CHAPTER-1

INTRODUCTION

1.0 Need for Solar Water Distillation System

In the developing countries, unsafe drinking water, poor sanitation, malnutrition, and poverty are the major causes of epidemic and deadly diseases. “Half of the World’s hospital beds are occupied by people suffering from water borne diseases”. In India, water-borne diseases alone are said to be the causes of 73 million work-days every year. The cost incurred in medical treatment and loss of production is around Rs.24, 000 million per year. More than 70 % of Indian population lives in rural and backward areas. India has nearly 559,553 villages, out of which about 28% are reported to have unsafe drinking water due to chemical adulterant as reported by World Health Organisation (WHO). They do not have the infrastructure which is necessary to develop and support large scale water distillation plants [1].

1.1 Importance of water

World Health Organisation (2012) has reported that one child die every minute due to water related disease and 130-150 million hours each day; time spent in collection of water. Therefore, in future there are two major crises facing the world; water and energy crisis because of rapidly growing population in turn increasing demand, largely due to gross mismanagement, misuse, an unsustainable life style. In order to cope with this kind of situation, we have to take speedy corrective measures otherwise especially developing countries including India, will have to face crisis of energy and water security in the near future. Today fresh water demand is increasing continuously, because of the industrial revolution, intensified agriculture, improvement of standard of living and increase of the world population. Only about 3 % of the world water is potable and this amount is not evenly distributed on the earth [2].

1.1.1 Water sources

From the Table 1.1, we can see, only 2.6% is fresh water, out of which less than 1% of fresh water is human reach.

TABLE 1.1 Fresh water distributions in our hydrosphere [1]:

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 1.2. Per capita water availability in India [1] :

Year	Population (Million)	Per capita water availability (m3/year)
1951	361	5177
1955	395	4732
1991	846	2209
2001	1027	1820
2025	1394	1341
2050	1640	1140

Source: Government of India, 2009.

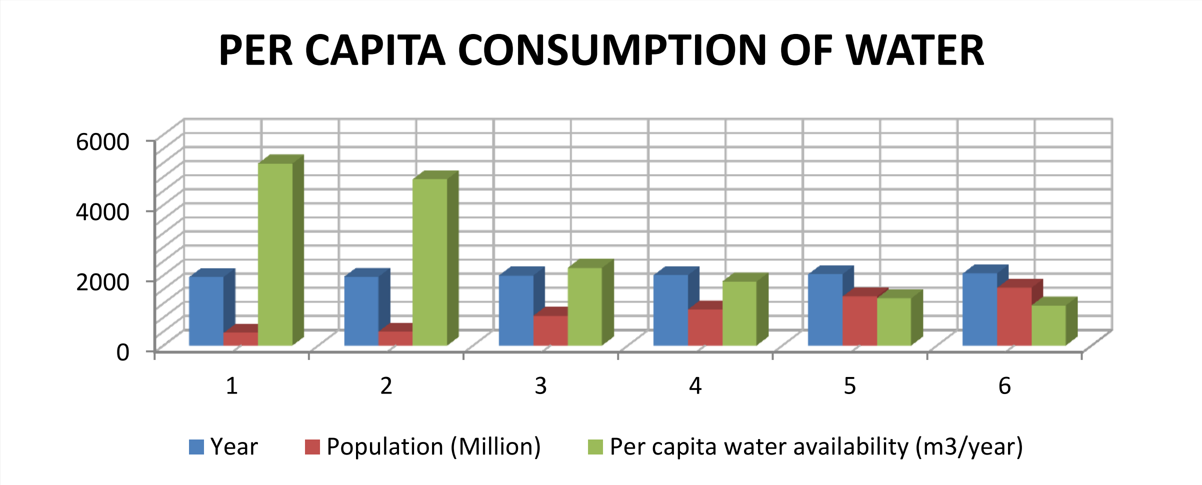

Figure 1.1 Per capita consumption of water [1]

1.1.2 Brackish water

Brackish Water is the feed water which is contaminated or adulterer fresh water and it is necessary to examine the composition of the foreign substance present in the contaminated feed water.

Table 1.3 The salinities of various samples [2]:

Water sample	Total dissolved solid s,(m g /l)
Well Water	300-500
Typical River Water	200-750
Typical Brackish Water	1500-6000
Typical Sea Water	36000
Water for Irrigation	1000

1.1.3 Water Quality

Standardisations of water purity limiting the desirable amount of chemical present in the water, not only the toxic part but also check parameters like corrosion, taste and scale formation.

Table 1.4 Purity Standards of Water [2]

Substance	Concentration*, mg/l Maximum acceptable	Maximum allowable	Troubles	Approximate Concentration in seawater, mg/l
Total solids	500	1500		36000
Chloride	200	600	Taste and corrosion	19800
Sulphides	200	400	Gastro-intestinal irritation	2760
Calcium	75	100	Scaling	420
Magnesium	30	150	Taste and scaling	1330
Fluoride	0,7	1,7	Fluorosis	1,5
Nitrate	< 50	100	Methaemoglobinaemia	small
Copper	0,05	1,5	Taste	0,01
Iron	0,1	1	Taste and discoloration	0,02
Sodium chloride	250	...		30000
Hydrogen (in pH units)	7.0 -8.5	6.5 - 9.2		

[International Standards for Drinking Water, World Health Organization and/or European Standards for drinking Water].[2]

Irrigation in India accounts for 84% of the ground water consumption and India is considered to be one of the fastest and largest consumers of ground water in the world, which is less than 1% (table1.1) of fresh water present in our hydrosphere. The water availability per person is decreasing almost five times by 2050 considering from 1951 from table-1.2.

Now apart from consuming water intelligently and spreading awareness of shortages of fresh water supply, there are various solution proposed like the Desalination Plants to produce fresh water and there are nearly 15000 Desalination Plants worldwide so far but the drawback with this kind of technologies: powered by fossil fuels, high cost if backed by Solar Photovoltaic System and thirdly hot Brine released into the river which disturb the ecosystem.

Still the Desalination Plants are widely popular in the developed world but most of the people who are suffering from unsafe drinking water are living in rural areas or underdeveloped countries having a bright sunshine day but could not afford to build an infrastructure to support this kind of large scale Desalination plants. FPSWD system can provide an alternative solution especially for rural areas because of low cost and simple design, solely work on the solar thermal energy which is provided by the Sun, as there is limited scope of electrification and shortages of investment in rural areas.

1.2 SOLAR DISTILLATION

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.

1.2.1 Types of Solar Distillation System

- **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

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

- **Membrane based processes :**

  Those based on a particular flow of water through semipermeable membranes.

  The major process comes under this category is based on the motivation:

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

1.2.2 Renewable Energy Technologies

Now a days the practice of Desalination system solve the purpose of water shortages in the areas having large salinity concentration specially Middle East countries beget issues of sustainability; which is still concern to researchers for improvement. The only option is to reorganize and go as far as possible to renewable energy driven desalination, a stronger vision to bring down the cost and a clean environmental impact.

The sources of renewable energy are natural, free, lifelong and do not exhaust with the passage of time.

This can be classified as given below:

- Solar
- Wind
- Geothermal
- Waves
- Tides
- Biomass
- Small Hydraulic

1.2.3 Distillation Using Solar Energy

Thermonuclear fusion process occurs in the Sun produce electromagnetic radiation. The part of the radiation spectrum received by the Earth can be converted into heat, electrical and mechanical energy. Thus the solar energy is clean, long lasting, silent and abundant in majority of the places on the Earth.

However, it has drawbacks of seasonal variation of low intensity and diffusion and a fraction of its energy reaching the Earth can be harnessed. Thus, the study of various parameters as an angle at which the beam incident on the sites are important to improve the efficiency of the Solar Plant.

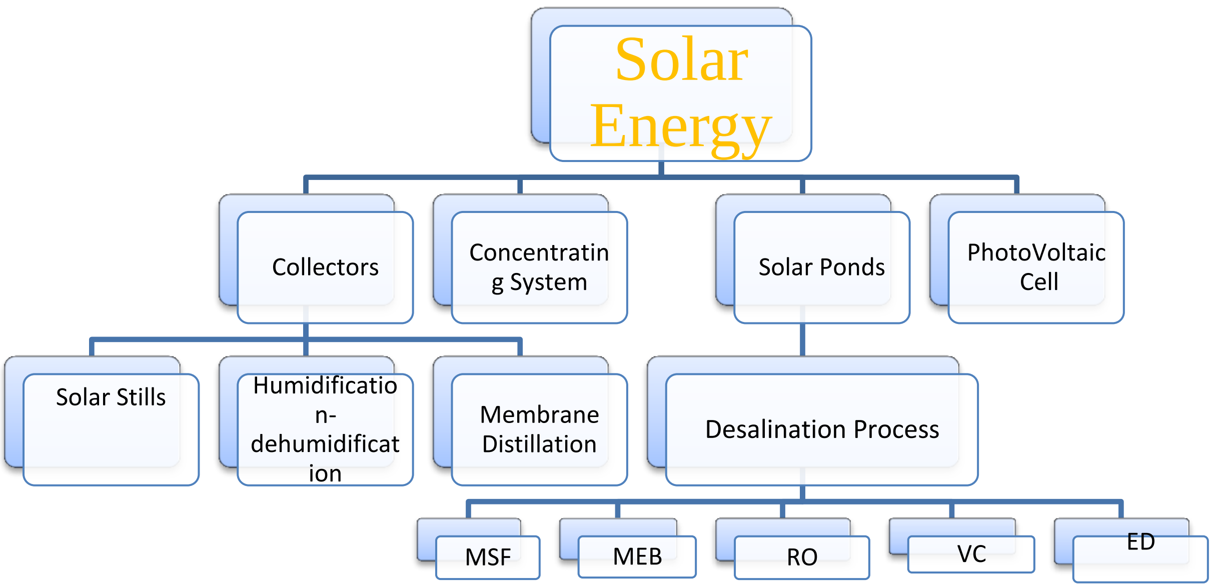

Figure 1.2 Utilization of Solar Energy [1]

The Solar Energy can be directly employed to the Distillation system in a solar still or indirectly by converting to heat or electricity to drive a conventional distillation system.

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 Solar Photo Voltaic power plants have been developed and installed in the country. The designing of Green Building is gaining popularity in India which is based on solar passive heating and cooling concept and expanding its status commercially. Moreover, the Government launches various schemes like Jawaharlal Nehru National Solar Mission to setup an institution to promote solar energy penetration across the country and to be a part of world's Solar Energy player and have been successful to some extend in electrification of many remote villages through Solar Photo-Voltaic system.

1.3.1 DIFFERENT TYPES OF SOLAR COLLECTORS

1.3.2 FLAT PLATE COLLECTOR (FPC)

Hottel and Whillier have developed the flat plate collectors in the 1950s, are the most basic type collectors. Flat plate collectors consist of a dark flat-plate absorber, a transparent cover which reduces heat losses, a heat transport fluid to remove heat from the absorber, and a heat insulating backup. The absorber consists of a thin absorber sheet (polymers, aluminum, steel, to which a selective coating is applied)which is often supported by a mesh like structure of fluid tubing placed in an insulated shell with a glass or cover. In water heating panels, fluid is usually circulated through the loop, transfer heat from the absorber to an insulated water tank. [3]

Figure 1.3 Flat-Plate Collectors (NISE) [3]

1.3.3 EVACUATED TUBULAR COLLECTOR (ETCS)

Evacuated heat pipe tubes (EHPT) are consist of evacuated glass tubes, each containing an absorber plate which is then joined to a heat pipe. The heat is given to the transfer fluid of a domestic hot water or 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 vacuum inside of the collectors have been proven to last more than 25 years, the reflective coating for the design is enclosed in the vacuum inside of the tube, which will not deteriorate chemically until the vacuum is lost. The vacuum which surrounds the outside of the tube greatly decreases convection and conduction heat loss phenomenon, therefore achieving greater efficiency than flat-plate collectors, especially in colder region. This benefit is largely lost in warmer climates, except in the cases where very hot water is desirable, e.g., for commercial processes. The high temperatures that can occur may require special design to prevent overheating. [4]

Figure 1.4 Evacuated Tubular Collectors (NISE) [4]

1.3.4 PARABOLIC TROUGH COLLECTOR (PTCS)

In this section, parabolic troughs, dishes and towers are explained which are used widely and almost unrestrictedly in solar power plants or for research purposes. Although simple, the performances of these solar concentrators are quite different from the theoretical maximum concentration, 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 [5].

Figure 1.5 Parabolic Trough Collectors (NISE) [5]

1.3.5 PARABOLIC DISH COLLECTOR

In a parabolic dish collector, one or more parabolic dishes concentrate solar energy at a single focal point and 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. Faulty feature in parabolic geometry lead to the major losses in such type of collectors. [6].

Figure 1.6 Parabolic Dish Collectors (NISE) [6]

1.3.6 LINEAR FRESNEL REFLECTOR (LFR)

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. This concentrated Sun energy from the mirror is reflected through the receiver which contains fluid or water which in turn convert into steam or store thermal energy.[7]

Figure 1.7 Field view of Fresnel Reflector (NISE) [7]

CHAPTER-2

LITERATUREREVIEW

2.0 INTRODUCTION

At present, the practice of desalination method is not entirely clean and largely depends on burning fossil fuels which pollutes the environment and the discharge of hot brine waste water into the sea is considered drawbacks. However the desalination is affecting the environment is emphasized by Einav, R. et.al (2002). The proposed plan is to switch over to renewable energies; a various method has been adopted to integrate Solar Energy into the distillation process to get fresh water. 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 REVIEW PAPERS

R. Bhardwaj et.al (2015) have increases by cooling the condensation surface for production of fresh water but the method of cooling is expensive and demands high maintenance .In mean time, they have conducted experiment in laboratory and under real condition , they found that the production of fresh water increases 65% by increasing the condensation surface by 7.5 times in Laboratory setup keeping constant solar intensity of 625 W/m^2 and it increases by 50% when the condensation surface area increases to 7.5 folds in real test condition. The study recommended to innovate design, cheap and reliable method to cool the condensation surface and built set-up of (1-5m^2) solar distillation system to supply a fresh and safe drinking water for rural families having children up to the age of 5 years [9].

Wang Geun Shim et. al. (2015) devised a method of 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 [23].

Pang Wang et. al. (2015) have pointed out that the Membrane distillation is a separation process based on the vapour transport across the hydrophobic micro porous membrane driven by the vapour pressure gradient across membrane. This process can be used for various applications such as sea water desalination, waste water treatment, separation of volatile compounds, and concentration of non-volatile compounds and processing of dairy fluids [24]. **Achmad Chafidz et. al. (2014)** 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 [25].

R. Schwantes B. et. al. (2013) have done the development of small to medium size, autonomous and robust desalination units which 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 [26].

Young-Deuk Kim et. al. (2013) have presented 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) [27].

John H. Lienhard V et. al (2012) have introduced a phase change material (PCM) layer of 8 cm below the absorber plate as energy storage in air heating solar collector which is sufficient to produce a consistent output temperature close to the PCM melting temperature with a time-averaged collector thermal efficiency of 35% for use in humidification–dehumidification desalination system. It is found that phase change material allows the plate temperature to be stabilized and the outlet temperature to be roughly limited to the melting temperature of the phase change material. Optimization of surface roughness characteristics can lead to greater temperature stability, and increasing the conductivity of the PCM layer though a metal mesh increases PCM utilization and temperature stability because energy can penetrate deeper into the layer. Built-in latent heat energy storage has shown great promise to maintain a consistent temperature output throughout the entire day and night. However, these benefits come at the cost of thermal conversion efficiency requiring large collector areas for small heat outputs, and has the potential to increase the cost of a large scale system, suggesting that this method of energy storage may not be the workable at large scales. If the cost of such a system can be reduced then this device has the potential to enhance the solar driven humidification–dehumidification distillation cycle by eliminating transients and warm up time associated with other system components by maintaining the top temperature of the system at an optimal operating temperature, thereby increasing overall system performance and water production[11].

Guofeng Yuan A. et. al. (2011) have studied 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 m^2 solar air heater field, a 12 m^2 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) studied 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) presented 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 analysed 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 vapour. 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) presented 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 m^2/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) stresses that major desalination processes consume a large amount of energy derived from oil and natural gas as heat and electricity, while emitting harmful CO_2. 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) presented 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].

Hikmet S. Aybar et al.(2005) have tested with variants : bare plate, black cloth-wick and black fleece wick and pointed out that by making longer path of incoming water on flat plate, greater the rate of evaporation and hence fresh water production rate was increased two to three times using wick instead of bare plate. They have made a great observation during the tests performed for 7 hours a day in Cyprus that the average difference in hot water temperature and air temperature inside the cavity is 2^0C -4^0C using black-cloth wick and the waste Hot Water can be used for domestic purpose. The study also suggested that the total dissolved salts(TDS) in fresh water using the black-cloth wick and the black-fleece is 79ppm and 140ppm respectively and while using the bare plate, the TDS limit in fresh water is only 42ppm and incoming feed water limit is 4060ppm[8].

Henry Shih et. al. (2005) have compared the effectiveness of thermal schematics, thermal efficiency, and performance ratio. A sulphuric 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 sulphuric 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 ^{o}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) have examined that 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) presented 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 vapour 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) has been carried out a numerical study 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) studied 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 vapour. 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

The main focus is to improve the rate of distillation of fresh water without affecting the overall cost. Although present solar distillation is effective in isolated place or rural areas, not quite popular commercially. As L.Scott (2005) et.al have reported that “the future of solar distillation lies in a more active approach”, by incorporating more heat transfer devices into the design of distillation They include ‘spray evaporation’ and related steam ‘flash distillation’, ‘baffling’, vacuum distillation, forced convection and separate condensation chambers.

Solar distillation systems are often neglected 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 neglected and unutilized.

CHAPTER 3

EXPERIMENTAL SETUP

3.0 System description:

The inclined Flat Plate Solar Water Distillation (FPSWD) system gives the maximum output with zero ppm of fresh water/drinking water. This system is a most efficient and cost effective from others distilled system. It can produce pure, clean fresh water on any scale from any water sources and also gives hot brine, which gives more advantages and additional efficiency. Each panel of this system is design with area of 3 m^2, weight 17 kg and having a thin black fiber sheet of 0.6 mm for absorbing the input water. The front glazing is of polycarbonate thin sheet (0.2 mm), which is tough, dimensionally stable, high impact resistance, good temperature capability and expected life of 8-10 years.

Table 3.1 System Specifications:

No. of Solar Panel	10
Weight of each panel	17 kg
Collector area	30 m^2
Material of Absorber	Black fiber sheet
Thickness of Absorber	0.6 mm
Space between membrane and sheet	25 mm
Material of front Glazing	Polycarbonate thin sheet
Thickness of front Glazing	0.2 mm

The cross section of such incline FPSWD is shown in figure 3.1. The saline water is located at the top side of the panel to the entire width of the black fiber sheet wick with the help of distributor at a flow rate of 6.6 kg/hour such that the entire area of the black sheet remains wet all the time and receives water by gravity into a feeder at the top of the panel. Solar energy absorbed by water in the wick which gets evaporated both of front and back side of the panel at the temperature of 60-65^{0}C and later condensed on the underside of the cover polycarbonate thin sheet and finally vaporized water gets condensed & collected in the condensate channel fixed on the bottom side of the polycarbonate sheet. Remaining hot brine water at the temperature of 45-50 ^{0}C runs down at the bottom of the system.

Figure 3.1 Experimental setup of Flat Plate type Solar Water Distillation system [NISE]

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

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

3.1 PROCESS INVOLVED IN FPSWD SYSTEM

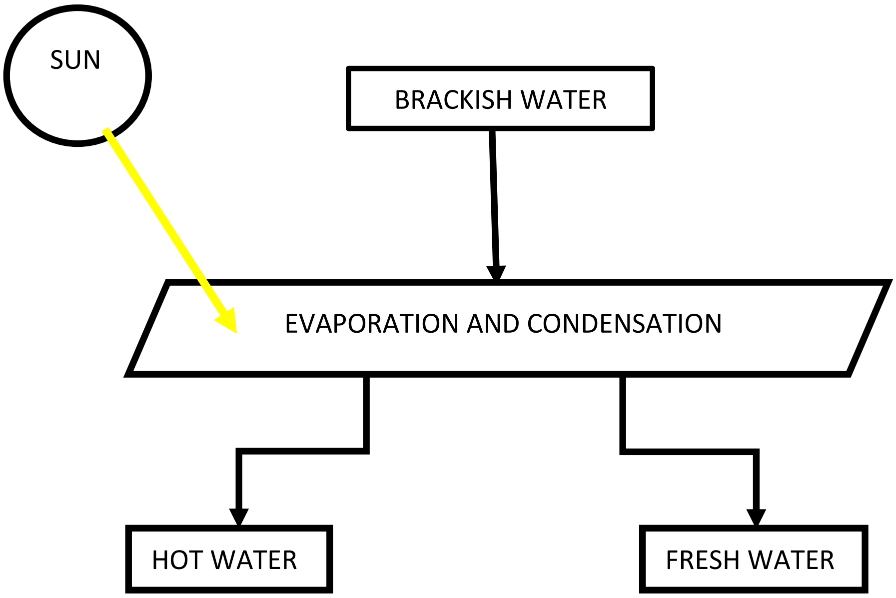

Figure 3.2 Block diagram of FPSWDs

3.2 Instruments and its Specification

3.2.1 Solar irradiation measurement: Pyranometer

The intensity of solar radiation incident on a horizontal surface is measured by a Pyranometer. The Pyranometer is set to 45^{o} as the Flat plate panels are set this angle and assumed Global Radiation as its reading is taken on tilted surface. The instrument consists of a sensor encapsulated in a transparent hemisphere that records the total amount of short-wave incoming solar radiation. Therefore, Pyranometers measure "global" or "total" radiation: the sum of direct solar and diffuse sky radiation.

Table 3.1 Specification of instrument:

Manufacturer :	**the Eppley laboratory Inc. USA**
Impedence :	**650 ohm approx.**
Receiver :	**Circular 1 cm^2, coated with Parson's black optical lacquer.**
Temperature Dependence :	**±1 % over ambient temperature -20 to 40 degree centigrade**
Linearity :	**±0.5 % from 0 to 2800 W/m^2**
Response time :	**1s**

Figure 3.3 Field Pyranometer(NISE)

3.2.2 DATA LOGGER

A **data logger** is an electronic device which records data over the time in relation to location either with a built-in instrument or sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on a digital processor (or computer). It consist of memory for data storage, sensors, battery powered, portable, and equipped with a microprocessor. It interfaces with a PC and utilize software to activate the logger and view and analyse the collected data.

Data logger may be seen in fig.3.

This logger records,

1. Wind speed
2. Wind direction
3. Global radiation
4. Temperatures
5. Ambient temperature

Figure 3.4 Data Logger

3.2.3 Anemometer

- Combined wind speed and direction sensor with 10 meter cable.
- ABS cups with retainer nut.
- Wiring details & test report copy.

Figure 3.5 Data Logger with Anemometer

CHAPTER 4
RESULT AND DISCUSSION

4.0 Performance Analysis:

The performance of inclined FPSWD has been carried out by installing the system which consists of 10 panels i.e. area of 30 m^2 at the Out –Door Test Bed of National Institute of Solar Energy, MNRE (latitude: 28^0 $25^/$ $31.2^{//}$N & longitude: 77^0 $9^/$ $18.8^{//}$E) shown in Fig 1. This system has been evaluated and observations were recorded on the basis of field data collected (period of 8-9 hours) in the month of May. The experiment was conducted during daylight between the hours of (9am-5pm) through the 06^{th} of May, 2015 to 18^{th} of May, 2015 to study the performance of the system. In the test, amount of fresh water produced every one hour of the day and measured corresponding to parameters like air temperature, solar radiation and wind speed.

Hourly data of Fresh Water and Hot Water production on relatively moderate sunshine in April have been taken for five hours of daylight.

4.1 Experiment Performance Data:

Table-4.1 Amount of fresh water and hot water obtained from testing on typical day in April on actual operating condition;

Sl.No.	Fresh Water (liters/hr per m^2)	Hot Water (liters/hr per m^2)	Global Radiation (kwh/m^2)
1	0.67	1.53	6.2
2	0.58	1.62	5.6
3	0.49	1.71	5.01
4	0.37	1.83	3.78
5	0.42	1.78	4.37

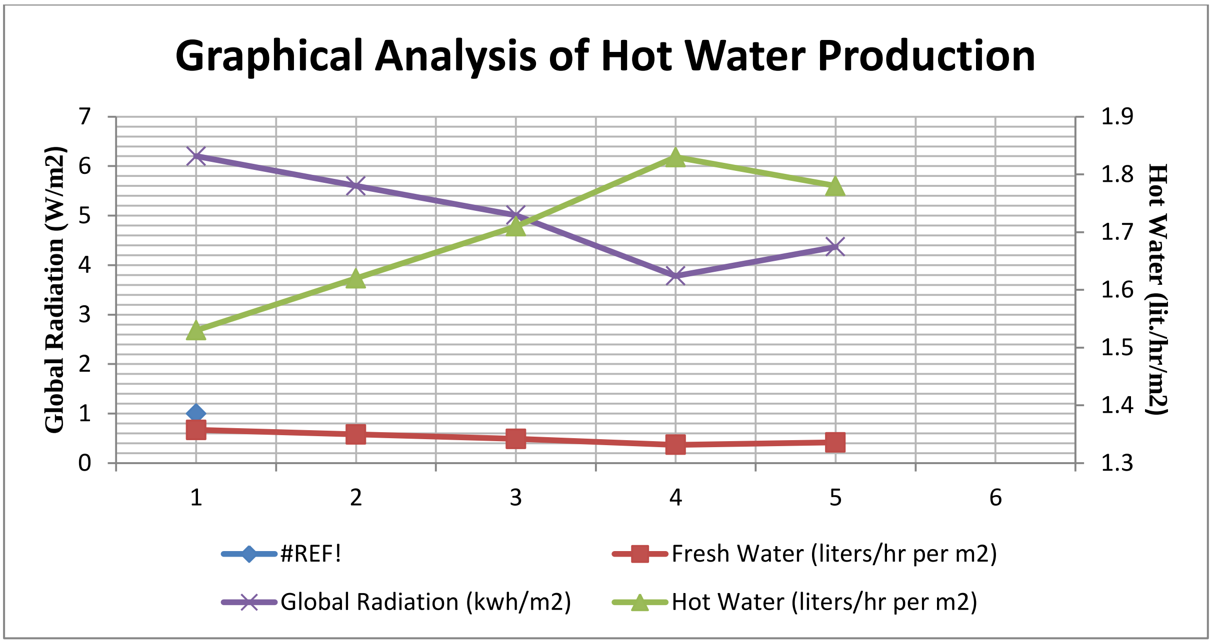

Figure 4.1 Graphical Analysis of Hot Water Production

From the Table-4.1, it has shown that the temperature of hot water is increasing with time, global radiation decreases with time and therefore Fresh Water production decreases. Hence, a continuous supply of hot water is available on a low sunshine hour which acts as a compensation for less production of fresh water.

Table-4.2 Hourly variation of Temperature of hot water , inside water temperature, outer cover sheet, ambient temperature & fresh water generation on daylight in April.

Time (hour:min)	Temperature of hot water (T_0 ^{0}C)	Inside Water Temperature (Tw, ^{0}C)	Outer cover sheet Temperature (^{o}C)	Ambient Temperature (T_i, ^{0}C)	fresh water (liters/hr/m^2)
10:00	42	52	46	24.3	0.396
11:00	50	59	53	24.7	0.528
12:00	51	64	55	25.8	0.785
13:00	52	65	56	28.7	0.799
14:00	51	62	56	27.9	0.687
15:00	49	60	55	25	0.623
16:00	44	53	47	23.8	0.391
17:00	46	51	48	23.5	0.294

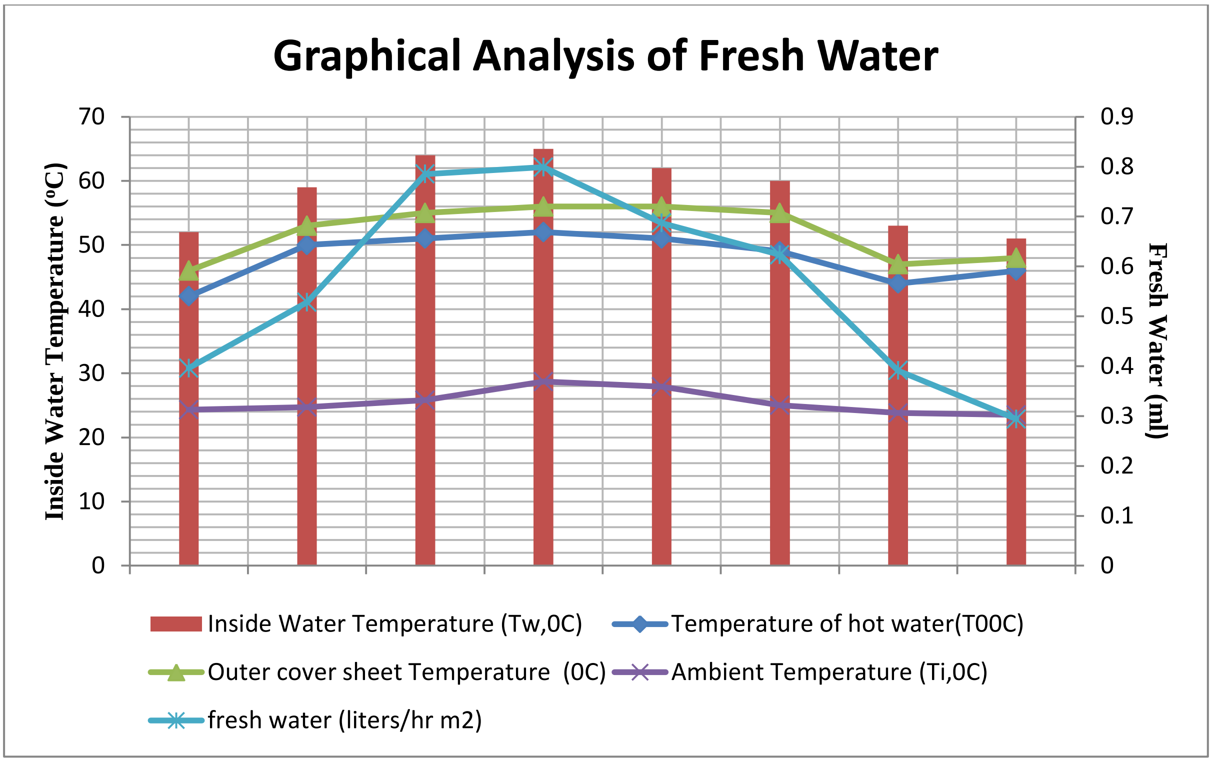

Figure 4.2 Graphical Analysis of Fresh Water

From the Table-4.1 and figure-4.2, the fresh water production value is high when the value of the Inside Water Temperature rises. The average maximum production of fresh water during the whole month is available at daytime hour (i.e.11.05 am to 2.55pm) of a day. Inside Water Temperature plays a major role in the production of fresh water as it reaches to maximum value i.e 65^{o}C.Now during the same daytime, at hour:min 13;00 pm corresponding values of air temperature is also increasing which greatly affect the production of water The fresh water has been achieved 5.2 litres/day per m^2 at the titled global radiation of 6.2kWh/m^2. The average temperature of hot water (brackish water) is 47 ^{0}C at the ambient temperature of 24^{0}C. The fresh water output is 4.68 litres/day m^2 and collected hot water (brackish water) is reached approximately 480 litres/day at 48^{0}C .

Table -4.3 Data collected on 06th May:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
09:00	33.45255	478.7699	0.61996	310	27.23921
10:00	35.51315	642.70782	2.30109	499	65.16686
11:00	38.03171	742.67767	1.57723	320	68.08339
12:00	39.79596	771.85693	1.62663	339	66.75068
13:00	41.53604	745.25574	2.78108	904	66.33206
14:00	42.20233	631.10791	1.47436	395	68.02742
15:00	42.30341	485.99985	2.88887	310	68.2242
16:00	41.98657	284.84174	3.24875	263	60.30944
17:00	41.73489	141.20242	3.07879	113	60.27201

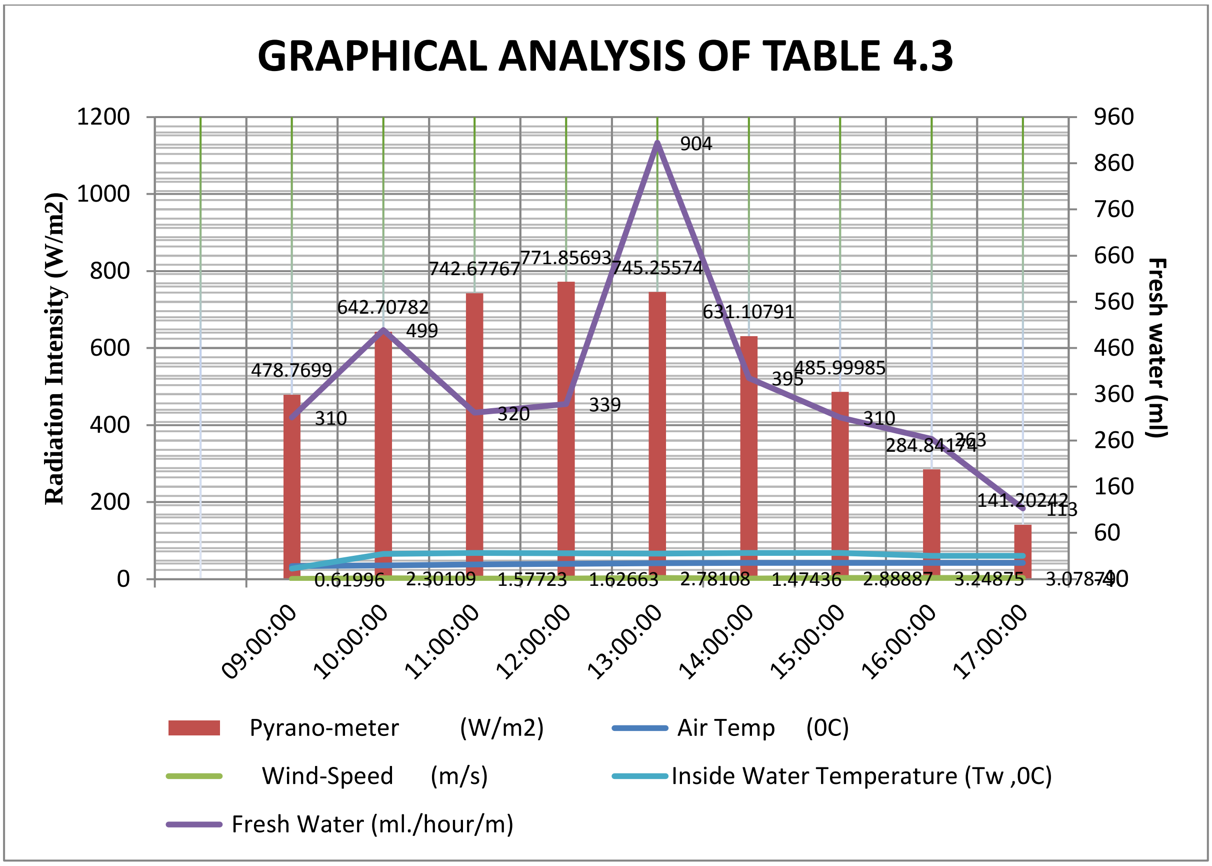

Figure 4.3- Graphical Analysis

Table-4.4 Data collected on 07th May :

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
09:00	34.75461	940.8655	3.07833	471	38.55045
10:00	36.89145	765.8278	4.18201	596	42.09304
11:00	38.90045	810.41248	2.99644	596	59.5967
12:00	40.02771	826.8866	3.03682	659	62.27885
13:00	40.99356	765.96368	3.65874	580	56.00854
14:00	42.17178	523.36902	3.04351	408	64.23489
15:00	42.10577	330.27515	3.0533	439	65.06105
16:00	41.68201	143.27626	2.06099	282	60.90418

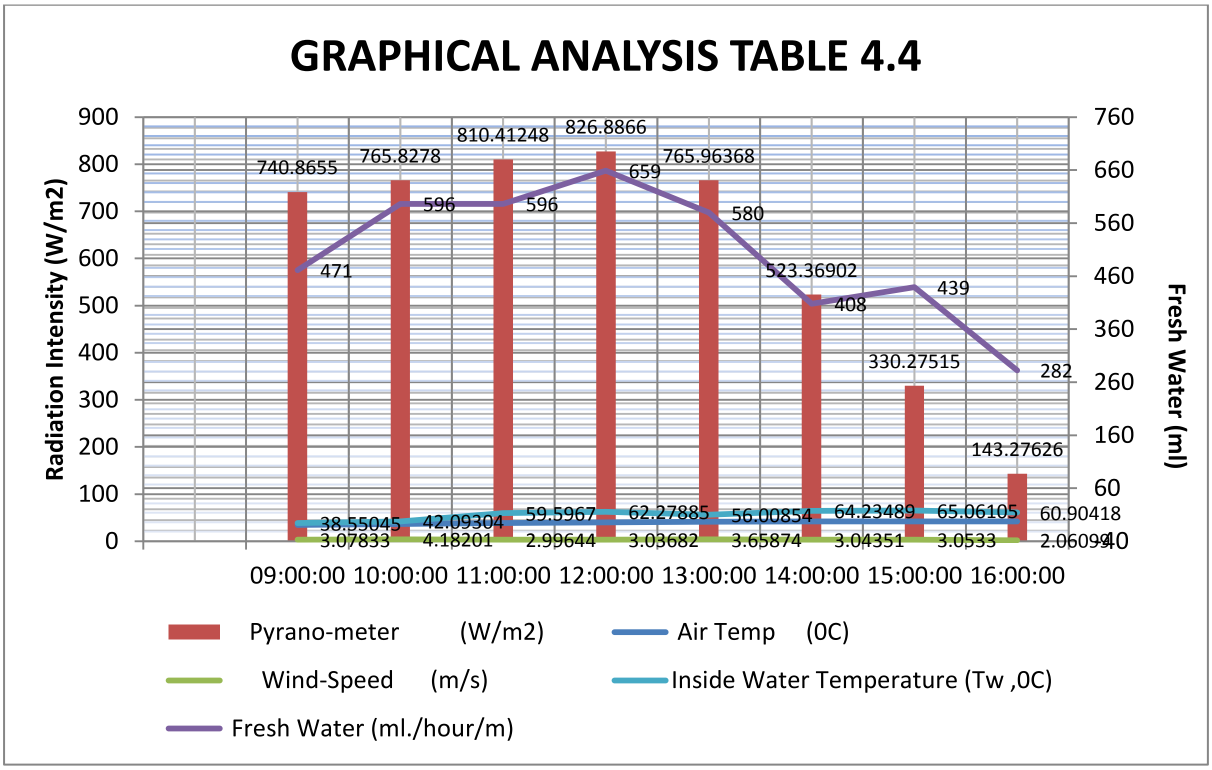

Figure -4.4 Graphical Analysis

Table 4.5 Data collected on 8th May:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^0C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^0C)
09:00	34.84152	628.9643	2.51146	486	37.43272
10:00	36.30872	366.76328	1.99103	502	36.27352
11:00	38.06628	521.60229	2.17936	439	42.178
12:00	38.772	882.04327	2.3874	753	42.098
13:00	40.64319	770.58398	1.44578	439	46.4682
14:00	41.65164	621.65009	2.05617	596	50.2424
15:00	41.15283	347.81738	1.8124	439	53.628
16:00	41.69058	363.14005	1.70354	345	55.697
17:00	40.05606	101.99415	1.66301	157	56.6501

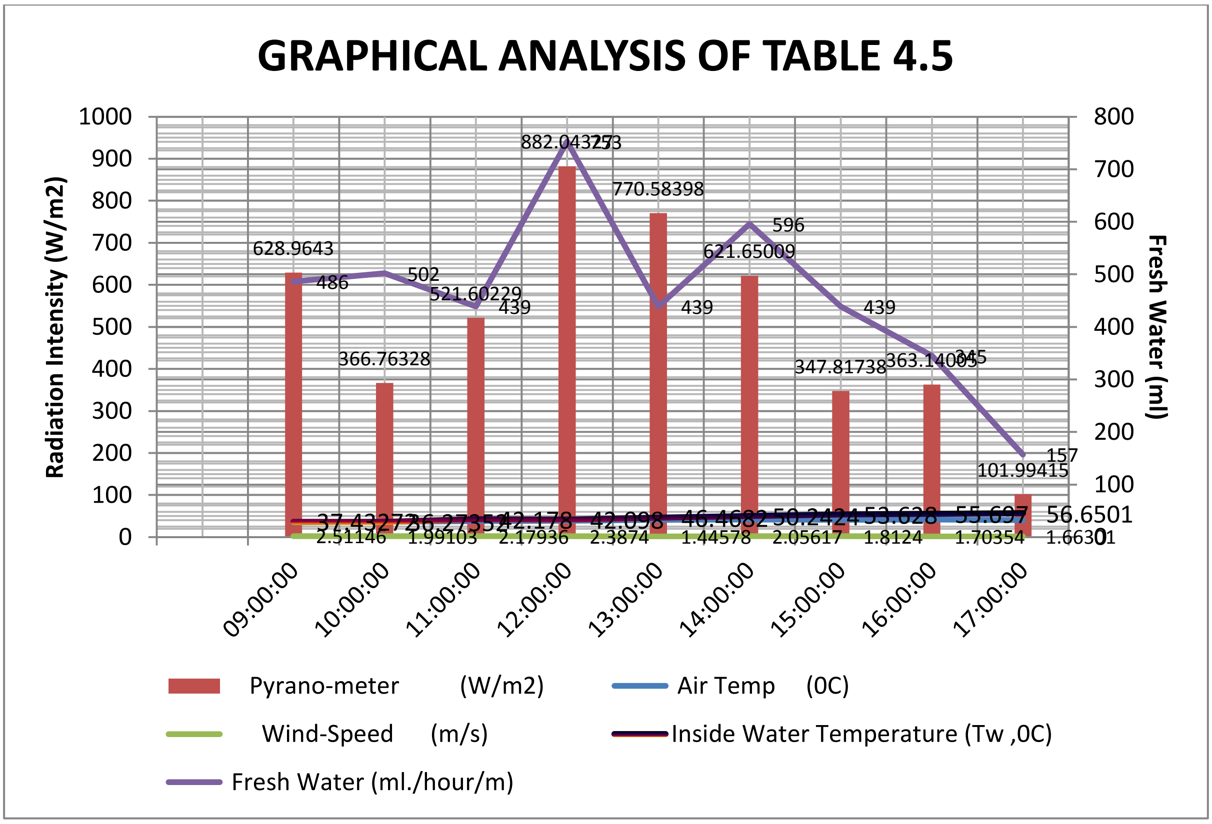

Figure-4.5 Graphical Analysis

Table 4.6 Data collected on 9th May:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_W ,^{0}C)
09:00:00	35.36053	60934.30469	1.85251	0.314	53.2904
10:00:00	36.47351	45397.14063	2.0833	0.3611	56.5081
11:00:00	38.26602	48255.42188	3.72773	0.7222	60.6526
12:00:00	40.13791	43899.28125	1.74053	0.6594	63.6131
13:00:00	40.7601	45196.15625	2.84008	0.4396	67.0895
14:00:00	41.50616	49263.99219	1.45673	0.6594	70.2814
15:00:00	42.10657	55906.87891	1.76664	0.5024	73.0122
16:00:00	42.05667	51790.94922	0.73908	0.4082	74.927
17:00:00	41.43481	53272.47266	1.48429	0.2826	75.8132

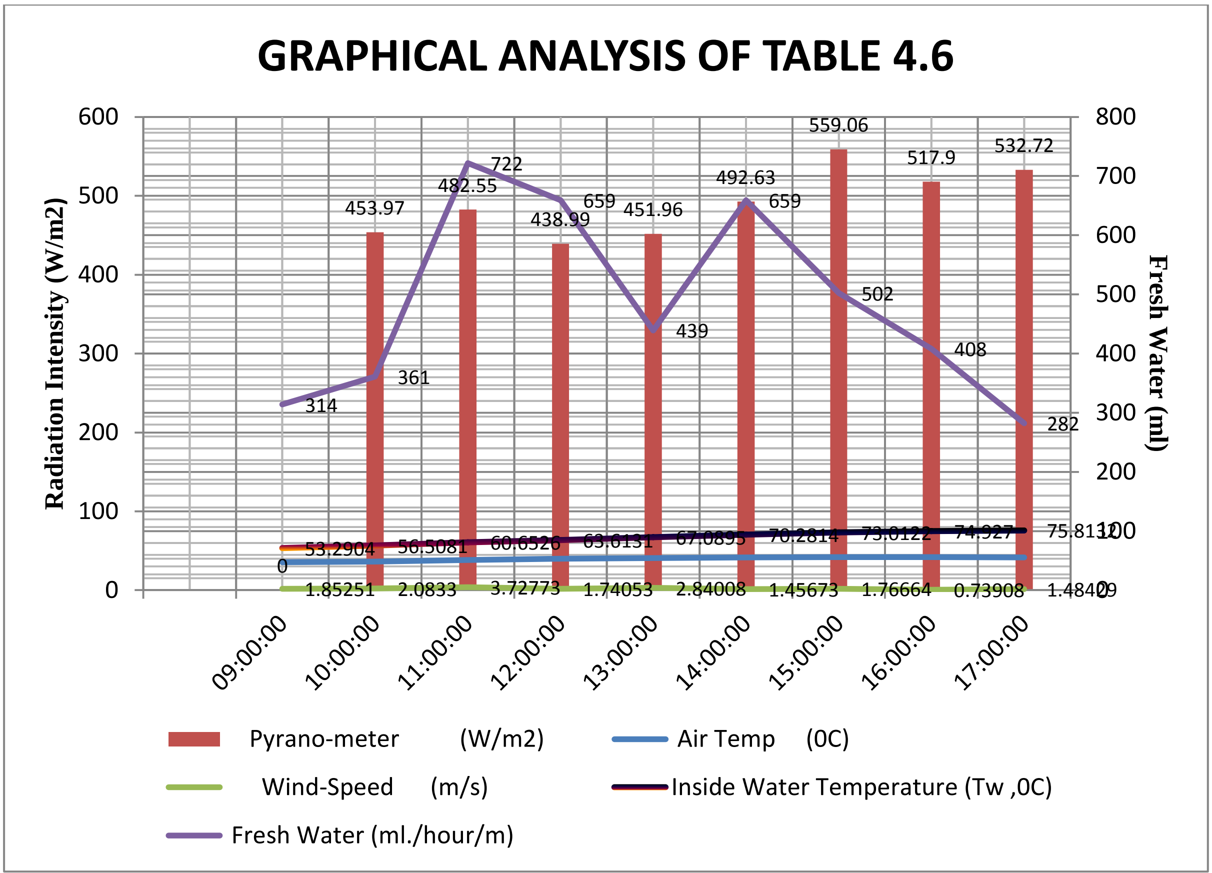

Figure-4.6 Graphical Analysis

Table 4.7 Data collected on 10th may:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
00:00.0	34.42236	584.5664	0.85667	0.3579	68.2989
00:00.0	35.82809	501.8542	1.87337	0.3862	70.9687
00:00.0	37.70319	699.2687	1.41319	0.405	74.0512
00:00.0	39.44379	751.893	1.73688	0.9137	79.9853
00:00.0	40.5701	587.7356	1.53536	0.7724	82.9753
00:00.0	41.05362	476.8027	1.19219	0.6876	84.7203
00:00.0	41.53577	501.4851	0.63071	0.6028	86.4253
00:00.0	41.67886	445.516	0.08229	0.471	86.5561
00:00.0	41.01633	500.3135	0.79737	0.345	85.9185

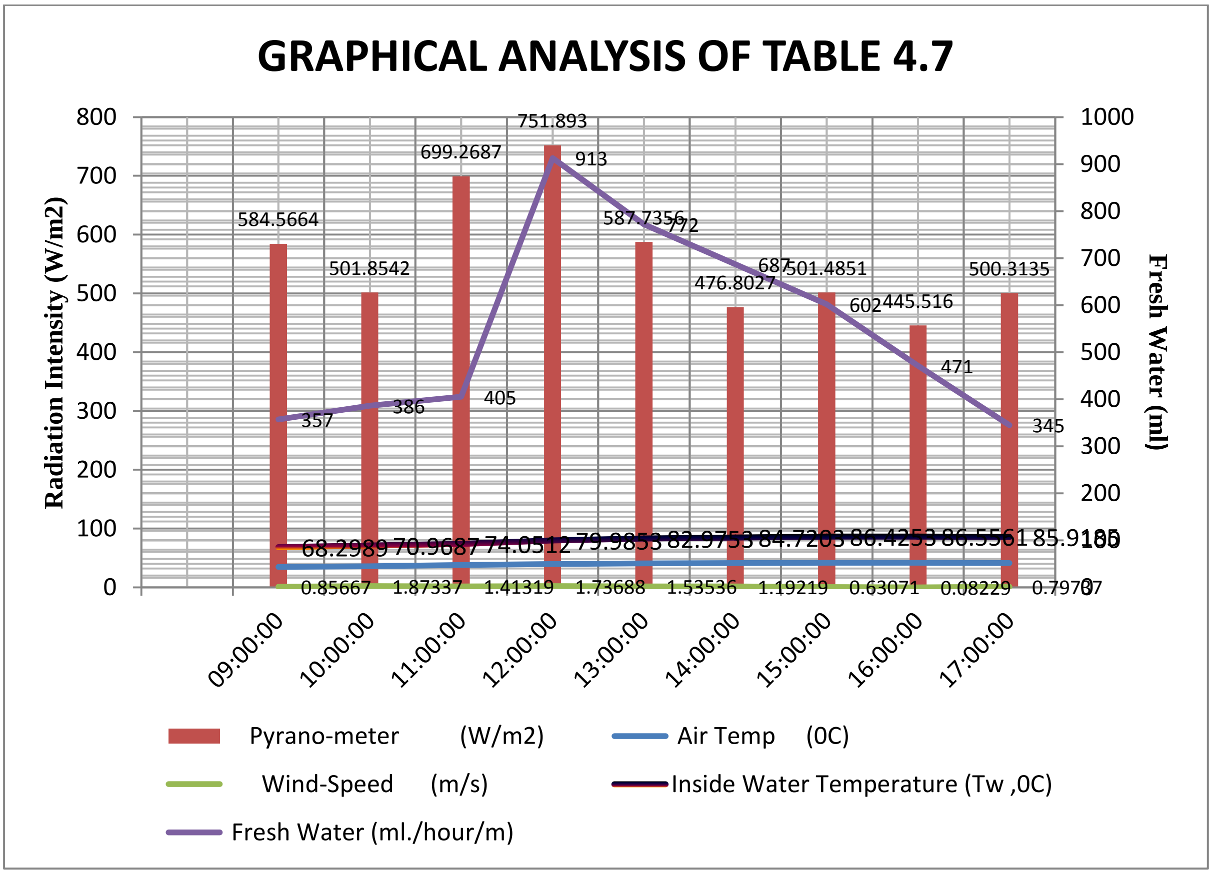

Figure 4.7 Graphical Analysis

Table 4.8 Data collected on 11th may:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
09:00:00	32.39691	645.914	0.69112	486	72.4158
10:00:00	34.78305	688.8064	1.43872	565	76.4689
11:00:00	35.90811	765.26282	1.20834	533	63.7654
12:00:00	37.53168	774.1059	1.3614	769	66.0541
13:00:00	38.59641	679.59155	0.52083	753	64.5259
14:00:00	38.84818	585.64423	0.63122	690	67.2836
15:00:00	38.73853	418.06793	1.4989	533	59.4203
16:00:00	39.04465	267.92203	0.93851	366	62.8986
17:00:00	39.03915	130.87457	2.02078	314	59.9707

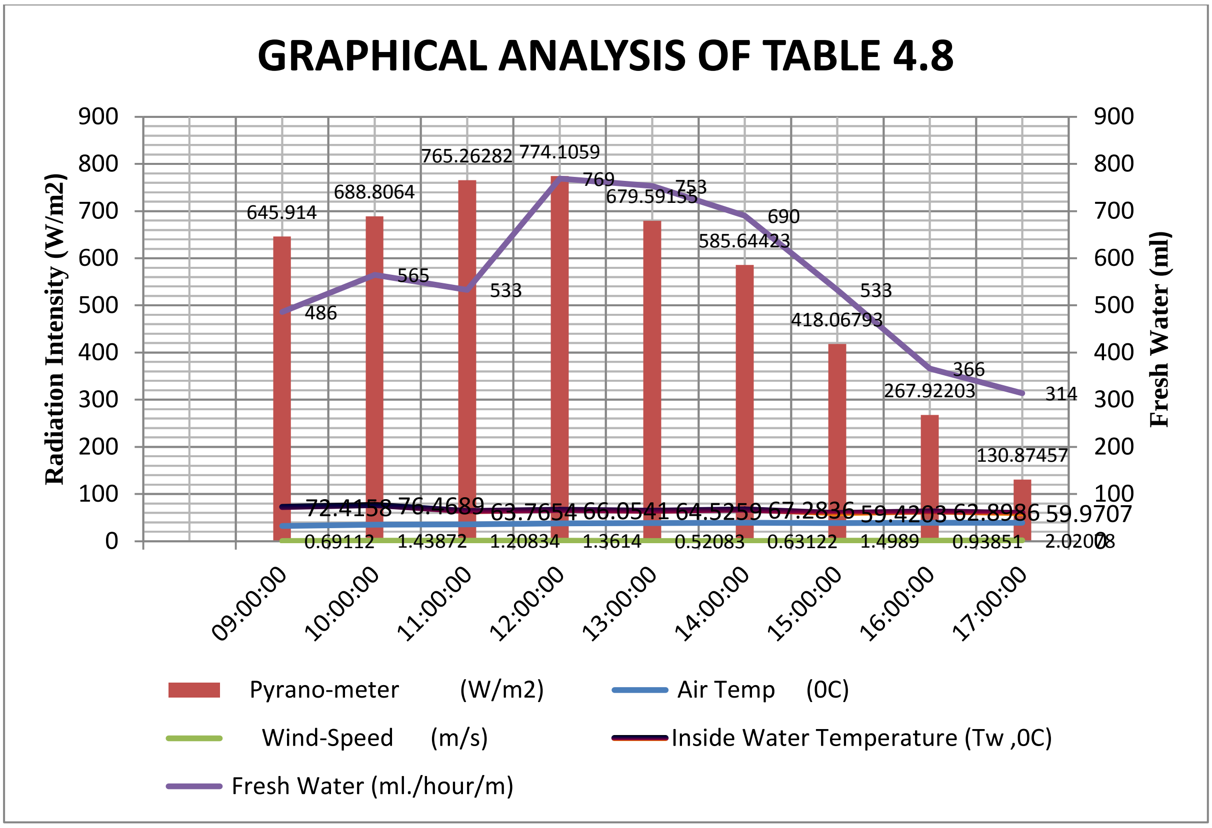

Figure 4.8 Graphical Analysis

Table 4.9 Data collected on 12th May:

Hourly variation of inlet water temperature, ambient temperature , solar intensity, wind speed & fresh water generation during daylight (9 hours) on 12/05/2015.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml/hour/m^2)	Inside Water Temperature (T_w ,^{0}C)
00:00.0	32.57416	602.1867	3.42071	504	56.11978
00:00.0	34.07135	783.5958	1.34787	475	34.56391
00:00.0	35.05377	771.7442	2.61759	765	39.44639
00:00.0	36.56097	733.3849	1.701	531	43.42786
00:00.0	37.08789	600.00238	1.60308	503	46.87576
00:00.0	37.26935	464.2027	0.29582	475	49.23582
00:00.0	37.41083	153.36758	0.96453	439	50.23085
00:00.0	37.05585	117.88979	0.28749	376	51.27628

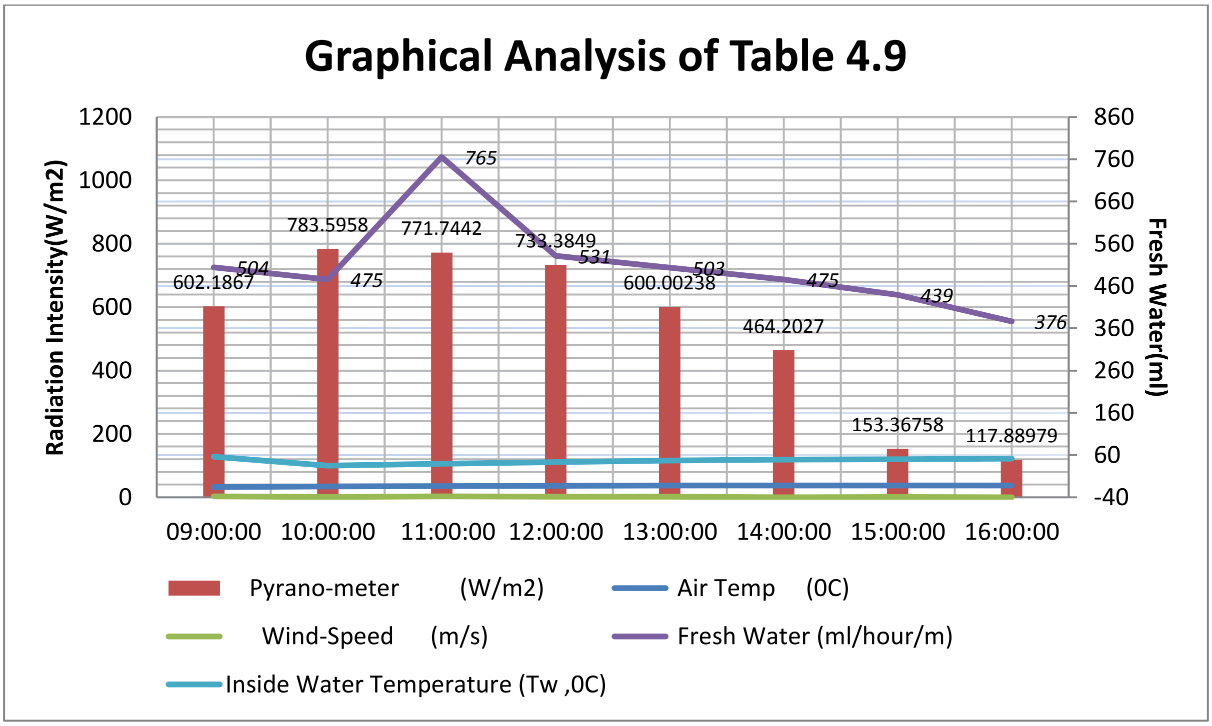

Figure 4.9 Graphical Analysis

Table 4.10 Data collected on 13th May:

Hourly variation of inlet water temperature, ambient temperature , solar intensity, wind speed & fresh water generation during daylight (9 hours) on 13/05/2015.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
00:00	32.29584	541.459	1.67495	502	49.73634
00:00	33.51428	468.6354	3.00922	549	48.76659
00:00	33.94537	571.3646	1.16558	612	49.97068
00:00	24.84534	710.0842	2.65514	439	48.65458
00:00	22.78204	641.3509	4.25638	439	50.77439
00:00	23.46246	382.4489	1.29895	314	50.47721
00:00	25.74991	824.6797	0.63123	471	51.80861
00:00	28.52863	383.2797	0.65103	439	53.24633
00:00	29.56369	765.6306	0.74271	251	54.66874

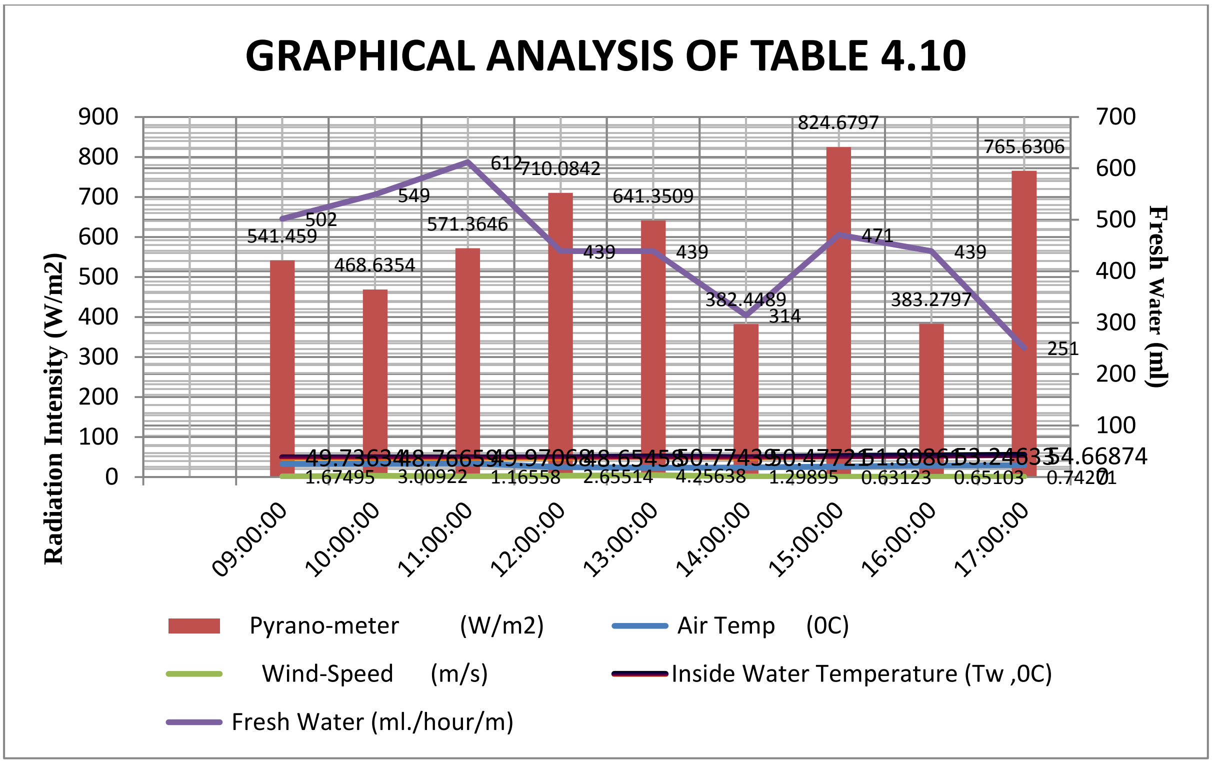

Figure 4.10 Graphical Analysis

Table-4.11 Data collected on 14-05-2015:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^0C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w , ^0C)
09:00	29.37314	512.8742	0.42811	102	52.28602
10:00	31.70096	517.5475	0.81633	471	55.89282
11:00	32.98926	396.4949	0.60655	596	59.6522
12:00	34.61777	518.2705	1.00464	612	63.1191
13:00	34.81516	343.0805	0.58908	596	66.50848
14:00	34.92328	755.3799	1.99786	659	69.63708
15:00	35.41232	723.632	0.66773	502	72.504
16:00	35.67923	562.0561	0.42082	471	74.46931
17:00	34.91492	674.4604	1.46341	549	75.21051

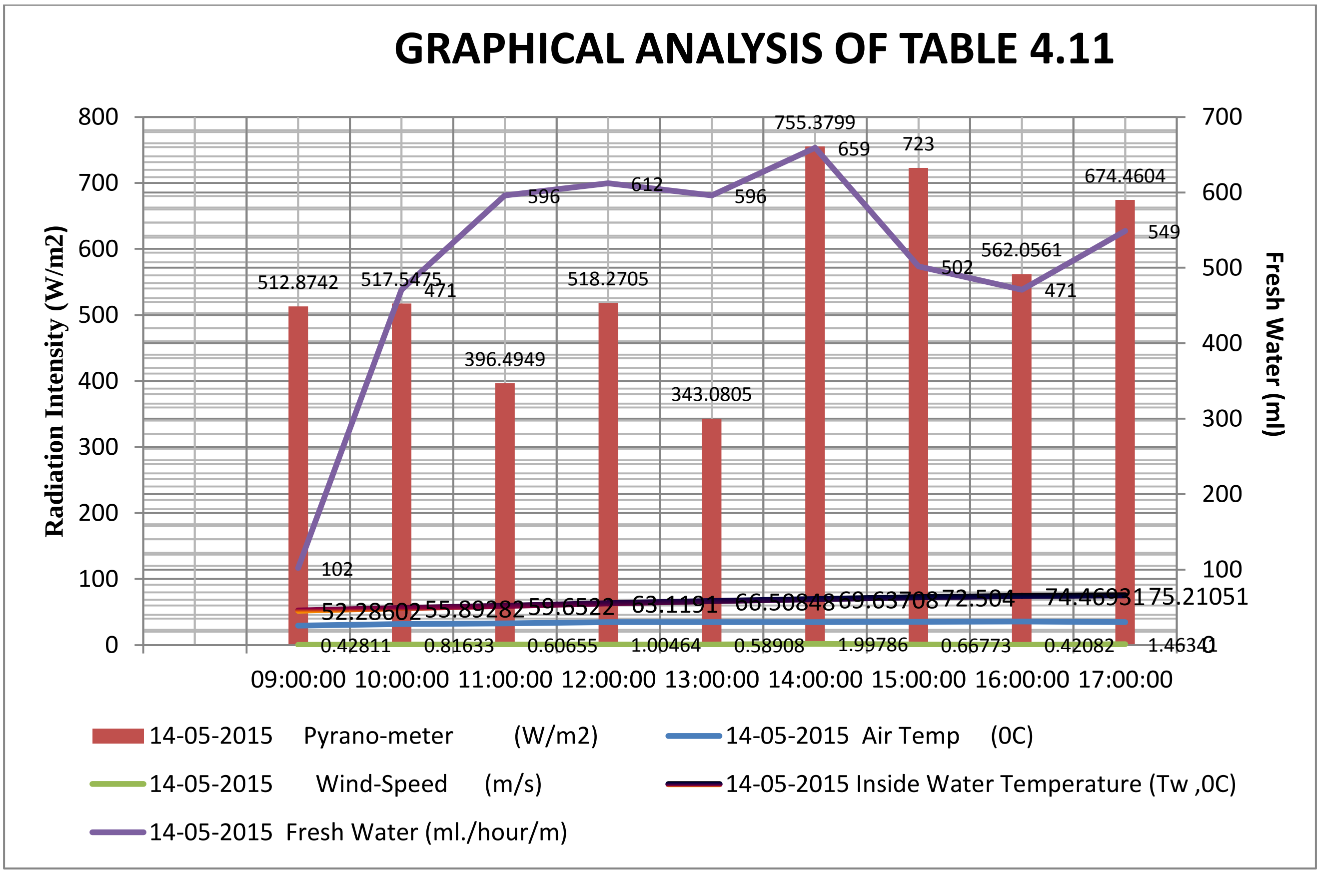

Figure 4.11 Graphical Analysis

Table-4.12 Data collected on 15-05-15:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation, wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
09:00:00	32.18176	413.0066	0.48787	315	67.17159
11:00:00	34.80026	111.66715	1.19374	518	73.11149
12:00:00	35.33505	512.5269	2.02175	628	76.22704
13:00:00	35.29483	733.0291	2.81139	6594	78.84106
14:00:00	33.59357	115.5751	0.63956	471	79.75795
15:00:00	31.42056	753.23	1.86456	502	79.52684
16:00:00	31.47614	546.4603	0.3927	314	78.83827
17:00:00	26.31592	728.8897	0.94473	298	78.90273

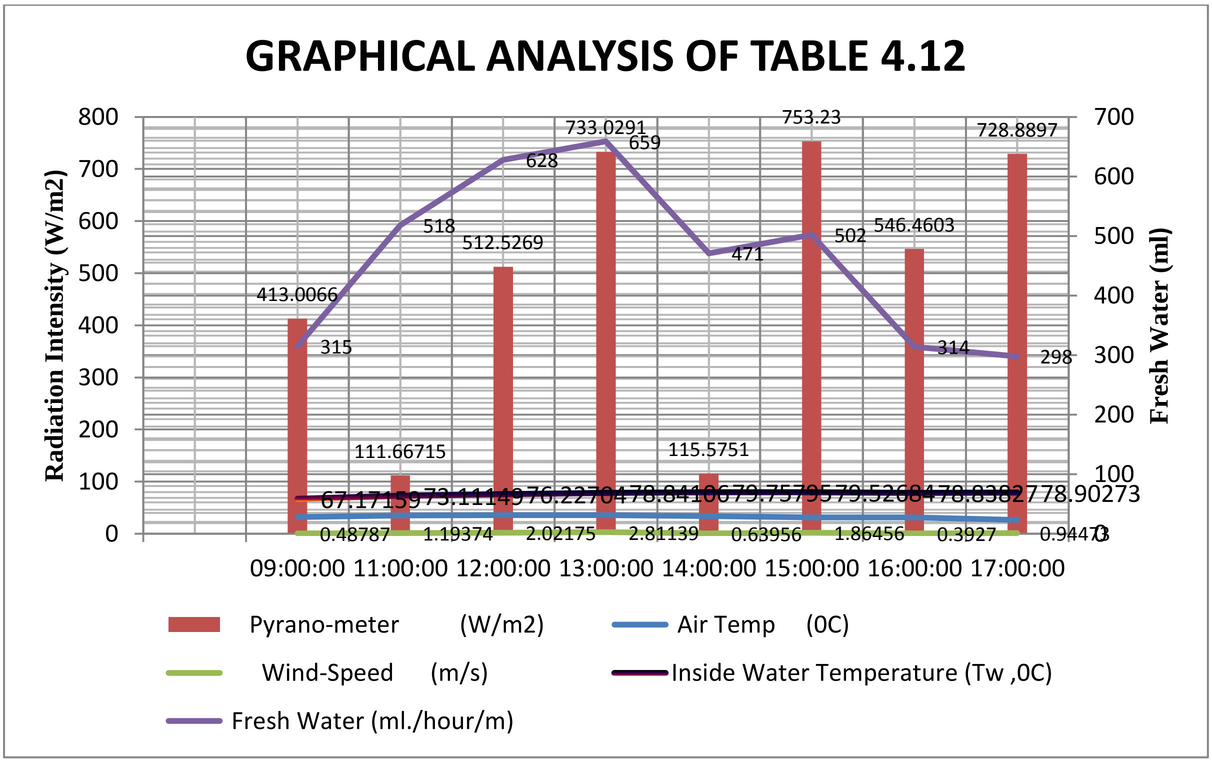

Figure 4.12 Graphical Analysis

Table 4.13 Data collected on 16-05-15:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
09:00	30.61215	417.0596	1.06912	392	70.24097
10:00	32.41714	402.3828	0.73074	596	72.67809
11:00	33.41971	610.8045	2.22689	565	75.41797
12:00	34.12326	693.2871	0.53047	596	78.15825
13:00	35.42496	162.9586	1.54786	408	81.06567
14:00	36.27335	779.7176	0.86857	533	84.1342
15:00	36.59839	440.3741	0.91562	298	85.51015
16:00	36.25363	461.4721	1.14744	325	87.05334
17:00	35.93005	508.2201	0.48227	219	86.8748

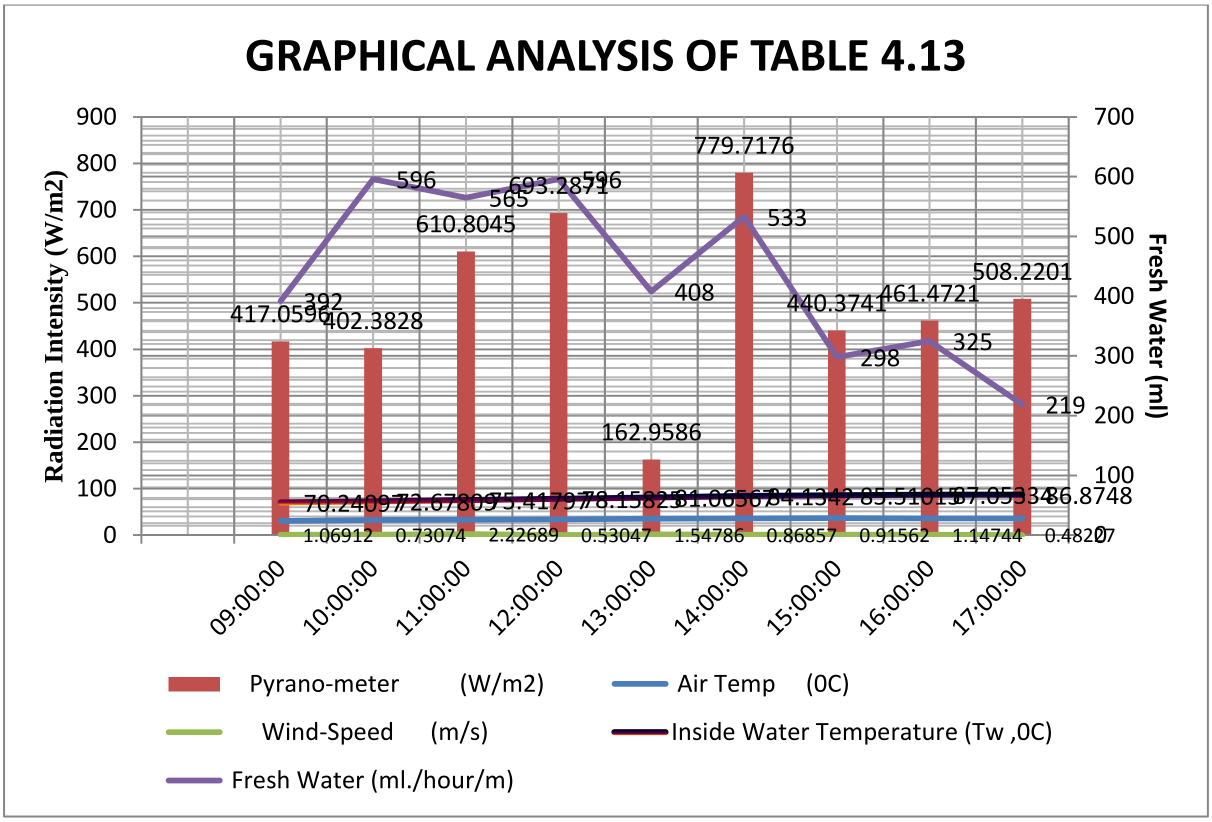

Figure 4.13 Graphical Analysis

Table- 4.14 Data collected on 17-05-15:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^{0}C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w ,^{0}C)
09:00	32.60541	714.7372	1.23607	298	75.7717
10:00	34.55743	691.0312	1.01247	659	78.77852
11:00	36.05292	544.6589	1.03019	612	82.04729
12:00	36.78705	675.0272	1.26145	690	85.1289
13:00	39.01236	492.6082	0.75337	675	87.3397
14:00	38.99548	495.5741	2.2239	533	89.31261
15:00	39.84982	420.9528	2.61934	659	91.49929
16:00	39.95743	552.8736	1.52285	664	93.3559
17:00	40.05524	528.7584	0.57395	502	93.48251

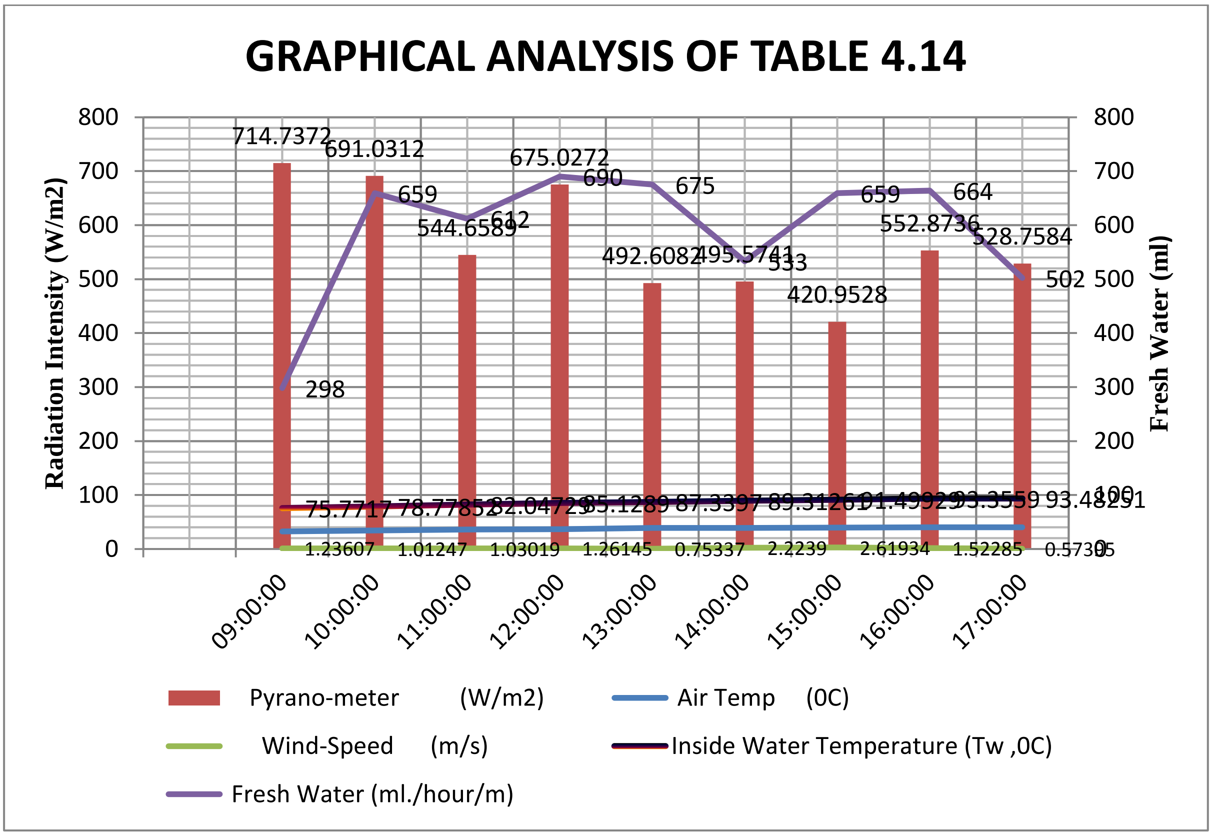

Figure 4.14 Graphical Analysis

Table-4.15 Data collected on 18-05-15:

Hourly variation of Temperature of ambient temperature, inside water temperature, global radiation , wind speed & fresh water generation.

Time (hour:min)	Air Temp (^0C)	Pyrano-meter (W/m^2)	Wind-Speed (m/s)	Fresh Water (ml./hour/m)	Inside Water Temperature (T_w , ^0C)
09:00	34.43539	879.6878	1.80306	314	79.60896
10:00	37.09247	116.8817	1.14934	361	83.13727
11:00	38.29956	716.13239	1.6912	722	35.26147
12:00	39.94409	747.12421	0.40696	659	39.35981
13:00	41.45157	721.33527	0.31905	439	43.4501
14:00	42.22018	582.30884	0.84166	659	46.4773
15:00	42.67072	477.69354	1.57272	502	50.95174
16:00	42.8909	278.42133	1.16454	408	53.65516
17:00	42.9274	134.37219	0.64166	282	54.11793

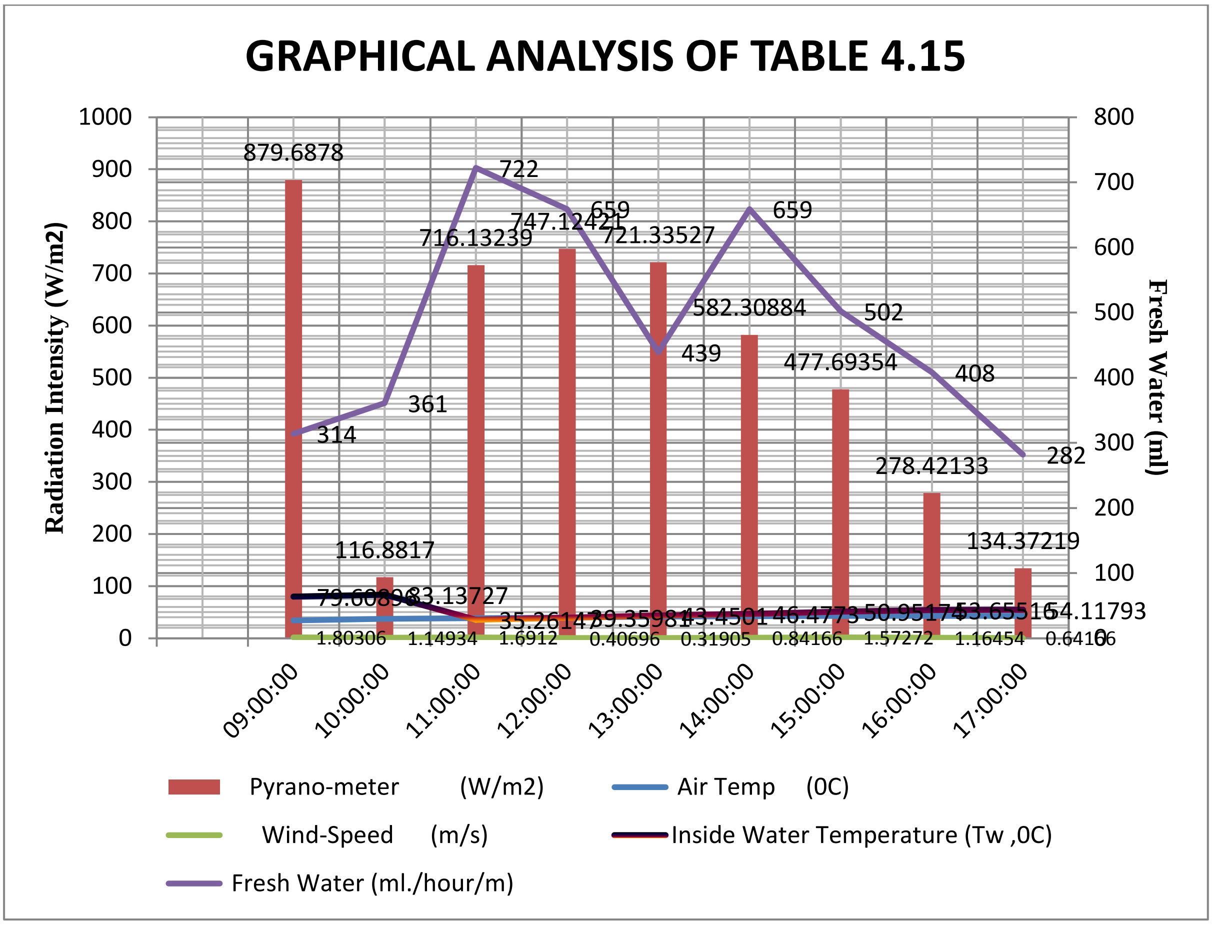

Figure 4.15 Graphical Analysis

The fresh water has been achieved 5.2 litres/day per m^2 at the titled global radiation of 6.2kWh/m^2 from Table 4.1. The average temperature of hot water (brackish water) is 47 ^{0}C at the ambient temperature of 24^{0}C. The fresh water output is 4.68 litres/day m^2 and collected **hot water (brackish water)** is reached approximately **480 litres/day** at 48^{0}C, which can be used for domestic proposes. The Average fresh water production during the data collected for thirteen days in bright sunshine hour is **4.91 liters/m^2/day** shown in Table 4.16, at tilted global radiation of **4.86 kWh/m^2**, corresponding Average Inlet Water Temperature is **65.69^o C** and Average Wind Speed of **1.57 m/s**.

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.

4.2 EFFECT OF THE FPSWD SYSTEM

The production of fresh water by this system is affected by the following environmental condition: ambient temperature, solar radiation and wind velocity. Operating conditions are inlet water temperature, collector area, depth of water and the orientation of distillation system 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.

TABLE 4.16 Average Daily Fresh Water Productions

DATE	Average Fresh water (ml)	Average Inlet Temperature (^{o} C)	Average Global Radiation (W/m^2)	Average Wind Speed (m/s)
06-May-15	383.66	61.15	547.15	2.17
07-May-15	503.87	56.09	613.35	3.13
08-May-15	461.77	46.74	511.16	1.97
09-May-15	482.88	66.13	491.22	1.96
10-May-15	586.66	79	561.04	1.12
11-May-15	556.55	65.86	550.38	1.14
13-May-15	446.22	50.9	587.65	1.78
14-May-15	506.44	65.47	555.86	0.88
15-May-15	463.12	76.54	489.29	1.29
16-May-15	436.88	80.12	496.36	1.057
17-May-15	588	86.3	568.96	1.35
18-May-15	482.88	54	517.1	1.06

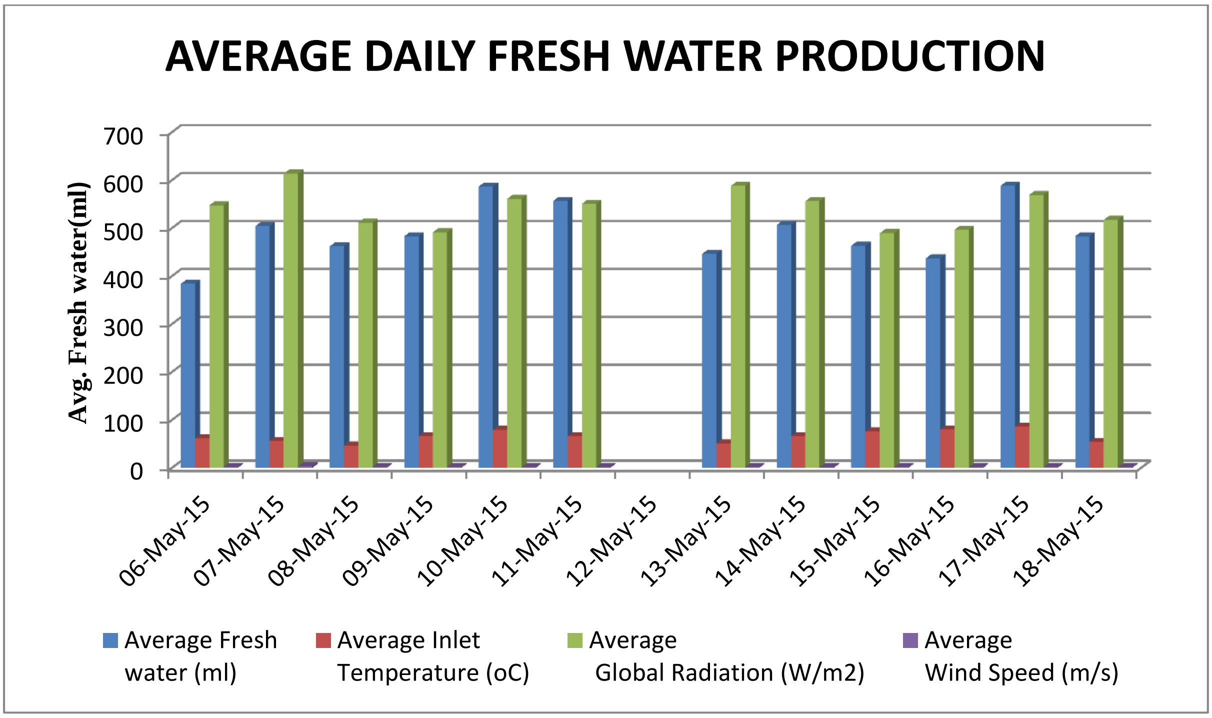

Figure 4.16 Graphical Analysis

4.2.1 EFFECT OF INLET WATER TEMPERATURE

The production of the fresh water is maximum during a day in the month of 17th May, (Table 4.16) corresponding to average inlet water temperature (86.3^{o}C).The average maximum production of fresh water during the whole month is available at daytime hour (i.e.11.05 am to 2.55pm) of a day. Solar Water Distillation system(SWDS) is simple ,require less maintenance and low installation cost makes it ideal for the larger rural population safe drinking water as other options of Desalination Technologies is not feasible because of high cost and no electrification in rural areas.

4.2.2 EFECT OF SOLAR RADIATION

The output of solar distillation system is increased as the solar radiation increased shown in Figure 4.16. the average maximum output of fresh water ,corresponding Average Global Radiation value (568.96 W/m^2) is 588 ml. 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.

4.2.3 EFFECT 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.

4.2.4 EFFECT OF AMBIENT AIR TEMPERATURE

The effect of ambient temperature variations on portable solar distillation is analysed by various graphical variations shown from Table 4.2 to Table 4.16. The graphical results showed that a slight increase of ambient temperature will increase the production of distilled water temperature.

4.2.5 EFFECT OF WIND VELOCITY

Wind speed plays a major role in the production of fresh water is maximum corresponding (inlet solar collector temperature is 46.74 0C,wind speed 1.97 m/s ,air temperature 34.7106 0C and solar radiation 511.61 W/m2) is 461.77ml on 8th May from Table 4.16. Now during the data taken on 13th May, corresponding (system inlet temperature 50.90^{o}C, air temperature 36 .209 0C and solar radiation 587.65 W/m^{2} and wind speed 1.78 m/s) produce only 446.22 ml providing maximum values of meteorological data except wind speed. Therefore wind speed accelerates the rate of evaporation and condensation process inside the system and hence produced more fresh water. The graphs shows the high wind speed will increase the production of fresh water compare to the low 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 vapours collected on the glazing sheet as seen in Figure 4.16, corresponding maximum wind speed (3.13),the fresh water production is 506.44ml which is less compare to other data recorded during the day.

.

CHAPTER-5

CONCLUTION AND SCOPE FOR FUTURE IMPROVEMENT

5.0 CONCLUSION

The performance has been analyzed for the period of 9 hours in day times i.e. 9:00 hours to 17:00 hrs. It is observed that, during the performance testing of inclined FPSWD, average field data on different parameters namely Temperature of cover sheet, hot brackish water (^{0}C), Tilted Global radiation (kWh/m^2) ,wind speed (m/sec), Ambient Temperature, generation of fresh water, hot brackish water have been recorded.

- The output of fresh water achieved about 5.33 liters/m^2 day at the radiation 5.6 kWh/m^2.
- The hot brine water is achieved about 14.3 litrs/m^2 day at the temperature of 46^{0}C which is good enough for domestic usage.
- It also observed that, the inlet brackish water was 350 ppm before distillation and distilled water was found at zero ppm.
- In this experiment, the temperature of the hot water, cover sheet temperature were measured with thermocouples. The fresh water and hot water (Brackish water) were measured and accumulated in tanks.
- The inlet feed water from tank is 360 ppm and out let of fresh water & hot brackish water reached at zero ppm & 650 ppm respectively.
- As seen this table-1, the fresh water generation increases as the tilted global radiation increase.
- The fresh water has been achieved 5.2 liters/day m^2 at the titled global radiation of 6.2kWh/m^2.

- The average temperature of hot water (brackish water) is 47 ^{0}C at the ambient temperature of 24^{0}C as shown in table-2.
- The fresh water output is 4.68 liters/day m^{2} and collected hot water (brackish water) is reached approximately 480 liters/day at 48^{0}C, which can be used for domestic proposes.
- It is noted that the brackish water temperature is mostly similar to cover sheet/polycarbonate sheet temperature. The temperature of hot brackish water has reached at 53^{0}C.
- It provides clean drinking water without use of an external energy source like fossils fuels and electric power.
- The solar distillation system will earn carbon credits as it is purely clean source of energy and pay-off of bills fast.

5.1 SCOPE FOR FUTURE DEVELOPMENT

The supply of freshwater is an important element for a rapidly growing populations now and in future, water and energy security is crucial to human beings as fossil fuels are finite. Climate issues will be the prominent issue in future and therefore adoption of Renewable Energy technologies will take place. According to the Central Ground Water Board's latest assessment (CGWB, 2009),84% of the total net irrigation in India has come from ground water but groundwater is being exploited in unsustainable way with an estimated 30 million groundwater structures in play, we are heading towards a serious crisis of groundwater over extraction and quality worsen. Although groundwater contributes less than 1% in hydrosphere as fresh water and will not be able to meet future requirements. The main challenges is to produce distilled water for larger communities for their growth, development and heath at affordable cost.

REFERANCES

[1] Gopal Nath Tiwari and Hriday Narayan Singh- "History, Development and Management of Water Resources" – Vol. II - Solar Distillation.

[2] D. Jamieson, "Experimental Methods for the Determination of the Properties of Saline Water, Measurements and Control in Water Desalination", edited by N. Lior (Elsevier, Netherlands, 1986) p:219-240.

[3] T. Beikircher, M. Möckl, P. Osgyan, G. Streib, "Advanced solar flat plate collectors with full area absorber, front side film and rear side vacuum super insulation", Solar Energy Materials and Solar Cells, Volume - 141, October - 2015, Pages 398–406.

[4] Ming Zhang, Lei Miaoa, Yi Pu Kang, Sakae Tanemura, Craig A.J. Fisher, Gang Xu, Chun Xin Li, Guang Zhu Fan, "Efficient, low-cost solar thermoelectric cogenerators comprising evacuated tubular solar collectors and thermoelectric modules", Applied Energy, Volume - 109, September - 2013, Pages 51–59.

[5] Ze-Dong Cheng, Ya-Ling He, , Bao-Cun Du, Kun Wang, Qi Liang, "Geometric optimization on optical performance of parabolic trough solar collector systems using particle swarm optimization algorithm", Applied Energy, Volume - 148, 15 June - 2015, Pages 282–293.

[6] K.S. Reddy, T. Srihari Vikram, G. Veershetty, "Combined heat loss analysis of solar parabolic dish – modified cavity receiver for superheated steam generation", Solar Energy, Available online 18 May - 2015.

[7] R. Abbas, J. Muñoz-Antón, M. Valdés, J.M. Martínez-Val, "High concentration linear Fresnel reflectors", Energy Conversion and Management, Volume - 72, August - 2013, Pages

60–68, The III International Conference on Nuclear and Renewable Energy Resources NURER2012.

[8] Hikmet S. Ayber, Fuat Egelioglu,U.Atikol, “An experimental study on an inclined solar water distillation system”,Desalination,vol.180,2005,pp.285-289.

[9] R. Bhardwaj , M.V. ten Kortenaar , R.F. Mudde , “Maximized production of water by increasing area of condensation surface for solar distillation”Applied Energy,Vol.154(2015),pp.480-490,ISSN-0306-2619.

[10]Edward K. Summers, Mohammed A. Antar, John H. Lienhard V, “ Design and optimization of an air heating solar collector with integrated phase change material energy storage for use in humidification–dehumidification desalination” Solar Energy,2004,Vol.(86),pp.3417-3429.

[11] Wang Geun Shim, Ke Hea, S. Gray c, Il Shik Moon,“Solar energy assisted direct contact membrane distillation (DCMD) process for seawater desalination”, Separation and Purification Technology, Volume 143, 25 March 2015, Pages 94–104.

[11] Edward K. Summers, Mohammed A. Antar, John H. Lienhard V, “ Design and optimization of an air heating solar collector with integrated phase change material energy storage for use in humidification–dehumidification desalination”, Solar Energy, Volume - 86, Issue 11, November - 2012, Pages 3417–3429.

[12] Guofeng Yuan a,Zhifeng Wang a, Hongyong Li , Xing Li, “ Experimental study of a solar desalination system based on humidification–dehumidification process”, Desalination, Volume - 277, Issues 1–3, 15 August - 2011, Pages 92–98.

[13]M.Zamena, M.Amidpourb ,S.M.Soufaria, “Cost optimization of a solar humidification–dehumidification desalination unit using mathematical programming”, Desalination, Volume - 239, Issues 1–3, April - 2009, Pages 92–99.

[14] Majed M. Alhazmy, “Minimum work requirement for water production in humidification–dehumidification desalination cycle”, Desalination, Volume - 214, Issues 1–3, 15 August - 2007, Pages 102–111.

[15] J. Orfia, N.Galanisb, M.Laplante, “Air humidification–dehumidification for a water desalination system using solar energy”, Desalination, Volume - 203, Issues 1–3, 5 February - 2007, Pages 471–481.

[16] Said Al-Hallaja, Sandeep Parekha, M.M. Faridb, J.R Selmana, “Solar desalination with humidification–dehumidification cycle: Review of economics”, Desalination, Volume - 195, Issues 1–3, 5 August - 2006, Pages 169–186.

[17] Shaobo Houa, Shengquan Yeb, Hefei Zhang, “Performance optimization of solar humidification–dehumidification desalination process using Pinch technology”, Desalination, Volume - 183, Issues 1–3, 1 November - 2005, Pages 143–149.

[18] Henry Shih, “Evaluating the technologies of thermal desalination using low-grade heat”, Desalination, Volume - 182, Issues 1–3, 1 November - 2005, Pages 461–469.

[19] Sandeep Parekh, M.M. Faridb, J .R. Selman, Said Al-Hallaj, “Solar desalination with a humidification-dehumidification technique a comprehensive technical review”, Desalination, Volume - 160 ,(2004), pages - 167-186.

[20] S. Al-Kharabsheh, D. Yogi Goswami, “Analysis of an innovative water desalination system using low-grade solar heat”, Desalination, Volume - 156, Issues 1–3, 1 August - 2003, Pages 323–332.

[21] Hassan E.S. Fath, Ahmad Ghazy, “Solar desalination using humidification-dehumidification Technology”, Desalination, Volume - 142, Issue 2, 1 February - 2002, Pages 119–133.

[22] Naser K. Nawayseh , Mohammed Mehdi Farld , Abdul Aziz Omar, Said Mohd. Al-Hallaj , Abdul Rahman Tamimi, A simulation study to improve the performance of a solar humidification-dehumidification desalination unit constructed in Jordan”, Desalination, Volume - 109, Issue 3, June - 1997, Pages 277–284.

[23] Peng Wang, Tai-Shung Chung,“Recent advances in membrane distillation processes :Membrane development, configuration design and application exploring”, Journal of Membrane Science, Volume - 474, 15 January - 2015, Pages 39–56.

[24] Achmad Chafidz, Saeed Al-Zahrani, Mansour N. Al-Otaibi, Choo F. Hoong , Tan F. Lai,Manoharan Prabu,“Portable and integrated solar-driven desalination system using membrane distillation for arid remote areas in Saudi Arabia”, Desalination. Volume - 345, 15 July - 2014, Pages 36–49.

[25] R. Schwantes b, A. Cipollina, F. Gross, J. Koschikowski, D. Pfeifle, M. Rolletschek, V. Subiela, “Membrane distillation Solar and waste heat driven demonstration plants for desalination”, Desalination, Volume - 323, 15 August - 2013, Pages 93–106.

[26] Young-Deuk Kim, Kyaw Thu, Noreddine Ghaffour, Kim Choon Ng, “Performance investigation of a solar-assisted direct contact membrane distillation system”, Journal of Membrane Science, Volume - 427, 15 January - 2013, Pages 345–364.

[27] Shihong Lin,Ngai Yin Yip,Menachem Elimelech, “Direct contact membrane distillation with heat recovery, Thermodynamic insights from module scale modeling”,Journal of Membrane Science, Volume – 453, (2014), Pages 498–515.

[28] M.C. Rodríguez-Hidalgo , P.A. Rodríguez-Aumente , A. Lecuona , M. Legrand , R. Ventas, “Domestic hot water consumption vs. solar thermal energy storage, The optimum size of the storage tank”, Applied Energy, Volume – 97, (2012), pages 897–906.

[29] E. Mezaache and M. Daguenet, “ Effects of inlet conditions on film evaporation along an inclined plate, Solar Energy”, 78 (2005) 535–542.

[30] A.A. Badran and A.A. Al-Hallaq, “A solar still augmented with a flat-plate collector, Desalination, 172 (2005) 227–234”.

[31] G. Yuan, “Experimental research of an integrative unit for air-conditioning and desalination, Desalination”, 182 (2005) 511–516”.