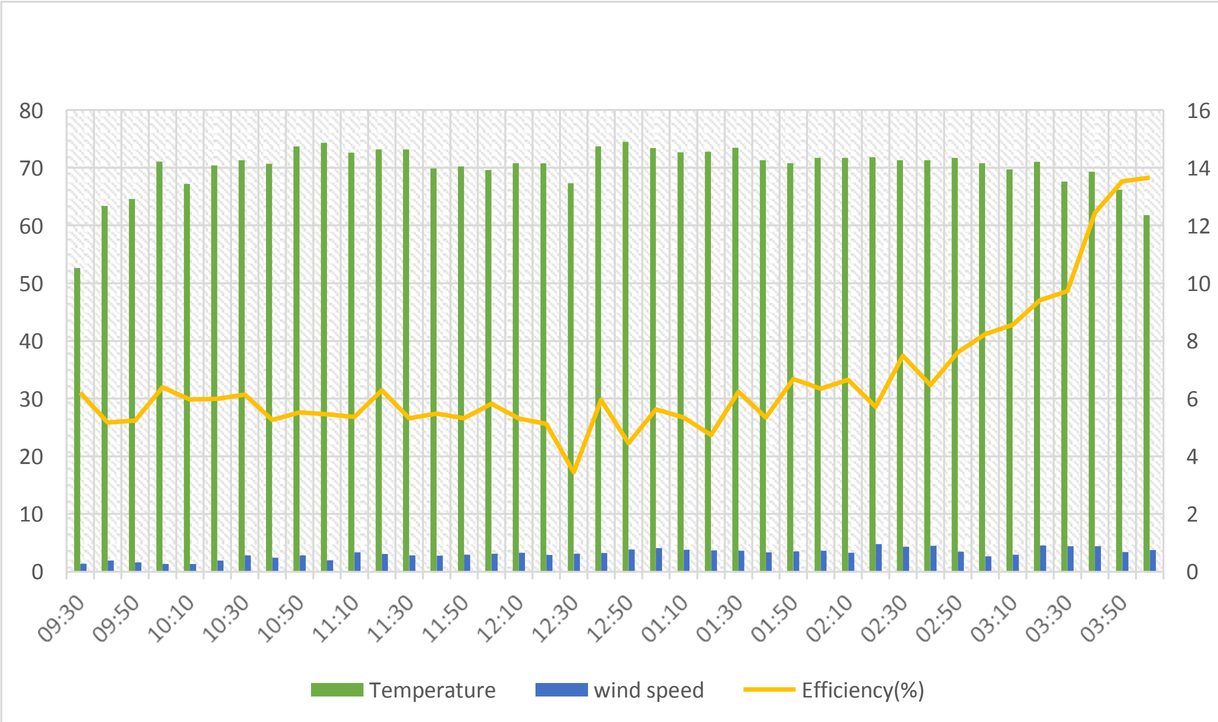
Tables show the measured parameters of the tests. The tests show the effect of mass flow rate on the fresh water generation. The results are also affected by environmental conditions, such as changing solar intensity, ambient temperature, and wind speed.

4.0 EXPERIMENTAL DATA OF PSWD SYSTEM

Time	Inlet Water Temp.	Inside Temp.	Flow Rate (ml)/10 min	Wind Speed	Air Temp.	Radiation Intensity w/m2	Efficiency (%)
09:30	22.5	52.6	24	1.38	19.31	6158	6.201494
09:40	22.7	63.4	21	1.92	19.26	6471	5.163839
09:50	22.8	64.6	22	1.62	19.67	6683	5.238127
10:00	22.9	71.1	28	1.34	20.64	6971	6.391278
10:10	22.9	67.2	27	1.35	21.2	7199	5.967829
10:20	23	70.4	28	1.94	21.05	7433	5.994027
10:30	23.2	71.3	30	2.81	20.89	7775	6.139678
10:40	23.4	70.7	26	2.412	21.34	7870	5.256823
10:50	23.6	73.7	28	2.81	21.59	8067	5.522945
11:00	23.7	74.3	28	1.98	22.07	8162	5.458662
11:10	24	72.6	28	3.33	22.1	8304	5.365318
11:20	24.2	73.2	33	3.07	22.17	8360	6.281053

11:30	24.4	73.2	28	2.81	22.27	8380	5.316659
11:40	24.6	69.9	29	2.76	22.72	8433	5.471932
11:50	24.8	70.2	28	2.94	22.86	8383	5.314756
12:00	25	69.6	31	3.1	22.68	8479	5.817573
12:10	25.2	70.8	28	3.28	23.05	8388	5.311588
12:20	25.4	70.8	27	2.9	23.6	8385	5.123721
12:30	25.6	67.3	18	3.11	23.71	8305	3.448718
12:40	25.8	73.7	31	3.25	23.69	8280	5.957391
12:50	26	74.5	23	3.84	23.49	8218	4.453346
01:00	26.2	73.4	27	4.11	23.59	7636	5.626296
01:10	26.4	72.7	29	3.81	23.96	8636	5.343307
01:20	26.8	72.8	23	3.68	24.04	7721	4.740008
01:30	26.7	73.5	28	3.6	24.06	7134	6.245248
01:40	26.9	71.3	23	3.32	24.27	6860	5.334927
01:50	27.2	70.8	30	3.52	24.08	7151	6.67543
02:00	27.2	71.7	27	3.65	24.3	6770	6.345997
02:10	27.5	71.7	27	3.26	24.63	6460	6.650526
02:20	27.6	71.8	23	4.76	24.63	6407	5.712127
02:30	27.5	71.3	29	4.32	24.97	6168	7.481323
02:40	27.9	71.3	24	4.47	25.03	5905	6.467197
02:50	28.1	71.7	26	3.48	24.8	5439	7.606398
03:00	28.1	70.8	26	2.64	24.8	5024	8.234713
03:10	28.3	69.7	25	2.95	24.84	4651	8.552999
03:20	28.4	71	25	4.54	24.78	4228	9.408704
03:30	28.5	67.6	24	4.45	24.64	3925	9.729631
03:40	28.6	69.3	27	4.41	24.61	3455	12.43485
03:50	28.7	66.2	24	3.4	24.82	2823	13.52774
04:00	28.7	61.8	22	3.76	24.73	2563	13.65837

[Table-4.1 Experimental data of 14 April 2015]



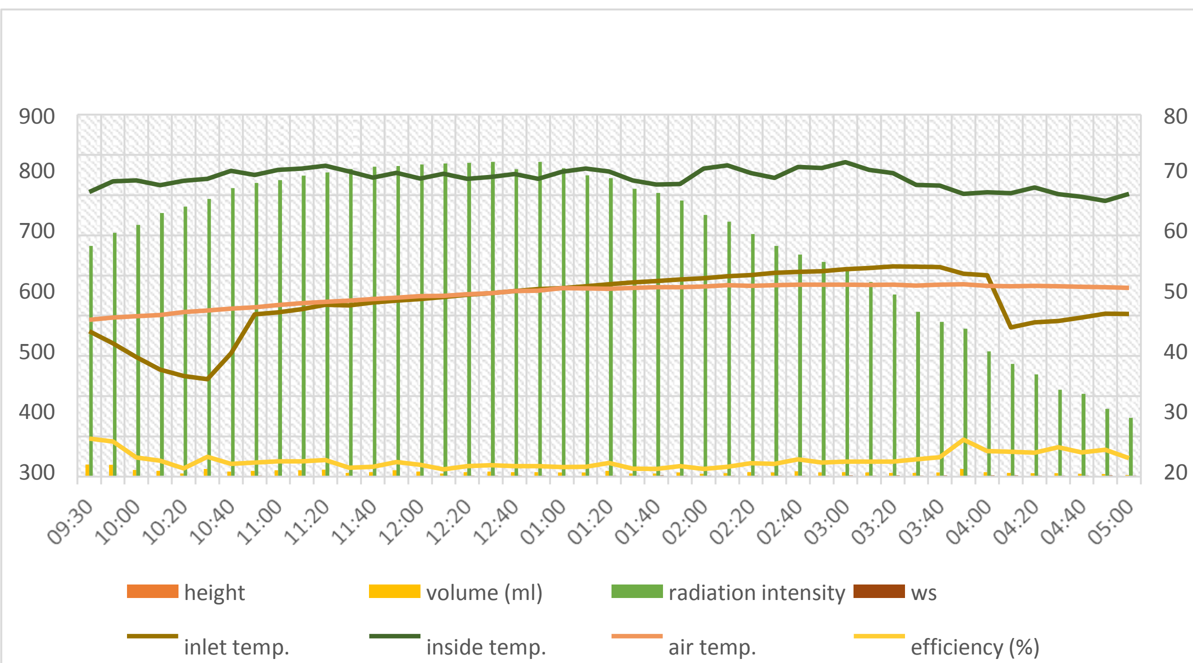
[Figure-4.1 Graphical analysis of PSWDs, 14April 2015

Time	Height	Volume (ml)	Volume (m^3)	Radiation Intensity	Wind Speed	Inlet Temp.	Inside Temp.	Air Temp.	Efficiency (%)
09:30	0.096	30.14	0.000030144	573.503	1.47	2.12	62.95	34.68	8.3624267
09:54	0.094	29.51	0.000029516	605.98	1.55	29.46	65.24	35.16	7.74882207
10:00	0.053	16.64	0.000016642	626.426	1.73	26.43	65.5	35.45	4.22676709
10:10	0.046	14.44	0.000014444	655.135	1.77	23.65	64.41	35.71	3.50720508
10:20	0.024	7.53	0.000007536	671.55	1.22	22.25	65.4	36.36	1.7841912
10:30	0.06	18.84	0.00001884	690.85	1.49	21.5	65.85	36.74	4.33932228
10:40	0.04	12.56	0.00001256	717.29	1.76	27.26	67.62	37.11	2.78624712
10:50	0.045	14.13	0.00001413	730.18	2.01	35.86	66.69	37.44	3.07919362
11:00	0.05	15.7	0.0000157	737.22	1.58	36.26	67.81	37.94	3.38865468

11:10	0.05	15.7	0.0000157	748.24	1.36	37.01	68.1	38.37	3.33874693
11:20	0.055	17.27	0.00001727	756.62	1.68	37.98	68.74	38.66	3.63194523
11:30	0.03	9.42	0.00000942	765.4	1.66	37.88	67.45	38.91	1.95833603
11:40	0.034	10.67	0.000010676	770.42	1.61	38.47	66.14	39.24	2.20374653
11:50	0.05	15.7	0.0000157	772.36	1.26	38.91	67.16	39.56	3.23448133
12:00	0.04	12.56	0.00001256	776.69	1.77	39.29	65.9	39.91	2.57315943
12:10	0.025	7.85	0.00000785	778.95	2.07	39.71	66.94	39.98	1.60355864
12:20	0.036	11.304	0.000011304	779.9	1.88	40.16	65.85	40.31	2.30631168
12:30	0.04	12.56	0.00001256	782.35	2.03	40.56	66.27	40.55	2.55454362
12:40	0.035	10.99	0.00001099	764.42	2	41.02	66.86	41.03	2.28765443
12:50	0.036	11.304	0.000011304	783	2.09	41.44	65.85	41.1	2.29718069
01:00	0.032	10.048	0.000010048	766.84	1.63	41.65	67.36	41.63	2.08496917
01:10	0.033	10.362	0.000010362	749.48	1.74	42.07	68.06	41.6	2.1999272
01:20	0.045	14.13	0.00001413	741.8	2.14	42.51	67.46	41.52	3.03095929
01:30	0.025	7.85	0.00000785	716.11	2.32	42.96	65.48	41.74	1.74427392
01:40	0.024	7.53	0.000007536	705.93	2.63	43.21	64.52	41.88	1.69729803
01:50	0.032	10.08	0.000010048	686.14	2.38	43.54	64.68	41.85	2.33761273
02:00	0.022	6.9	0.000006908	650.7	2.22	43.82	68.1	42.03	1.6873029
02:10	0.028	8.79	0.000008792	634.25	2.43	44.26	68.79	42.32	2.20522633
02:20	0.036	11.3	0.000011304	603.2	2.56	44.56	67.08	42.19	2.98086207
02:30	0.032	10.04	0.000010048	573.41	2.47	45.03	66.01	42.33	2.78607768
02:40	0.042	13.18	0.000013188	552.01	1.87	45.3	68.47	42.46	3.79920943
02:50	0.033	10.36	0.000010362	533.57	2.46	45.43	68.25	42.45	3.08953502
03:00	0.034	10.67	0.000010676	516.61	2.6	45.84	69.51	42.47	3.28644509
03:10	0.032	10.04	0.000010048	484.21	2.27	46.08	67.81	42.34	3.29932219
03:20	0.03	9.42	0.00000942	452.96	2.69	46.47	67.1	42.41	3.30914518

03:30	0.031	9.73	0.000009734	409.82	2.42	46.43	64.51	42.25	3.77784784
03:40	0.033	10.36	0.000010362	384.39	2.59	46.36	64.36	42.41	4.28856942
03:50	0.06	18.84	0.00001884	367.51	2.07	44.83	62.5	42.48	8.15711355
04:00	0.035	10.99	0.00001099	311.15	2.99	44.47	62.84	42.16	5.62021147
04:10	0.031	9.73	0.000009734	280.06	2.6	33	62.65	42.12	5.52823538
04:20	0.027	8.47	0.000008478	253.78	2.4	34.07	63.94	42.13	5.310688
04:30	0.028	8.79	0.000008792	216.08	2.25	34.36	62.4	42.08	6.47290263
04:40	0.022	6.9	0.000006908	205.95	2.58	35.147	61.87	41.95	5.33104151
04:50	0.02	6.28	0.00000628	168.24	2.72	35.99	60.98	41.85	5.93957204
05:00	0.012	3.76	0.000003768	146.32	2.25	35.96	62.47	41.77	4.08892291

[Table-4.2 Experimental data of 22 April 2015]



[Figure-4.2 Graphical analysis of PSWDs, 22 April 2015]

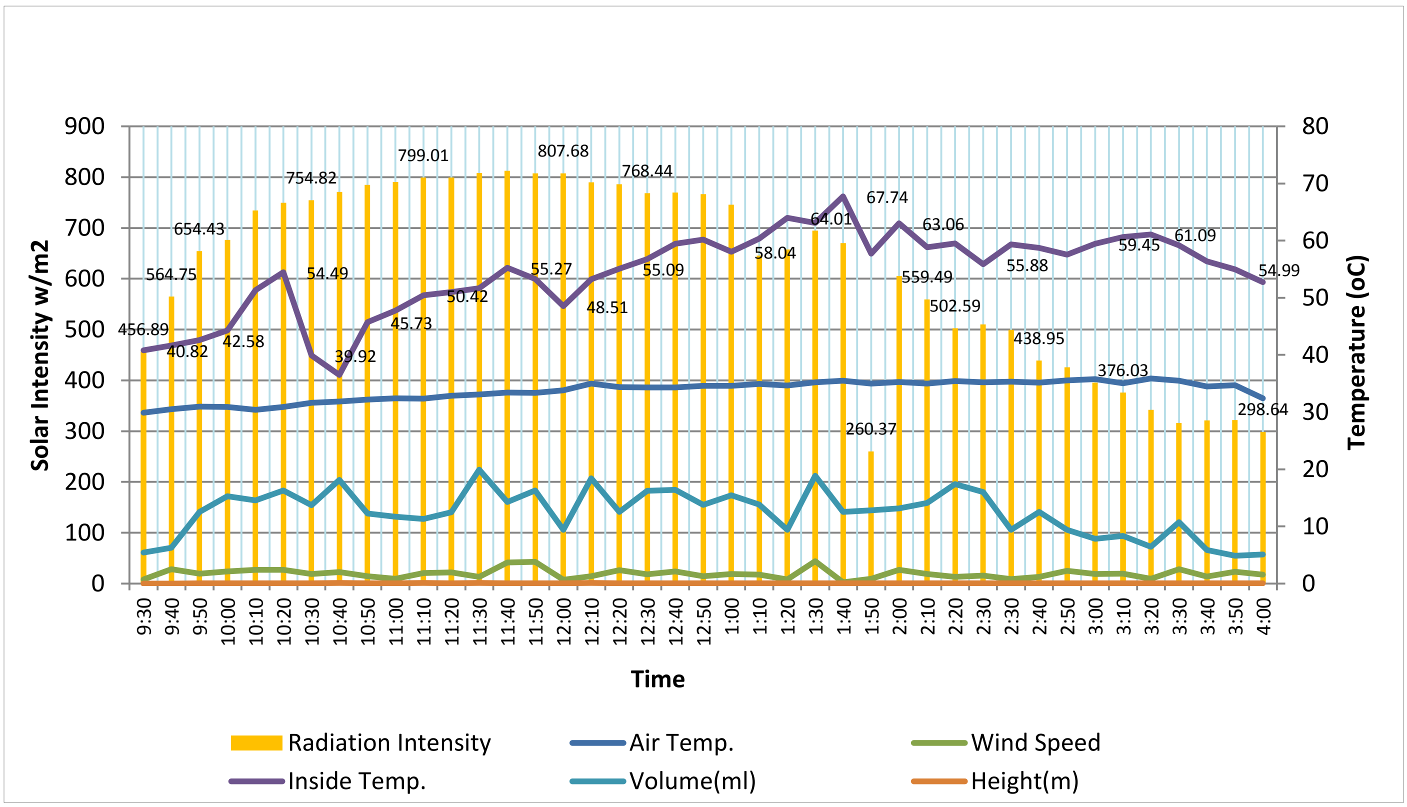
[Figure-4.3 Graph Taken by Data Logger]

Time	Air Temp. (°C)	Radiation Intensity (w/m^2)	Wind Speed (m/s)	Inside Temp. (°C)	Volume(ml)	Height(m)
9:30	29.89	456.89	0.75	40.82	5.45	0.02
9:40	30.52	564.75	2.54	41.65	6.28	0.021
9:50	30.97	654.43	1.73	42.58	12.54	0.062
10:00	30.91	676.13	2.15	44.27	15.28	0.061
10:10	30.41	734.45	2.42	51.34	14.53	0.06
10:20	30.92	749.79	2.39	54.49	16.28	0.075

10:30	31.63	754.82	1.67	39.92	13.71	0.07
10:40	31.87	771.16	2.02	36.48	18.14	0.087
10:50	32.19	784.88	1.26	45.73	12.28	0.055
11:00	32.41	790.39	0.86	47.73	11.71	0.045
11:10	32.35	799.01	1.83	50.42	11.28	0.087
11:20	32.84	799.28	1.93	50.99	12.47	0.062
11:30	33.09	808.32	1.15	51.69	19.9	0.086
11:40	33.41	812.24	3.71	55.27	14.28	0.059
11:50	33.36	807.64	3.78	53.32	16.28	0.075
12:00	33.82	807.68	0.65	48.51	9.42	0.03
12:10	34.97	789.76	1.28	53.26	18.42	0.086
12:20	34.35	785.87	2.36	55.09	12.56	0.023
12:30	34.33	768.44	1.61	56.78	16.22	0.058
12:40	34.34	769.68	2.11	59.45	16.42	0.028
12:50	34.57	766.73	1.29	60.19	13.792	0.067
1:00	34.61	745.94	1.69	58.04	15.42	0.075
1:10	34.92	645.45	1.55	60.37	13.85	0.053
1:20	34.66	657.38	0.71	64.01	9.42	0.06
1:30	35.19	694.67	3.89	63.09	18.84	0.04
1:40	35.49	669.88	0.21	67.74	12.56	0.041
1:50	34.97	260.37	0.83	57.72	12.84	0.042
2:00	35.27	605.31	2.41	63.06	13.18	0.045
2:10	35.01	559.49	1.65	58.83	14.13	0.03
2:20	35.43	502.59	1.16	59.51	17.42	0.075
2:30	35.19	509.92	1.41	55.88	15.99	0.065
2:30	35.31	499.58	0.76	59.34	9.42	0.04
2:40	35.15	438.95	1.19	58.71	12.56	0.045
2:50	35.53	425.86	2.22	57.55	9.42	0.035
3:00	35.77	395.72	1.68	59.45	7.85	0.025

3:10	35.02	376.03	1.74	60.64	8.32	0.034
3:20	35.87	341.72	0.86	61.09	6.43	0.045
3:30	35.49	316.08	2.52	59.18	10.76	0.05
3:40	34.51	321.32	1.22	56.4	5.87	0.056
3:50	34.71	322.07	2.07	54.99	4.89	0.054
4:00	32.41	298.64	1.56	52.71	5.09	0.043

[Table-4.3 Experimental data of 28 April 2015]

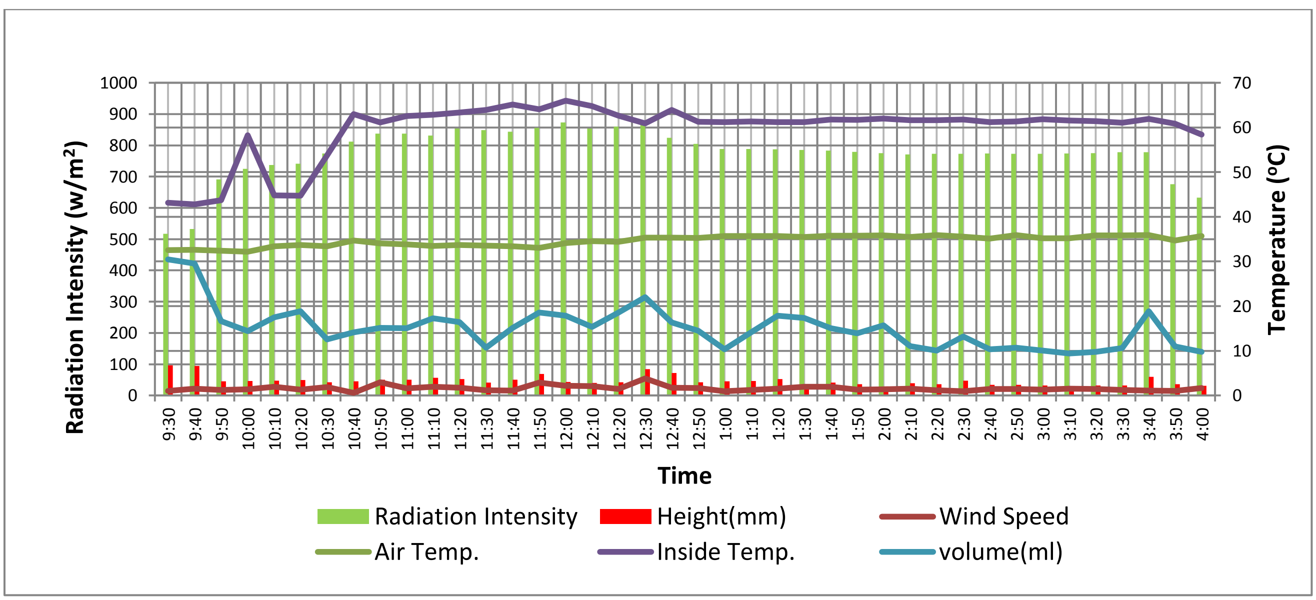


[Figure-4.4 Graphical analysis of PSWDs, 28April 2015]

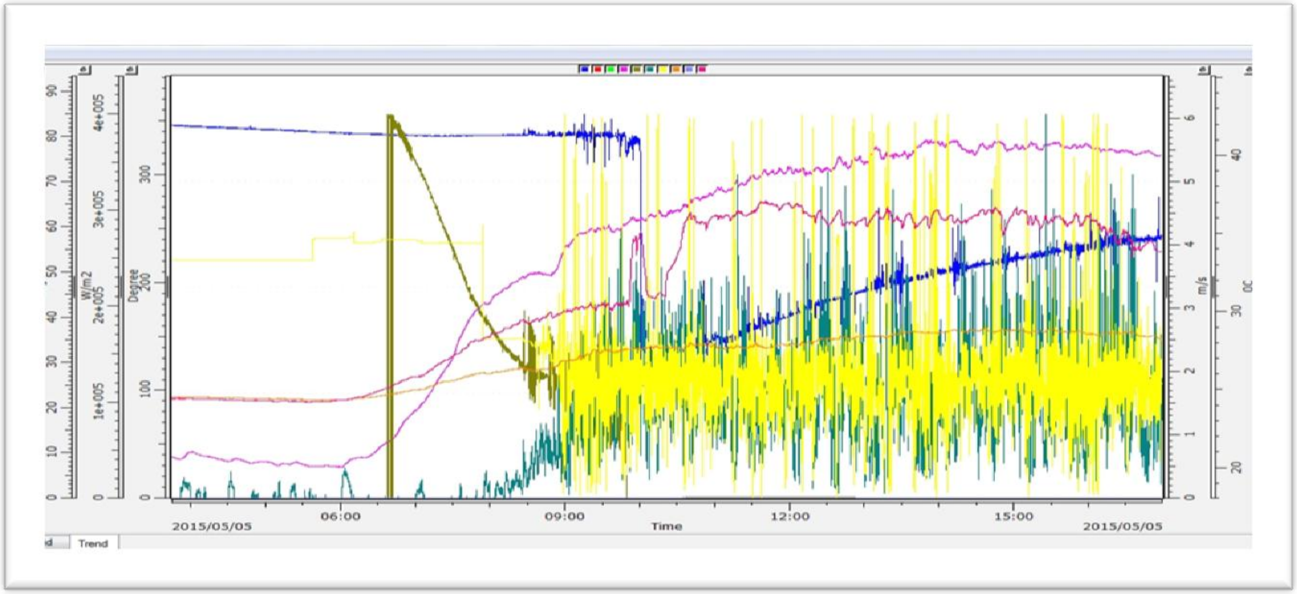
Time	Radiation Intensity (w/m^2)	Wind Speed (m/s)	Air Temp. (^oC)	Inside Temp. (^oC)	volume(ml)	Height(mm)
9:30	517.14	1.05	32.53	43.12	30.44	96
9:40	532.29	1.53	32.64	42.77	29.56	94
9:50	691.01	1.26	32.41	43.75	16.62	45
10:00	724.65	1.36	32.19	58.26	14.44	46
10:10	737.07	1.93	33.38	44.82	17.53	47
10:20	741.14	1.31	33.68	44.73	18.84	49
10:30	773.88	1.89	33.41	53.76	12.56	42
10:40	812.04	0.63	34.72	62.98	14.13	45
10:50	837.33	2.99	34.04	61.15	15.17	50
11:00	837.02	1.57	33.86	62.56	15.07	50
11:10	831.06	1.96	33.49	62.83	17.27	57
11:20	853.29	1.74	33.67	63.35	16.42	52
11:30	848.58	1.14	33.56	63.93	10.67	41
11:40	843.35	1.07	33.37	65.11	15.17	50
11:50	855.56	2.86	33.07	64.06	18.56	69
12:00	873.15	2.15	34.11	65.96	17.85	43
12:10	853.56	2.13	34.54	64.78	15.34	40
12:20	860.29	1.45	34.41	62.61	18.56	42
12:30	872.07	3.82	35.34	60.89	21.99	84
12:40	824.09	1.71	35.32	63.93	16.34	72
12:50	804.31	1.69	35.27	61.29	14.48	42
1:00	788.17	0.92	35.66	61.18	10.32	45
1:10	787.75	1.21	35.71	61.36	14.13	46
1:20	786.88	1.56	35.67	61.18	17.85	52
1:30	784.74	1.99	35.47	61.23	17.36	36
1:40	783.33	1.97	35.74	61.76	15.08	41

1:50	779.04	1.34	35.78	61.72	13.9	36
2:00	774.54	1.35	35.85	61.97	15.72	29
2:10	771.25	1.53	35.45	61.64	11.04	39
2:20	772.99	1.16	35.94	61.65	10.08	36
2:30	772.85	0.97	35.55	61.75	13.18	47
2:40	774.23	1.46	35.14	61.16	10.36	34
2:50	773.33	1.48	35.93	61.37	10.67	34
3:00	772.71	1.28	35.19	61.84	10.08	32
3:10	773.54	1.52	35.18	61.54	9.42	30
3:20	775.18	1.45	35.81	61.39	9.74	32
3:30	777.55	1.22	35.87	61.06	10.62	32
3:40	778.03	1.09	35.92	61.94	18.84	60
3:50	675.43	1.04	34.67	60.81	10.99	36
4:00	632.64	1.64	35.67	58.41	9.74	31

[Table-4.4 Experimental data of 5 May 2015]



[Figure-4.5 Graphical analysis of PSWDs, 5 May 2015]

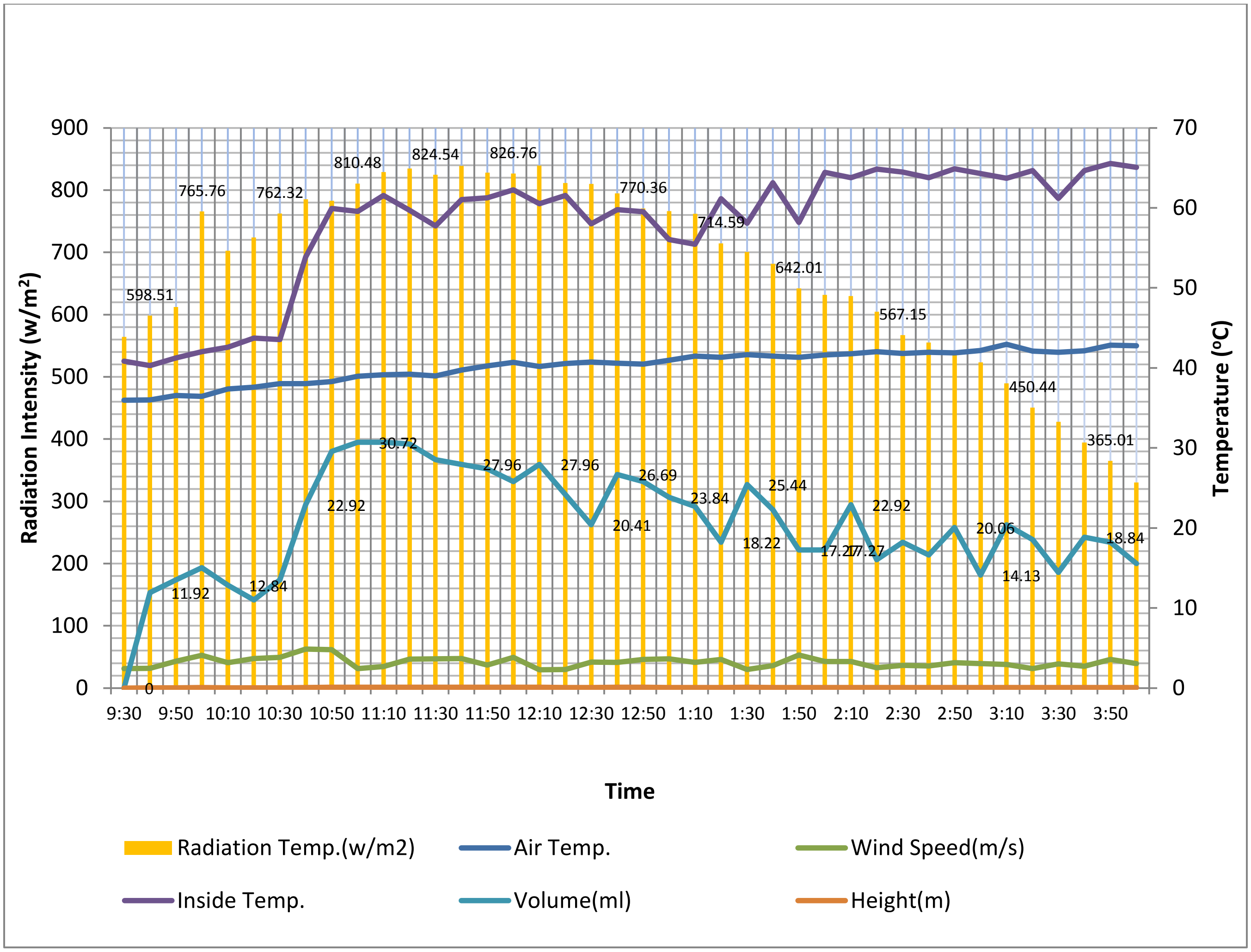


[Figure-4.6 Meteorological graph taken by Data Logger (NISE)]

Time	**Air Temp. (^oC)**	**Radiation Temp.(w/m^2)**	**Wind Speed(m/s)**	**Inside Temp. (^oC)**	**Volume(ml)**	**Height(m)**
9:30	35.96	564.25	2.42	40.84	0	0
9:40	36.02	598.51	2.48	40.31	11.92	0.038
9:50	36.55	612.15	3.36	41.25	13.52	0.043
10:00	36.45	765.76	4.11	42.04	15.02	0.048
10:10	37.37	702.48	3.18	42.59	12.84	0.041
10:20	37.59	724.09	3.68	43.75	10.99	0.035
10:30	38.02	762.32	3.82	43.56	13.52	0.043
10:40	38.03	785.43	4.88	53.88	22.92	0.073
10:50	38.31	782.97	4.79	59.91	29.56	0.094
11:00	38.95	810.48	2.44	59.57	30.72	0.098
11:10	39.14	829.02	2.68	61.55	30.72	0.098
11:20	39.23	834.71	3.61	59.69	30.48	0.097
11:30	39.01	824.54	3.64	57.74	28.54	0.091

11:40	39.75	839.03	3.67	61.05	27.96	0.089
11:50	40.25	828.18	2.88	61.26	27.38	0.087
12:00	40.71	826.76	3.82	62.25	25.78	0.082
12:10	40.17	839.33	2.29	60.53	27.96	0.089
12:20	40.55	811.32	2.31	61.57	24.178	0.077
12:30	40.73	809.76	3.23	58.02	20.41	0.065
12:40	40.59	794.51	3.21	59.78	26.69	0.085
12:50	40.49	770.36	3.57	59.51	25.78	0.082
1:00	40.96	765.98	3.64	56.04	23.84	0.076
1:10	41.47	761.77	3.19	55.44	22.68	0.072
1:20	41.32	714.59	3.59	61.15	18.22	0.058
1:30	41.65	700.71	2.33	58.09	25.44	0.081
1:40	41.46	681.81	2.79	63.14	22.29	0.071
1:50	41.33	642.01	4.12	58.19	17.27	0.055
2:00	41.61	631.46	3.32	64.45	17.27	0.055
2:10	41.79	629.55	3.33	63.76	22.92	0.073
2:20	42.03	604.48	2.54	64.85	16.04	0.051
2:30	41.82	567.15	2.85	64.47	18.22	0.058
2:40	41.96	554.97	2.77	63.77	16.64	0.053
2:50	41.87	540.04	3.18	64.88	20.06	0.064
3:00	42.18	523.32	3.04	64.29	14.13	0.045
3:10	42.97	489.68	2.93	63.69	20.41	0.065
3:20	42.12	450.44	2.44	64.66	18.56	0.059
3:30	41.94	427.71	3.02	61.19	14.44	0.046
3:40	42.14	394.54	2.74	64.67	18.84	0.06
3:50	42.85	365.01	3.59	65.53	18.21	0.058
4:00	42.77	330.25	3.05	65.05	15.55	0.075

[Table-4.5 Experimental data of 7 May 2015]



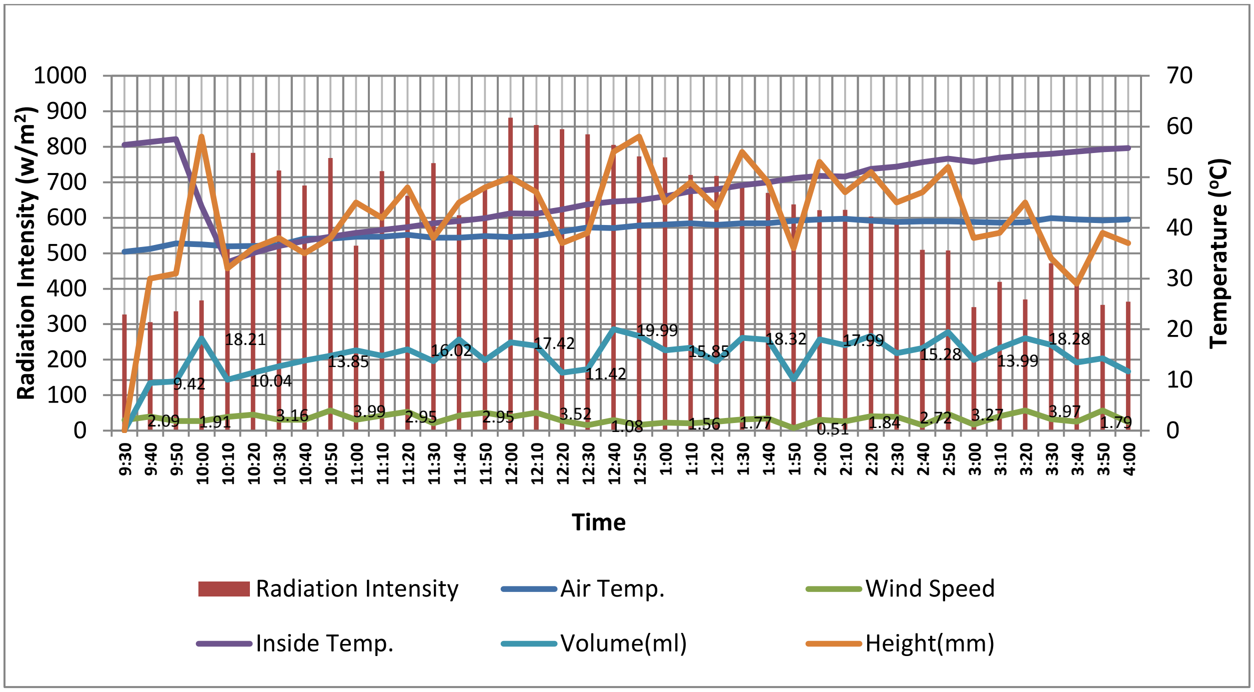
[Figure-4.7 Graphical analysis of PSWDs, 7 May 2015]

Time	Air Temp. (^{o}C)	Radiation Intensity (w/m^2)	Wind Speed (m/s)	Inside Temp. (^{o}C)	Volume(ml)	Height(mm)
9:30	35.32	327.32	2.09	56.39	0	0
9:40	35.87	306.11	2.76	56.95	9.42	30
9:50	36.93	336.68	1.91	57.51	9.73	31
10:00	36.72	366.78	1.93	44.28	18.21	58

10:10	36.36	527.28	2.75	33.24	10.04	32
10:20	36.42	783.08	3.16	35.01	11.44	36
10:30	36.62	732.98	2.18	36.44	12.72	38
10:40	37.85	691.13	2.14	37.41	13.85	35
10:50	37.86	768.52	3.99	38.23	14.79	38
11:00	38.28	521.69	2.16	38.99	15.85	45
11:10	38.27	731.29	2.95	39.59	14.78	42
11:20	38.61	662.39	3.72	40.18	16.02	48
11:30	38.08	754.37	1.48	40.89	13.72	38
11:40	38.04	607.02	2.95	41.36	17.99	45
11:50	38.37	687.15	3.55	41.93	13.92	48
12:00	38.2	882.07	2.74	42.88	17.42	50
12:10	38.45	861.45	3.52	42.78	16.74	47
12:20	39.28	849.58	1.99	43.63	11.42	37
12:30	40.12	835.51	1.08	44.64	12.16	39
12:40	39.94	805.47	2.12	45.22	19.99	55
12:50	40.48	772.72	1.14	45.45	18.72	58
1:00	40.64	770.58	1.56	46.21	15.85	45
1:10	40.88	720.49	1.46	47.24	16.34	49
1:20	40.62	717.46	1.77	47.61	13.66	44
1:30	40.9	698.49	2.21	48.45	18.32	55
1:40	40.93	670.45	2.44	48.96	17.92	49
1:50	41.44	637.18	0.51	49.81	10.08	36
2:00	41.65	621.69	2.17	50.26	17.99	53
2:10	41.81	622.54	1.84	50.12	16.85	47
2:20	41.42	603.65	2.86	51.66	18.72	51
2:30	41.16	588.37	2.72	52.11	15.28	45
2:40	41.3	509.91	1.11	52.96	16.28	47
2:50	41.28	508.07	3.27	53.66	19.42	52

3:00	41.15	347.88	1.24	53.04	13.99	38
3:10	41.02	419.71	2.85	53.85	16.28	39
3:20	41.07	370.22	3.97	54.32	18.28	45
3:30	41.91	471.64	2.29	54.59	16.9	34
3:40	41.69	426.21	1.79	55.07	13.44	29
3:50	41.48	354.57	4.01	55.48	14.28	39
4:00	41.69	363.15	1.74	55.71	11.71	37

[Table-4.6 Experimental data of 8 May 2015]



[Figure-4.8 Graphical analysis of PSWDs, 8 May 2015]

Time	Inside Temp. (°C)	Air Temp. (°C)	Radiation Intensity (w/m^2)	Wind Speed (m/s)	Volume(ml)	Height(mm)
9:30	60.79	30.99	682.69	0.03	10.62	33
9:40	58.97	32.94	691.58	0.84	13.88	42
9:50	55.07	33.72	688.02	0.77	13.86	44
10:00	54.45	33.57	704.55	0.95	18.22	58
10:10	60.93	33.31	699.12	1.85	14.13	45
10:20	58.53	33.61	709.92	1.89	14.44	46
10:30	52.57	33.73	711.39	1.45	10.36	33
10:40	55.22	33.83	710.21	0.76	13.86	44
10:50	50.02	33.79	716.54	0.74	14.78	47
11:00	54.94	33.38	715.26	2.56	12.46	41
11:10	51.11	33.67	722.85	0.27	11.93	43
11:20	59.34	33.28	718.77	0.95	12.56	40
11:30	58.54	33.96	732.62	1.85	13.88	48
11:40	54.66	34.12	730.71	0.84	12.56	42
11:50	50.88	34.57	739.64	1.42	11.93	39
12:00	56.24	33.86	744.61	2.61	19.46	68
12:10	52.27	33.45	749.06	0.88	11.34	34
12:20	56.46	33.14	744.23	1.78	14.74	51
12:30	55.97	33.49	745.33	0.56	8.79	29
12:40	56.57	33.55	751.28	2.84	18.78	57
12:50	54.48	33.52	759.04	0.51	7.85	25
1:00	58.86	32.99	750.95	1.35	11.16	41
1:10	53.88	32.62	752.58	1.83	13.74	50
1:20	57.57	31.99	748.95	1.43	10.99	38
1:30	58.17	31.64	749.03	2.72	16.79	49
1:40	49.61	32.41	742.57	0.35	9.74	36

1:50	56.99	32.62	706.31	1.98	15.62	48
2:00	49.31	31.78	688.43	0.98	10.48	40
2:10	56.93	31.33	670.94	0.27	10.99	37
2:20	56.66	31.23	669.73	2.44	10.48	36
2:30	54.18	30.23	654.71	3.47	10.76	32
2:40	53.37	29.77	617.96	0.73	9.42	30
2:50	55.48	29.33	614.96	1.86	9.42	30
3:00	49.56	28.34	578.28	0.67	8.43	29
3:10	52.95	28.59	535.44	2.87	14.43	39
3:20	55.71	28.89	532.04	1.67	12.26	35
3:30	55.92	27.31	501.54	1.84	13.62	34
3:40	58.74	27.12	484.65	0.85	7.52	25
3:50	58.64	26.63	484.54	1.58	9.59	28
4:00	53.95	26.72	410.09	2.53	11.81	32

[Table-4.7 Experimental data of 22 May 2015]

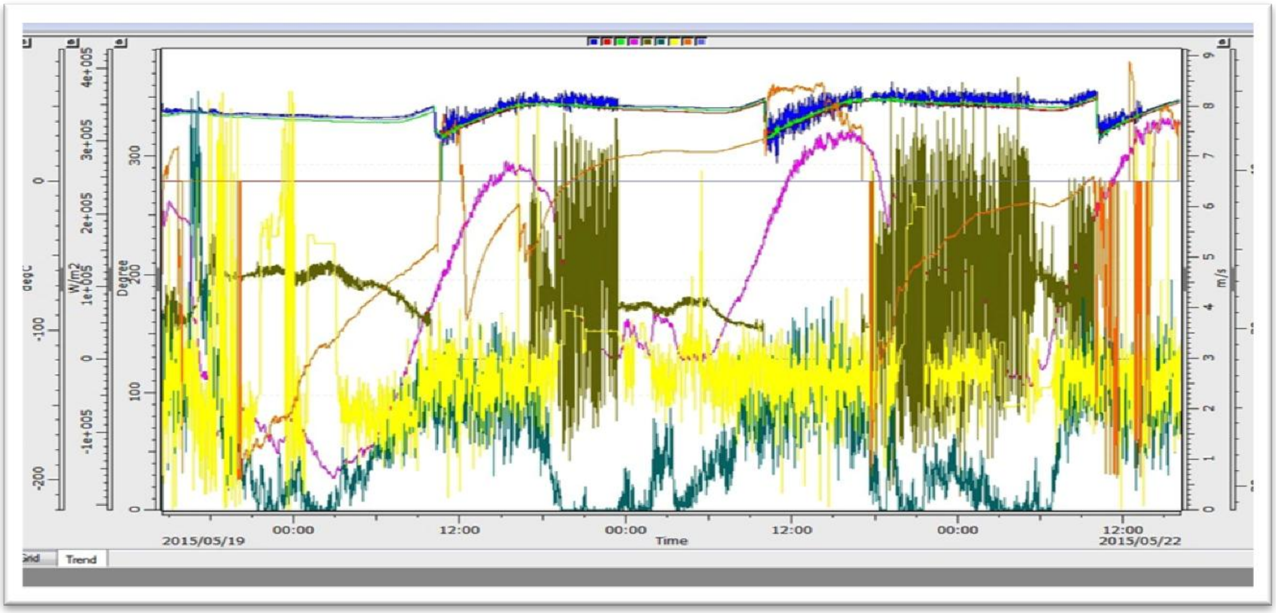
ist all channels Update

] Show hidden channels ⦿ Manual

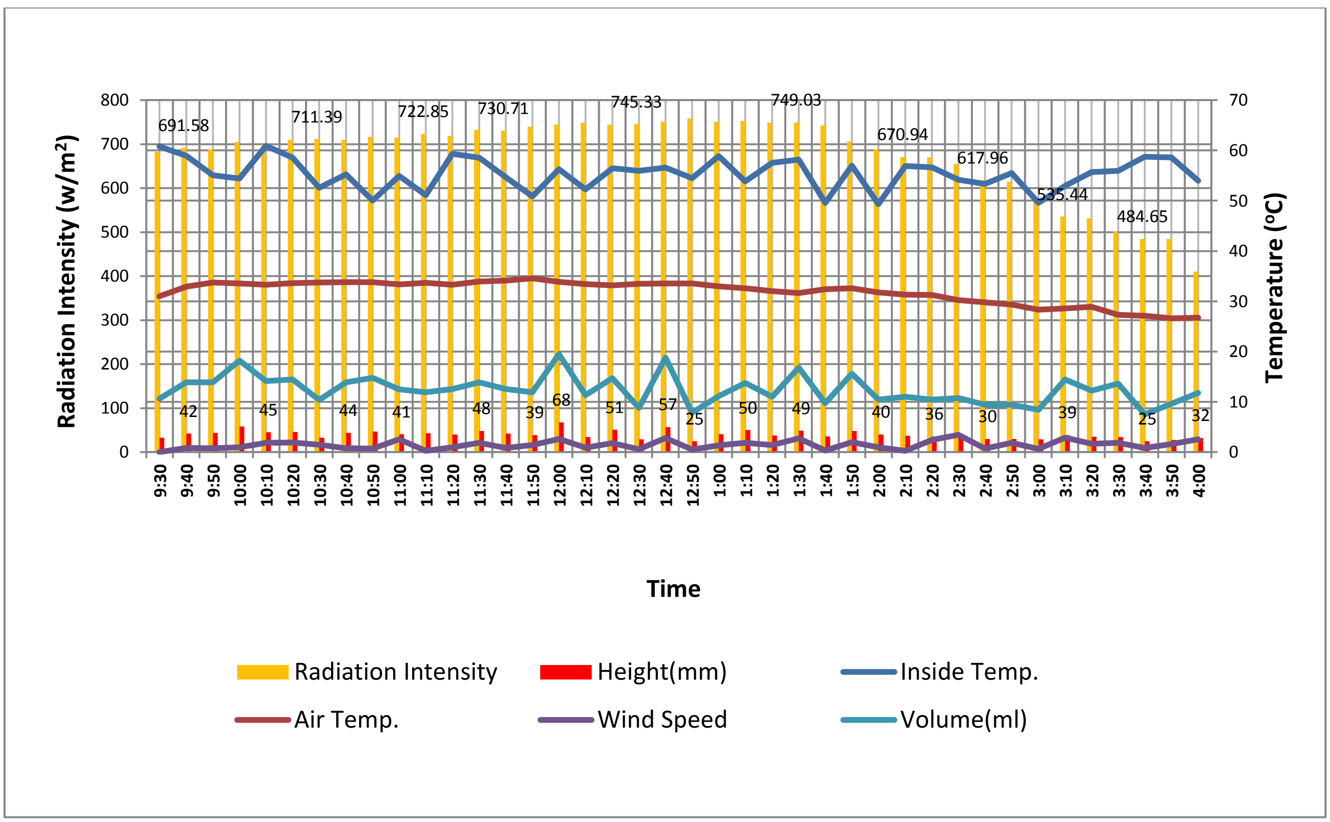
3elow is a list of all channels in the current job. ◯ Auto

Run ▲	Name	Value	Units	Alarm	Time stamp	Log	Input	Schedule
✓	AIR TEMP	24.730835	0C		2015-04-09, 09:06:20	✓	2*R	(A) Schedule_
✓	PYRO METER	469.77966	W/m2		2015-04-09, 09:06:20	✓	101V	(A) Schedule_
✓	Temp1	55.043316	degC		2015-04-09, 09:06:20	✓	4TJ	(A) Schedule_
✓	Temp2	68.033577	degC		2015-04-09, 09:06:20	✓	5TJ	(A) Schedule_
✓	Temp3	69.060364	degC		2015-04-09, 09:06:20	✓	6TJ	(A) Schedule_
✓	WD	70.984329	Degree		2015-04-09, 09:06:20	✓	3R	(A) Schedule_
✓	WS (m/s)	1.4098877			2015-04-09, 09:06:20	✓	1HSC	(A) Schedule_

[Table-4.8 Readings of Data Logger]



[Figure-4.9 Meteorological graph taken by data logger (NISE)]



[Figure-4.10 Graphical analysis of PSWDs, 22 May 2015]

The parameters that are used in the Experiments are given in Tables the thermo- physical properties given in this table are assumed constant in all calculations.

The efficiency, η, was obtained by summing up the minute wise condensate Production *M*, multiplied by the latent heat of vaporization *hfg*, and divided by the daily solar radiation *I* over the whole area *A* of the device:

$$n = \frac{\sum Mhg}{\sum IA}$$

The efficiency is shown in the last column of Table 1 & 2, which also includes a summary for the results of all the figures that follow below data.

Seven days data is analyzed for April & May, as ambient & inlet temperature is less in march's data the efficiency is quite higher and also the system takes some time to attain steady state during evening hours as the absorber maximum temperature is about 73 ^{0}C and after 4:00 p.m. it is about 60 ^{0}C so the efficiency is quite higher for some time then it falls down as intensity of radiation also falls down.

As mentioned above, the system produces hot water and distilled water from the feed water simultaneously. If the feed water is brackish cold water, the system produces hot water, but the salt concentration of the brackish water increases at the exit of the system. Then, this hot brackish water may still be used as domestic purpose. In case of seawater, having high salt concentration at the end of distillation process, the remaining hot water (i.e., hot brine) cannot be used as domestic purpose because of high salt concentration. In this case, the hot brine at the exit may be recirculates to the feed water inlet of the system and mixed with feed water to obtain a higher inlet temperature of the feed water. Then the system produces distilled water only.

4.1 CRITERION OF THE PSWD SYSTEM

The production of fresh water by this system is affected by the following environmental limits. These are ambient conditions, ambient temperature, solar radiation and wind velocity. Operating conditions are depth of water, the orientation of distillation system and inlet temperature of water, etc. Design conditions are the selection of the material of the distillation system and cover, slope of the cover, distance between the water and the cover (gap distance) etc. It is clear that environmental conditions are not in control, and hence only the optimum design can satisfy the requirements of the system.

4.1.1 CRITERION OF WIND VELOCITY

Wind velocity has little effect on production of distilled water, high wind speeds increases the production rates as compared to zero wind speed. The graphs shows the high wind speed will increase the production of fresh water compare to the low or zero wind speed but at the same time the high wind speed also increase the convective heat loss from the surface of glazing sheet to the atmosphere. This decreases the condensing of water vapors collected on the glazing sheet

.4.1.2 CRITERION OF AMBIENT AIR TEMPERATURE

The effect of ambient temperature variations on portable solar distillation is analyzed by various graphical variations. The graphical results showed that a slight increase of ambient temperature will increase the production of distilled water temperature.

4.1.3 CRITERION OF THE GAP DISTANCE

Decreasing the distance between the evaporating surface and the condensing glazing sheet cover improves the performance of the distillation system. The impact of the gap distance is more important than the impact of the glazing surface. Reducing the gap distance will decrease the height of the side walls of the distillation system and hence will reduce the shadowing effect of these sides. Also less time is required by the saturated air to reach the glazing surface and therefore continuous and quicker air movement in the system is reached and increases the production of fresh distilled water.

4.1.4 CRITERION OF SOLAR RADIATION

The output of solar distillation system is increased as the solar radiation increased. As the solar intensity increase the phenomenon of evaporation increase automatically this evaporated vapors condensed on the surface of the glazing sheet. The distillation output is highest during summer season (April to August). But the production is low during winter season when the intensity of solar radiation is low compare to the summer season.

CHAPTER-5

CONCLUTION AND SCOPE FOR FUTURE IMPROVEMENT

5.0 CONCLUSION

A PSWD system was designed and tested under actual environmental conditions. The system generates fresh water and hot water simultaneously, which are collected. It was observed that the fresh water generation rate was more in month of April and a bit lower than that during May.

- Ground water level was found to be one of the factors of clean water production.
- An asymmetrical design is found to be the more economical and efficient type of solar distillation system.
- The optimal angle of the glazing surface is found to be around 45°.
- The higher temperature difference between the glazing surface and black membrane will lead to more water production.
- Minimizing heat loss is maximizing the distilled production.
- Maximum output of PSWDs is around to be 1.2 liters of water per day.
- Easy to use operate.
- Provide clean drinking water without use of an external energy source like fossils fuels and electric power.
- Reasonably compact and work on renewable source of energy (solar energy).
- Efficiency of the solar distillation system has a little change with increasing of ambient air temperature.

- The solar distillation process requires low grade energy which is available in abundant amount and also there is no greenhouse pollutant as present in case with other water purification techniques using fossil fuels.

5.1 SCOPE FOR FUTURE IMPROVEMENT

- Thin and good quality glazing sheets cover having high transmissivity to allow more solar radiation to pass to saline water in the distillation system.
- Solar distillation system can be coupled with a device such as solar collector to increase initial brackish water temperature.
- Design of portable solar water distillation cheaper but long lasting materials could be preferred.
- In future PSWDs is very useful for remote places and villages of India where there is no availability of electricity and fuels.
- There is a lot of scope for researchers, scientists and engineers for the improvement of design and enhancing the production of fresh water using renewable energy.

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