FABRICATION AND TESTING OF SMALL CAPACITY SOLAR DESALINATION SYSTEM USING HUMIDIFICATION-DEHUMIDIFICATION METHOD

By

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PROJECT REPORT

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Faculty of Agricultural Engineering and Technology
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Department of Land & Water Resources & Conservation Engineering

Kelappaji College of Agricultural Engineering & Technology

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DECLARATION

We hereby declare that this project entitled "**Fabrication And Testing of Small Capacity Solar Desalination System Using Humidification-Dehumidification Method**" is a bonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us for any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Anil Babu, A. K.
(2008-02-004)

Place: Tavanur **Pravitha, M.**
Date: **(2008-02-022)**

CERTIFICATE

Certified that this project report entitled "**Fabrication and Testing of Small Capacity Solar Desalination System Using Humidification-Dehumidification Method**" is a record of project work done independently by Anil Babu, A. K., Pravitha, M. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

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Anil Babu, A. K.

Pravitha, M.

DEDICATED TO

OUR LOVING PARENTS

&

PROFESSION

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SYMBOLS AND ABBREVIATION

&	and
^{o}C	degree Celsius
≥	greater than or equal to
″	inches
<	less than
µ	micron
/	per
%	percentage
BIS	Bureau of Indian Standards
Dept.	department
et al.	and other people
etc.	etcetera
Fig.	Figure
Ft	feet
g	gram
hrs	hours
i.e.	that is
KCAET	Kelappaji College of Agricultural Engineering and Technology
Kg	Kilogram
KW	Kilo Watt
Lps	Liters per second
ml	milliliter
no.	number
ppm	parts per million

INTRODUCTION

Chapter 1

INTRODUCTION

Water is an essential and unique natural resource that provides life support for plants and animals. For human, there can be nothing which is more important than water. The world's water consumption rate is doubling every 20 years, outpacing by two times the rate of population growth. It is projected that by the year 2025 water demand will exceed supply by 56%, due to persistent regional droughts, shifting of the population to urban coastal cities, and water needed for industrial growth. Fresh water is a precious and limited resource that nourishes innumerable life forms. As population pressure increase, the majority of communities around the world are facing decreasing supplies of fresh water, in general may lack access to potable water at all. The main reason for the decline of fresh water supply is increase in water demand for food, industry and people. Lack of fresh water reduces economic development and lowers living standards. Clearly, there is a critical worldwide need to better manage this increasingly valuable resource.

There are two kinds of water; salt water and freshwater. Salt water contains great amounts of salt, whereas freshwater has a dissolved salt concentration of less than 1%. Only freshwater can be applied as drinking water. Only 2.5 percent of water on Earth is fresh water, the remaining 97.5 percent is brackish or saline water. That is if the entire world's water were fit into a gallon jug, the fresh water available for us to use would equal only about one tablespoon. The scarcity of fresh water resources and the need for additional water supplies is already critical in many arid regions of the world and will be increasingly important in the future. It is very likely that the water issue will be considered, like fossil energy resources, to be one of the determining factors of world stability. There is a famous script that explains this situation is “Water, water, everywhere, nor any drop to drink”. Today’s scientific advances in water desalination promise to edit that script into “and every drop to drink”. Dramatically increase of our ability to transform sea water into fresh water help to quench the thirst of 1.2 billion people facing shortage of water. In many arid regions of the world, and especially in the Middle East, where conventional sources of fresh water (e. g., rivers, lakes and groundwater) are not readily available, seawater desalination will continue to supply drinking water. The world-wide availability of renewable energies and the availability of mature technologies in this field make it possible to consider the coupling of desalination plants with renewable energy production processes in order to ensure the production of water in a sustainable and environmentally friendly scheme for the regions concerned.

Desalination is a water treatment process that converts brackish or saline water to fresh water by removing dissolved minerals from the water. Solar desalination is used by nature to produce rain which is the main source of fresh water on earth. All available man-made distillation systems are duplication on a small scale of this natural process. Recently, considerable attention has been given to the use of renewable energy as sources for desalination, especially in remote areas and islands. This is because of the high costs of fossil fuels, difficulties in obtaining it, attempts to conserve fossil fuels, interest in reducing air pollution, and the lack of electrical power in remote areas.

Desalination/Distillation is one of mankind's earliest forms of water treatment, and it is still a popular treatment solution throughout the world today. In ancient times, many civilizations used this process on their ships to convert sea water into drinking water. Today, desalination plants are used to convert sea water to drinking water on ships and in many arid regions of the world, and to treat water in other areas that is fouled by natural and unnatural contaminants. A proven technology that has been used for many years, desalination is increasingly common in areas with scarce water supplies. However, because of its relatively high cost, it is generally used only if fresh water supplies are limited. Water desalination technologies can be categorized on the basis of the energy used to run them, usually thermal or electric. The technologies utilizing thermal energy are known as the multi-stage flash (MSF), multiple-effect distillation (MED) and vapour compression (VC). The desalination technologies that use electric energy rely on a membrane system, such as reverse osmosis (RO) and electro dialysis (ED). There are also other technologies that rely on solar energy or combined electric and thermal energy. Each of these technologies has advantages and disadvantages, based on the quantity and quality of the required water and the location.

Desalination processes require large amounts of thermal or electric energy; however, advances in desalination technology continue to make these processes more efficient. Recent investigations have focused on the use of renewable energy to provide the required power for the desalination processes. The most popular renewable energy source being solar energy, it could supply all the present and future needs of the world on a continuing basis. Solar energy is clean, non-depleting energy available almost everywhere. At ground level the energy ranges from 10 to 1000 watts/sq.m. Solar energy reaching the earth in a year is equivalent to the energy from burning 120 million tonnes of coal which is about 25 times the total coal supply. Solar desalination systems are simple and easy to operate and maintained. They are also environmentally friendly because they do not require fossil fuels. Due to the large energy consumption in the major commercial desalination processes, along with the growing concern about CO_2 emission, there is a strong interest in alternate sources of energy to run desalination units, and in particular, renewable energy sources. By evaluating current costs of desalination methods in opposition with similar economic models developed in recent years, one can ascertain that significant advancements have been made both economically, and in the field of renewable energy itself.

In countries with abundant solar energy, solar desalination could be one of the most successful applications of solar energy. Solar energy represents a huge energy resource for the world, particularly in the southern countries close to the Equator, where the deserts have some of the best solar resource levels. In the last two decades a remarkable development has been noticed in a variety of solar assisted thermal applications. Solar stills developed as desalination units display the inherent major problem of energy loss in the form of latent heat of condensation of water. Solar desalination based on the humidification–dehumidification principle leads to a major improvement in the efficiency of direct solar distillation units. Although desalted water may be produced using free energy such as solar or wind, the technology could still be expensive, depending on fixed and operating costs. The estimation or stipulation of an economic price is essential for poor small communities lacking fresh water. Although market prices for renewable energies are high; it could gradually become lower in the future and would be competitive with conventional energy sources. The advantage of using “free” energy is partly offset by increased amortization costs; however, distillation with solar energy remains one of the most favourable processes for small capacity water desalting for remote regions where there is substantial solar radiation, and a lack of skilled personnel and erection and maintenance facilities.

Different solar energy collectors may be used in order to convert solar energy to thermal energy. In most of them, a fluid is heated by the solar radiation as it circulates along the solar collector through an absorber pipe. This heat transfer fluid is usually water or synthetic oil. The fluid heated at the solar collector field may be either stored at an insulated tank or used to heat another thermal storage medium. The solar collector may be a static or sun- tracking device. The second ones may have one or two axes of sun tracking. Otherwise, with respect to solar concentration, solar collectors are already commercially available; nevertheless, many collector improvements and advanced solar technologies are being developed. The main solar collectors suitable for seawater distillation are salinity gradient solar ponds, flat plate collector, evacuated tube collector, parabolic trough collector etc.

Flat-plate collectors (FPCs) are used for heating of heat transfer fluid, which circulates through absorber pipes made of either metal or plastic. The absorber pipes are assembled on a flat plate and they usually have a transparent protective surface in order to minimize heat losses. They may have different selective coatings to reduce heat losses and to increase radiation absorption. A typical flat-plate collector is an insulated metal box with a glass or plastic cover and a dark- coloured absorber plate. The flow tubes can be routed in parallel or in a serpentine pattern. They have been used for relatively small desalinated water production volumes; production of large volumes of water would require an additional energy source.

In order to obtain a small scale desalination unit humidification and dehumidification is the best principle can apply. The technology of humidification (HD) satisfies some of these demands, in particular flexibility in capacity with moderate installation and operating costs. The current HD installations are in very compact units containing two exchangers: an evaporator where air is humidified and a condenser where distilled water is recovered. The main idea of the humidification de-humidification solar desalination system based on the evaporation of water and the condensation of steam to and from humid air. The humid air circulation driven by natural convection between evaporator tower (humidifier) and condenser tower (dehumidifier). Evaporator and condenser are located in the same insulated box. The heated seawater from central receiver is distributed onto the evaporator tower through a vertically hanging sprayer and is slowly trickling downwards. The condenser unit is located opposite to the evaporator. Here the saturated air condenses on a single tube copper coil. Water with ambient temperature was used as a coolant for the condenser. The distillate runs down to a collecting tank. Two modifications can be introduced on the desalination chamber to enhance the desalination system productivity. The first modification was using water jacket at one side of the dehumidifier tower to increase the condensation surface. The second modification was to use seven flat mirrors to concentrate solar radiation on one side of the humidifier tower (0.003 m ordinary window glass) to heat the humid air to increase the system productivity.

Compared to other distillation processes, the HD process functions at atmospheric pressure so that the components are not submitted to mechanical solicitations. The only characteristic required is resistance to corrosion. Commonly evaporation takes place in this type of arrangement is at temperatures between 40 °C and 85°C at ambient pressure. The HDH cycle has received much attention in recent years and many researchers have investigated the intricacies of this technology.

Out of 6000 km sea coast of India, Kerala has a coastal line of 589.5 km, which is about 10% of India's cost. The state is endowed with rich inland water bodies consisting of 44 rivers (having an area of 0.85 lakh ha), 45 backwater bodies and extensive brackish water area (2.43 lakh ha). The average population density along the Kerala coast is very high compared to the inlands of the state. It has been resulted from the growing pollution in the coastal area and the left over by the factories in large volume. One of the main water problems in the coastal area is the availability of fresh water. Due to sea water intrusion, most of the wells and ponds and water bodies near the coastal region are having salt water. All along the coastal areas including the lake sides, ponds and canals are bearing the brunt of factory outlets. It causes severe fresh water scarcity in the coastal areas.

Desalination is the best possible solution to meet the growing demand for fresh water. This necessitate the need our project i.e., water desalination for economical production of pure water.

Main objectives of this work are:

1. Design and fabricate a small scale saline water desalination plant.
2. Compare the total productivity of plant with respect to temperature and flow rate.
3. Evaluation of total productivity of the system.
4. Compare the water quality before and after the experiment.

REVIEW OF LITERATURE

Chapter 2
REVIEW OF LITERATURE

Drinking water of acceptable quality has become a scarce commodity. In many places of the world only brackish or polluted water is available. This leads to an increasing interest in new desalination technologies. Humidification and dehumidification is the basic principle of small scale desalination system. Recent investigations have focused on the use of renewable energy to provide the required power for the desalination processes.

Humidification and Dehumidification

Water desalination by humidification and dehumidification has been the subject of many investigations. Different experimental data are available for using HD at the pilot or industrial scale. An inspection of these data allows establishing many perspectives for this process.

The principal variant consists in preheating air at the place of preheating salt water. Since the HD process allows low-temperature energy to be used, particular attention was paid to the use of solar energy in this kind of process. Efforts have been focused for some time on recovering the latent heat from condensation. Preheating of the feed water by passing it over the glass cover allows only partial utilization of the latent heat, resulting in a limited increase in still production. The multiple-effect humidity process allows increasing the efficiency of the system.

Metha et. al., (1994) was the first to introduce an air- recycling system in which air coming from the dehumidifier is recycled in the humidifier. It was shown that the use of air recycling gives a cost reduction of more than 7%. The advantages obtainable by this air-recycling system consist of more than a 20% reduction in the packed height of the humidifier and more stable operation of the plant. He also investigated the economics of combining an HD plant with power plants or with chemical industries using seawater as coolant.

Vlachogiannis et. al., (1995) developed a new desalination process based on a combination of the principles of HD and mechanical vapour compression. This process combines the principles of intensive evaporation, vapour compression and heat pump (mechanically intensified evaporation. Air is injected in the evaporation chamber through a porous bottom wall and is dispersed as small diameter bubbles. The emerging saturated stream is compressed by a blower to a slightly higher pressure (Δp = 0.05–0.25 bar) and is directed to the adjacent condensation chamber. Because of the increased pressure, water condensation occurs at a slightly higher temperature than evaporation, and the latent heat is transferred back to the evaporation chamber through the thermally conducting sidewall. The advantages of this process are low-cost construction, simple and flexible operation and suitability for modular design.

Chaibi et. al., (1998) investigated three different configurations for water desalination by humidification: a solar desalination plant with a single- effect process using heat pipes collectors, an integrated solar desalination system in a green house and a solar multiple condensation evaporation (SMCE) cycle process. The economy evaluation showed that the integrated solar still as a part of a greenhouse with a controlled environment is more economical than the assisted solar desalination plants by 35% and 50%, respectively, when compared to the SMCE cycle process and single-effect process using heat pipes.

Bourouni et. al., (2002) developed a new HD process using geothermal energy to reduce the capital cost of humidification installation, especially the solar collectors, other energy resources can be used. The unit consists of two horizontal-tubes, falling-film exchangers (an evaporator and a condenser). Both exchangers are made of horizontal tube bundles made of polypropylene. In the evaporator the cooled hot water enters at a temperature of about 70°C and moves down in the tubes. The cooling air moves up in the space between the tubes. The salt liquid film is dripped from a distributor in the top of the evaporator and falls from tube to tube. A fraction of water is evaporated and carried by the ascendant air flow, maintained by a blower. At the top of the exchanger the hot humid air is driven to the condenser where distilled water is recovered. Heat recovery in a low-temperature process requires an important exchange surface. For this reason, 2000 m of tubes are used in the evaporator and 3000 m in the condenser.

Abd Elkader et. al., (2004) designed a new multi-effect humidification (MEH)-dehumidification solar desalination system coupled with solar central receiver installed and outdoor tested in the faculty of Engineering, Suez Canal University, Port Said, Egypt. The experimental test results showed that, increase of seawater mass flow rate from 0.07 lps to 0.09 lps increases the productivity of the system by 10%. Two modifications were introduced on the desalination chamber to enhance the desalination system productivity. The first modification was using water jacket at one side of the dehumidifier tower to increase the condensation surface. The second modification was to use seven flat mirrors to concentrate solar radiation on one side of the humidifier tower to heat the humid air. The test results showed that, the first modification increases the system productivity by 15% and the use of the second modification increases the system productivity by 12%. It was found also that the use of the two modifications together increases the system productivity by 22%. The productivity of the system in this case was 3.5 kg/day.

Farid et. al., (2004) conducted studies on alternative desalination concept is the collection of potable water by first humidifying an air current by contact with warm seawater and then dehumidifying by cooling. These authors consider the use of solar energy as the heat source and determine the principal operating parameter for the system consisting of a humidifier, a dehumidifier and heating equipment for air and feed water. Inlet water temperature is singled out as the most significant factor affecting system productivity, and the use of latent heat of condensation to preheat saline feed water is implemented to increase energy efficiency.

Klaussner et. al., (2004) described an innovative diffusion-driven desalination technology to overcome the aforementioned shortcoming. To enhance the condensation in the presence of air, a direct-contact condenser was used in diffusion-driven desalination. The Diffusion-driven desalination was powered by waste heat derived from low-pressure condensing steam from a power plant and is viable for industrial-scale freshwater production.

Al-Hallaj et. al., (2005) investigated a solar desalination unit functioning by humidification and dehumidification. In their unit the circulated air by natural or forced convection was heated and humidified by the hot water obtained either from a flat-plate solar collector or from an electrical heater. The latent heat of condensation was recovered in the condenser to preheat the saline feed water.

Two units of different sizes were constructed from different materials. The productivity of these units was found to be much higher than those of the single-basin stills. Moreover, these units were able to product a large quantity of saline warm water for domestic uses other than drinking. The authors showed that no significant improvement in the performance of the desalination units was achieved using forced air circulation at high temperatures. While at lower temperatures, a larger effect was noticed. The authors related this behaviour to the low mass transfer coefficients at low temperatures and to the non-linear increase in the water vapour pressure with temperature.

According to this investigation, it was shown that the mass of the unit is another factor that negatively affects the unit performance. A delay of 3 h was noticed between sunrise and the start of production of fresh water. It was noticed that most of the energy received in these early hours is used as sensible heat to warm up the large mass of the unit, which was about 300 kg. This lag time could be avoided by using a lighter material than galvanized steel for construction.

Lixi Zhang et. al., (2009) introduced a solar desalination process using air humidification and dehumidification. In order to increase the output of freshwater, multi-technologies are adopted; the double-pass solar air heater and tubular solar collector are used to heat the air and seawater respectively. The air is humidified by bubbling in the seawater pool, and dehumidified in the inorganic heat pipe condenser. Moreover, the heat transfer performance of the solar air heater with double vacuum glass-covers and double air passes is analyzed, and the theoretical model of its heat transfer and the calculating method are given.

Narayan et. al., (2011) The objective of this simulation study is to investigate the performance of a sun powered desalination system using humidification-dehumidification (HDH) technique based on closed-water, open-air cycle under the geographical conditions of Dhahran (26.5°N, 50.2°E), Saudi Arabia. They have made comparisons of different components; systems and gain output ratio limit for each layout were made and presented. This study is expected to fill an existing gap in the literature regarding the effect of solar heater tilt angle, using selective surface for the solar heater and considering humidifier performance in terms of the relative humidity of air leaving the humidifier on the system productivity.

Solar energy as a source of heat for desalination

Many studies have been compared between the different renewable energy as desalination driven power for each of brackish and seawater.

Cemil et. al., (1998) , investigated theoretically the effect of different system operating conditions, types of air heater, and some different design parameters and a weather condition on a solar water desalination system performance under the climatologically conditions of Ankara. Also, another study had been conducted in Tunisia for solar desalination by HDDS. This study 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 m3/d).

There are different solar energy collectors. They may be classified in terms of the measured temperature as low (<100 °C), medium in the range of (100–150 °C) and high temperature (>150 °C). For water production, solar energy plays an important role as a source of energy for low enthalpy/temperature desalination systems. For low temperature collectors, which more available, humidification–dehumidification desalination system (HDDS) is suitable.

Gao et. al., (1998) developed a new type desalination unit of heat pump with humidification and dehumidification. The study proven that the new system is efficient desalination unit to produce fresh water.

Tzen et. al., (1998) found that solar energy is suitable for different desalination process at reasonable cost wherever a proper source is available. One of the main disadvantages is that energy storage is required.

Bourounia et. al., **(2001)** presented and analyzed the operation and performance of different HDDS plants worldwide. This study recommends that HDDS installations can be used for the low temperature part of classical distillers to avoid the effects in which distillers have to function under vacuum.

Geyer et. al., (2009) have developed the high performance parabolic trough collector models ET100 and ET150 for the utility scale generation of solar steam for process heat applications and solar power generation. The system was designed to work for different working fluids. The collector modules had been qualified in the years 2000–2002 with a synthetic heat transfer fluid. In addition to the electrical solar power generation from PTC, it is also used to generate the heat to drive the thermal desalination plants. For the long-term scenario for the demand of fresh water in the MENA region, seawater desalination system based on concentrating solar power had been studied. The system of offered affordable, sustainable and secure freshwater potentials those are large enough to cope with the growing deficits in the MENA region.

Systems used for water heating

Sopian et. al., (1997) studied the thermal efficiency of the double-pass solar air heater with or without porous medium in the lower channel, and given the theoretical model of the air heater. The results show if the porous medium is filled in the lower air pass, the outlet temperature of airflow through the porous media and the thermal efficiency of collector are increased, but the pressure drop is higher at the same time.

Cemil Yamal et. al., (1998) studied the effects on freshwater output under different conditions by experiment. It is obtained that the freshwater output can be increased 15% if solar air heater is used. In addition, the output also be enhanced with the rising of the seawater temperature in the water tank, with the rising of the spraying speed and the flow velocity of cooling water, but affected hardly by the changing of air speed.

Voivontas et. al., (1999) analyzed water management strategies based on advanced desalination schemes (such as reverse osmosis and electro dialysis) powered by renewable energy sources (such as wind and solar energy). A framework was presented for developing a decision procedure that monitors water shortage problems and identifies the availability of renewable energy resources to power desalination plants. The cost of alternative solutions, taking into account energy costs or profits by energy selling to a grid, was estimated. Emphasis was given to the market forces and the relationships among technology prices and market potential.

While their study is based on the application of wind and solar energy to run a RO desalination plant rather than direct solar distillation, it does give a good description of the factors and decision steps that need to be taken into account.

Mohamad et. al., (2000) developed a high efficiency double-pass air heater, comparing with conventional double-covers single-pass collector, which adds an air pass between up and own glass cover forming a U-return flue line, and uses absorbing heat plate with filled porous medium in air pass to increase the heat transfer area. It decreases the heat loss from the front cover, and enhances the thermal efficiency which more than 75% under normal operating condition. If the U-return line is designed reasonably and high porous medium is used, the pressure drop in the two air passes will be not high.

Yanniotis et. al., (2000) considered two types of air humidifiers as a part of multi stage solar desalination process. The first one is the tubular spray humidifier and the other one is the pad humidifier. They also presented some computational results for the pad humidifier. Their results showed no substantial differences between both types in terms of pressure drop. Evaporation rate was higher for a thicker pad system at high air to water flow rate ratios.

Fath et. al., (2001) reported that air heated HDH system productivity improved with increased solar energy for air heating, decreased wind velocity and increased air flow rate up to a certain value. They also reported that the dehumidifier size has an insignificant effect on the system performance. The latter is an issue of controversy among investigators that requires further exploration.

MATERIALS AND METHODS

Chapter 3

MATERIALS AND METHODS

The materials that were used for the fabrication of desalination plant and the methods employed to measure the various parameters are described in this chapter.

3.1 Study area

The study has been conducted in KCAET campus, Tavanur, Malappuram district. It is situated at 10°52'30" north latitude and 76° east longitude. Flat plate solar collector is used as the heat source. The desalination unit is installed in the back side of the guest house. The study was conducted during 2011 in successive days to ensure the same climatic conditions for all tests.

3.2 Climate

The climatological data of the study area for the period is given below.

Mean maximum temperature	: 32.5°c
Mean minimum temperature	: 22°c
Average relative humidity	: 83%
Average annual rainfall	: 2000mm
Mean evaporation	: 7mm/day
Mean solar radiation	: 85W/m^2/day

3.3 Saline water Tank

Syntax Water tank having 2000 L capacity was used for the storage of saline water. The tank was fixed at a height about 3.5 m above the solar water heater so that water is allowed to flow under gravity. Flexible PVC pipe was used to convey saline water from the tank to heater. Saline water of different concentrations was made by mixing salt in fresh water. The prepared concentrations for the study were 33 g/l, 36 g/l, 41 g/l.

3.4 Solar Water Heater

JAIN Sun watt Solar water heater of capacity 120L was used for heating the saline water. The technical specifications were,

3.4.1. Solar Flat Plate Collector

a) Absorber Material	: Copper 34 SWG, 99% Pure.
b) Absorber Coating	: Selective Black Chrome Coating.
c) Header Tube	: Copper (Dia. - 29 mm) 22 SWG
d) Riser Tube	: Copper (Dia. - 12.7 mm) 24 SWG
e) Glass	: 3.2 mm thick (tempered, textured, rupture resistance, highest transmittance, low reflectance)
f) Insulation	: PUF – Bottom 25 mm, sides 15 mm.
g) Casing	: Specially extruded weather tight, corrosion resistant, powder coated
h) Size	: 1891 x 1205 x 90 mm
i) Area	: 2.64 Sq. meters
j) Weight	: 45 Kg.
k) Absorptivity	:> 0.92
l) Emissivity	: < 0.20
m) Efficiency	: 80-83 %

3.4.2. Hot Water Storage Tank

a) Material	: 316 “L Marine grade stainless steel
b) Shape	: Cylindrical Horizontal
c) Insulation	: 40mm thick Poly Urethane Foam (PUF)
d) Cladding	: G.I. precoated sheet, Oven baked

3.4.3. Stand

Made out of thick “L” sections, hot dip galvanized material.

3.4.4 Poly Urethane Foam (PUF)

Rigid insulation, minimum 90% closed cells, remains durable for years, no thermal bridges, high mechanical strength, maintains insulation effectively.

Pressure strength	: 0.5 to 6 kg/cm²
Water absorbency	: 0.5 to 3% of foam volume
Effective temperature range	: 40°C to 180°C
Heat conductivity factor	: 0.017 - 0.025 kcal - M - HR °C

3.4.5 Hot Water Insulated Pipeline

Specially manufactured HDPE cladded PUF Insulated Pipes GI “B” Class Pipeline and fittings as required.

The saline water from the tank enters the solar water heater under the force of gravity; the black absorbing surface (absorber) inside the flat plate collector absorbs solar radiation and transfers the energy to water flowing through it. Heated saline water is collected in the tank which is insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to thermo siphon system. Insulated pipe is used to convey hot water from heater to Humidification-Dehumidification unit.

3.5 Design of Humidification-Dehumidification unit

A box which is made up of galvanized iron sheet having thickness of about 0.003m act as Humidification-Dehumidification unit. Dimension of this box is 0.5m x 0.5m x 0.5m and which is formed by bending and assembled by soldering. It is divided into two parts, evaporator tower (humidifier) and condenser tower (dehumidifier). Heated salt water from the solar water heater is sprayed into the evaporator section by using a shower head hanging vertically in the middle of the evaporator chamber. The condenser unit is located opposite to the evaporator. The condenser consists of a 0.025 m single tube copper coil which is wound helically and placed in it. A cold water supply is allowed to flow through the tubes for the purpose of condensation. The fresh water from the condenser is collected in the fresh water tank and measured for a particular duration. The inside portion of the unit is coated with anti corrosion paint in order to avoid corrosion by saline water. The joints are well sealed to avoid the loss of steam produced.

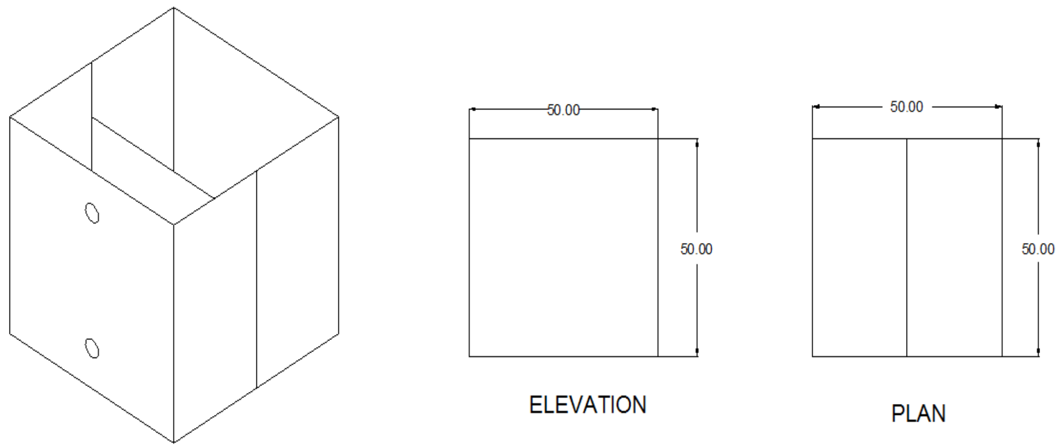

Fig1. Schematic diagram of Humidification De-Humidification Chamber1

Plate 1. Sectional view of Humidification De-Humidification Chamber

3.6 Working

A schematic diagram of the solar desalination system using humidification-dehumidification method is shown in Fig 2. The saline water from the water tank enters the solar water heater under the force of gravity. The flat plate collector of solar water heater catch up heat from sunlight that passes through the cover and then gives heat to the saline water flowing in a copper single tube past the absorber surface. The heated water flows to the humidification unit through a vertically hanging sprayer under the force of gravity through a valve which is used to control the flow rate. The dehumidification chamber located opposite to the humidification unit. Here the saturated air condenses on a single tube copper coil. Water with ambient temperature was used as a coolant for the condenser. The distillate runs down to collecting tank. The fresh water from the condenser is collected and measured every hour in the fresh water tank.

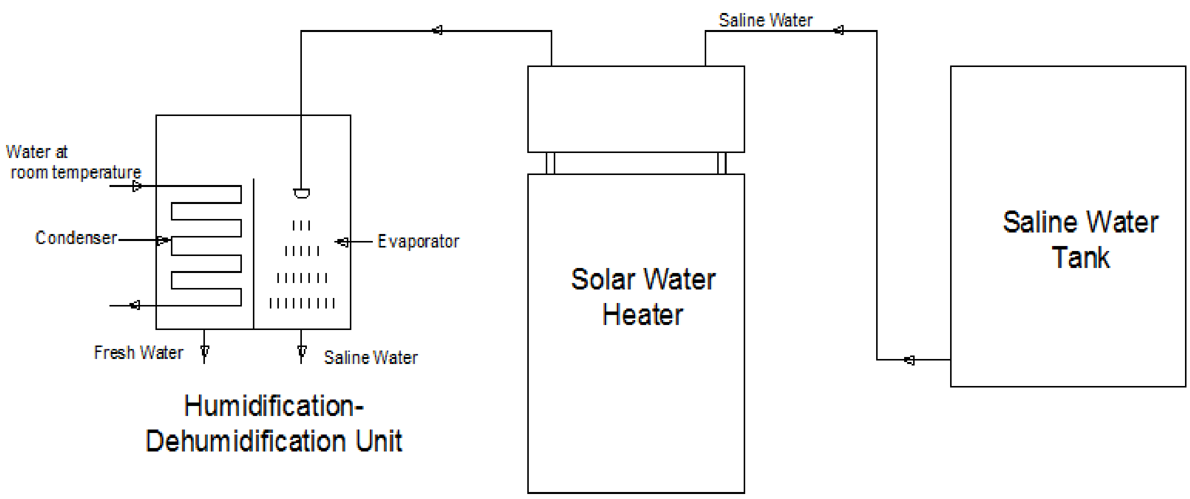

Fig 2. Schematic diagram of solar desalination system

3.7 Productivity of the system

The yield of the system with different temperatures and flow rates were noted. Temperature was within a range of 55 to 75^{o}C and flow rates were in between 3000 to 6000 ml/min. Three concentration of saline water was used for the study. The yield was taken daily during the month of December 2011.

Plate 2. Experimental Setup

3.8 Estimation of water quality

The quality of condensed water and saline water which is feed into the solar collector wants to be tested in order to determine the efficiency of the unit. The water has gone through physical and chemical analysis to check whether the quality of condensed water meets the standards specified by WHO.

3.8.1 Physical analysis

The physical parameters include temperature, pH, and electrical conductivity.

3.8.1.1 pH

The acidity or alkalinity of water is expressed as pH. The pH of an aqueous solution is a measure of the acid base equilibrium achieved by various dissolved compounds. The Bureau of Indian Standards recommendation of pH value of drinking water is 6.5 to 8.5. pH is determined by using pH meter. The working of pH meter is based on electrometric method.

3.8.2 Chemical analysis

Chemical analysis is done to estimate the dissolved oxygen.

3.8.2.1 Dissolved oxygen

A high dissolved oxygen level in a community water supply is good because it makes drinking water taste better. Generally, 4 to 5 mg/L of dissolved oxygen content is a borderline concentration if considering an extended time period. More oxygen can be dissolved in water having low salinity. For finding the dissolved oxygen in water, following reagents were used.

Reagents

1. MnSo4
2. Alkaline KI
3. Sodium thiosulphte
4. Starch indicator

Procedure

Collect sample in a bottle. The bottle should be completely filled without bubbling. Add 2ml of MnSo4 dipping the end of the pipette just below the surface of the liquid. Add 2ml of alkaline KI in the same manner and mix. Allow the whole solution to stand 50 minutes. Then titrate 100 ml of the sample with 0.025 sodium thiosulphate.

$$\text{Dissolved Oxygen} = \frac{V2 \times N \times 8 \times 1000}{V1}$$

V1=Volume of sample

V2=Titrate volume

N=Normality

3.7.2.2 Electrical conductivity

Electrical conductivity or specific conductance is the reciprocal quantity, and measures water's ability to conduct an electric current. The salinity of the water is usually represented by the electrical conductivity. Salinity is the saltiness or dissolved salt content of a body of water. It is a general term used to describe the levels of different salts such as sodium chloride, magnesium and calcium sulphates, and bicarbonates. The Bureau of Indian Standards recommendation of electrical conductivity of Drinking water is 0.005 – 0.05 S/m. It is measured using a conductivity meter having a conductivity cell consisting of a pair of platinum electrodes. The conductivity is expressed in deci Siemens per meter.

RESULT

AND DISCUSSION

Chapter 4

RESULT AND DISCUSSION

Experimental tests were carried out in successive days during December 2011 to ensure the same climatic conditions for all tests. The yield of desalinated water under different temperatures and flow rates of input saline water were noted. The experiment repeated using different concentrations of salinity. The pH, electrical conductivity, dissolved oxygen content of both saline and desalinated water was noted. The quality of desalinated water and that specified for drinking water by Bureau of India standards were compared.

4.1 Effect of Temperature

It has been observed that temperature have a great influence on the yield of desalinated water in the Humidification-dehumidification unit. Different temperatures were obtained by allowing the saline water to re-circulate inside the solar water heater several times. The temperature was noted using a dry bulb thermometer. The experiment was repeated for different salinity and the result showed the same.

The variation of yield under different temperatures is presented in fig.1 – fig.3. In case of 33 g/l salinity, yield started at the temperature of 55^{o}C and corresponding yield is 11 ml/min. As the temperature increases from 55 to 75^{o}C, yield also started increases and finally at the temperature of about 73^{o}C, a maximum yield of 30 ml/min was obtained. A change of hot water temperature from 55°C to 70°C showed the yield to rise from 11 ml/min to 30 ml/min.

Similarly in case of 36g/l and 41 g/l salinity, yield started near about a temperature of 57 to 58^{o}C and yield obtained were 16 ml/min and 17ml/min respectively. The maximum yield obtained in both the cases was in about 75^{o}C and were nearly36 ml/min in both the cases. A change of hot water temperature from 55°C to 70°C showed the yield to rise from 17 ml/min to 36 ml/min.

It is clear from the curve that yield increases with increase in temperature of the saline water that sprayed in the humidification unit. As the temperature of the saline water increases more water get vaporised which on condensation increases the yield. It also shows that concentration of saline water is having only a little effect on yield.

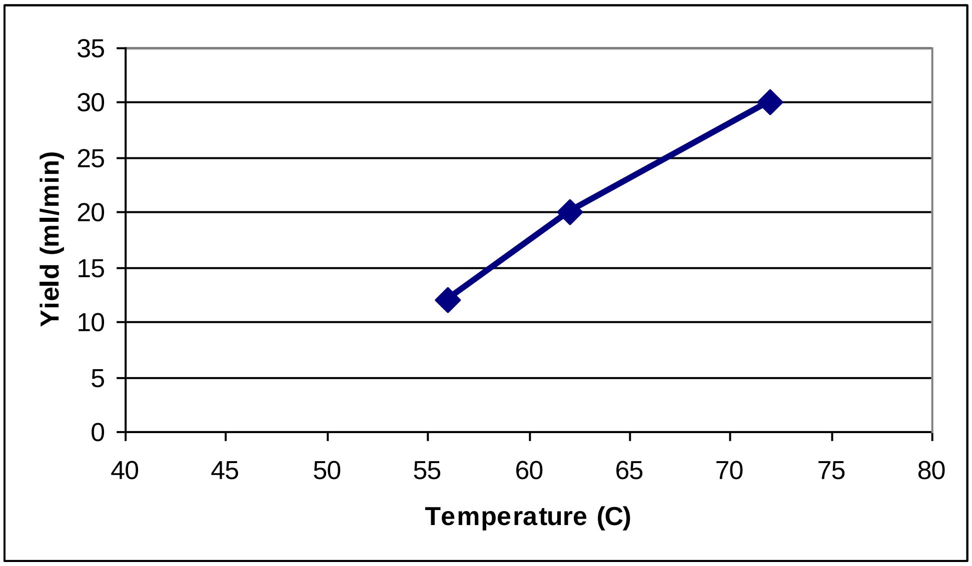

Fig.3. Yield of the system with different temperatures with 33 g/l salinity

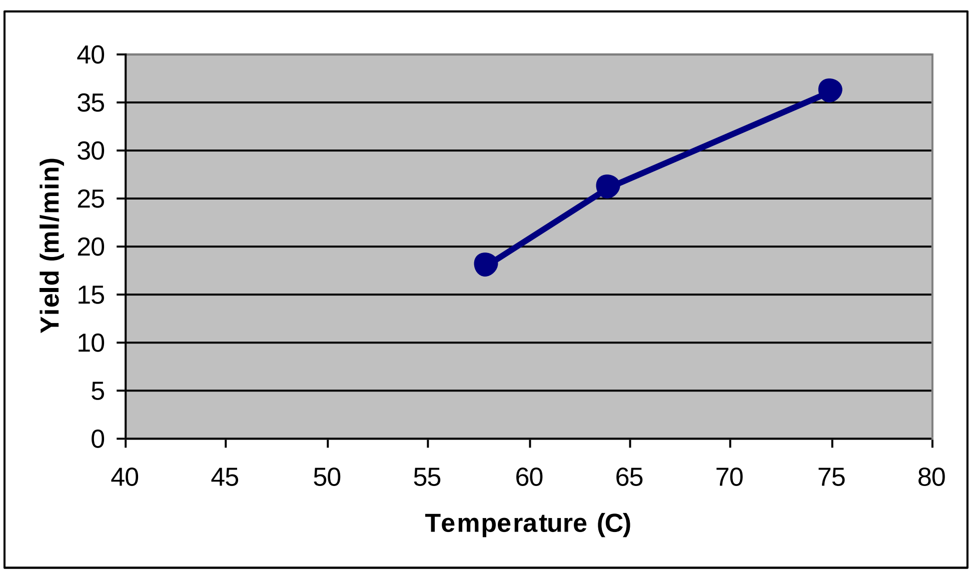

Fig.4. Yield of the system with different temperatures with 36g/l salinity

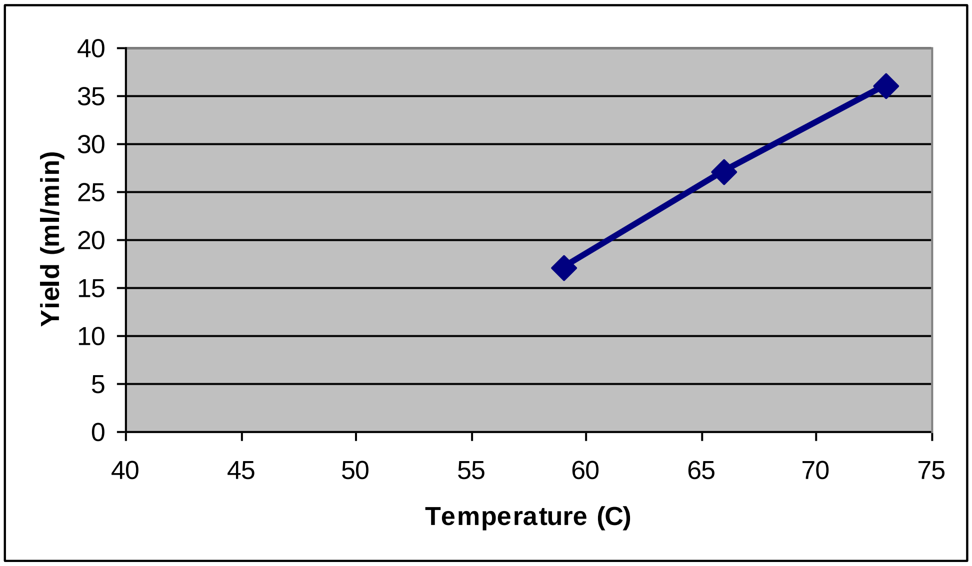

Fig.5. Yield of the system with different temperatures with 41g/l salinity

4.2 Effect of flow Rate

It has been observed that the flow rate of saline water into the humidification unit also has considerable effect on the yield of desalinated water. The hot water under different flow rates were provided by using a flow control valve. The rate of flow of hot water was measured by collecting the hot water from outlet in a measuring jar for a specified time. The experiment was repeated for different salinity and the result is verified.

The variation of yield under different flow rates is presented in fig.4 – fig.6. In case of 33 g/l salinity, with a flow rate of 3250 ml/min, yield obtained was about 18 ml/min and yield increases with increase in flow rate and finally for a flow rate of 6000 ml/min, maximum yield of 31ml/min was obtained. Similarly, in case of 36 g/l salinity, with a flow rate of 2700 ml/min, yield was about 15 ml/min and finally it reached a yield of 30 ml/min with a flow rate of 5900 ml/min. In case of 41 g/l salinity, yield started from 16 ml/min with 3700 ml/min flow rate and finally obtained a maximum yield of 36 ml/min with a flow rate of 6100 ml/min. An increase in the yield with respect to an increase in flow rate can be clearly observed in all the cases of different salinity levels.

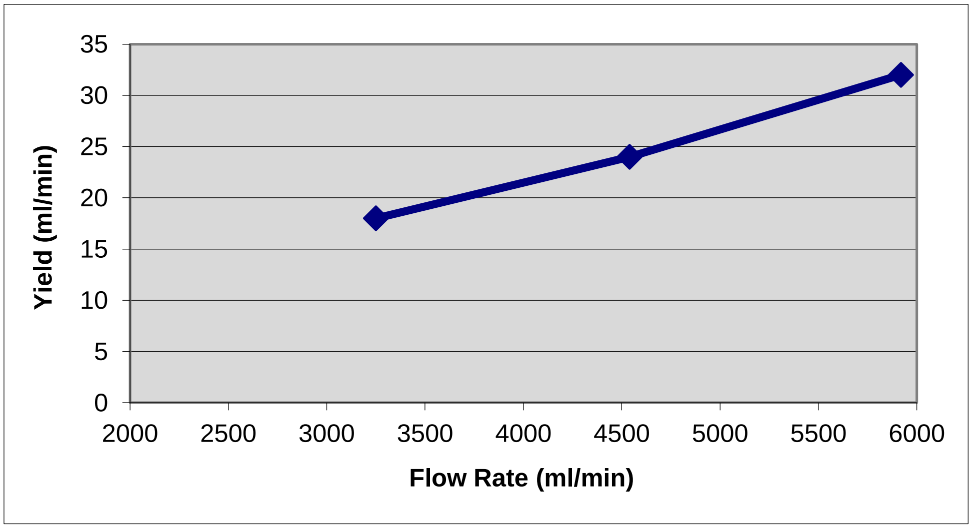

Fig.6. Effect of flow rate on yield with 33 g/l salinity

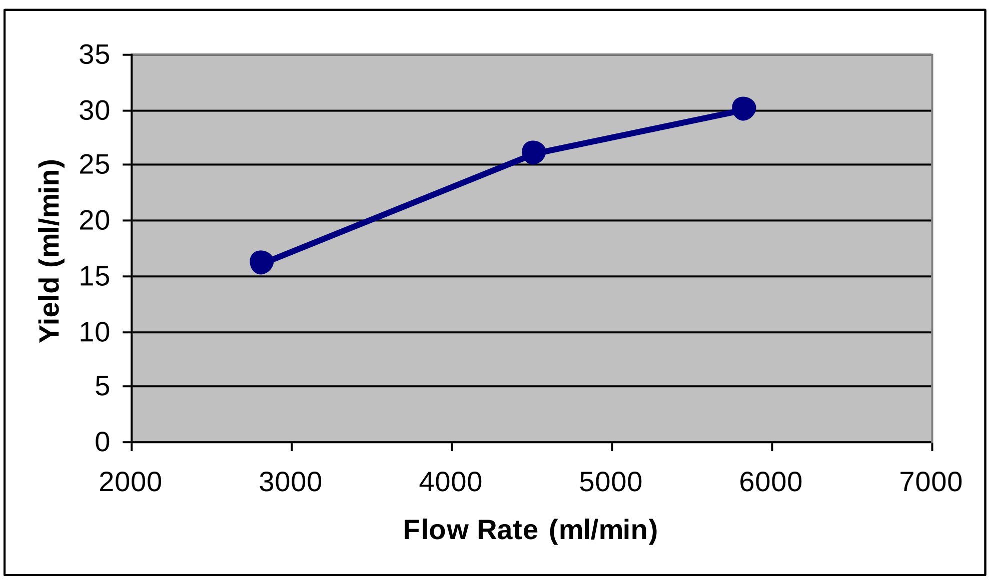

Fig.7. Effect of flow rate on yield with 36 g/l salinity

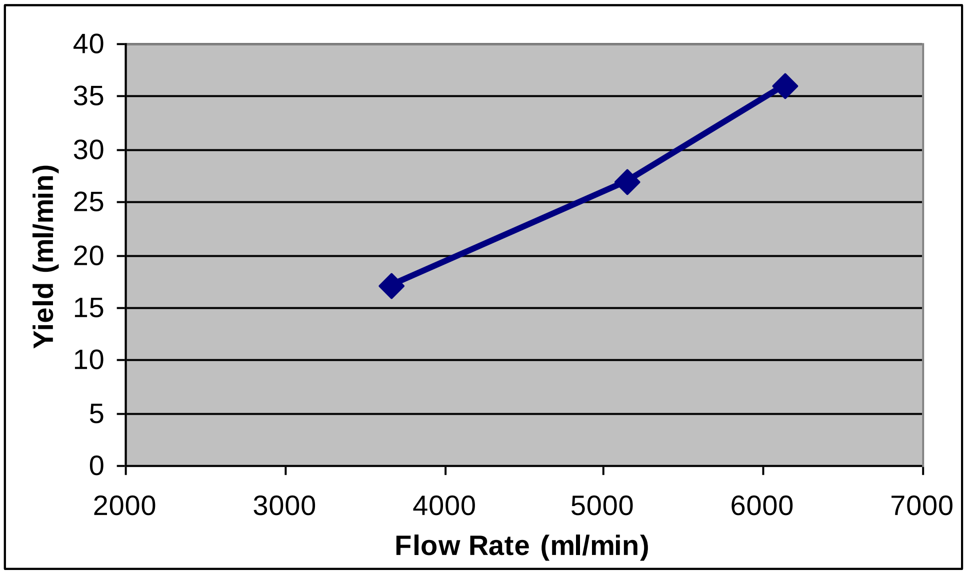

Fig.8. Effect of flow rate on yield with 41 g/l salinity

The maximum yield obtained in the system was 36 ml/min with a temperature of about 75^{o}C and a flow rate of 6000 ml/min.

4.3 Comparison of water quality of saline and desalinated water

The Electrical Conductivity, pH, dissolved oxygen of saline and desalinated water were found out and compared. Values are noted for different salt concentration and an average value is recorded.

Property	Saline water	Desalinated Water
Electrical Conductivity	14.49 mS	0.25 mS
pH	8.3	7.4
Dissolved Oxygen	6 ppm	3 ppm

Table 1. Quality comparison of saline and desalinated water

4.4 Comparison of water quality of desalinated water and drinking water under BIS

The electrical Conductivity, pH, dissolved oxygen of desalinated water and that of drinking water specified by BIS were compared.

Property	**Desalinated Water**	**Drinking Water (BIS)**
Electrical Conductivity	0.25 mS	0.2-0.3 mS
pH	7.4	6.5-8.5
Dissolved Oxygen	3 ppm	3-9 ppm

Table 2. Quality comparison of Desalinated and Drinking Water (BIS)

SUMMERY AND CONCLUSION

Chapter 5

SUMMARY AND CONCLUSION

The study was conducted to fabricate and test a small capacity solar desalination system using humidification-dehumidification system. The yield of desalinated water under different temperatures and flow rates of input saline water were noted. The experiment repeated using different concentrations of salinity. The pH, electrical conductivity, dissolved oxygen content of both saline and desalinated water was noted. The quality of desalinated water and that specified for drinking water by Bureau of India standards were compared.

The results obtained from the experiments conducted in the present study can be summarised as follows.

It has been observed that temperature have a great influence on the yield of desalinated water in the Humidification-dehumidification unit. A change of hot water temperature from 55°C to 75°C showed the yield to rise from 17 ml/min to 36 ml/min., which clearly indicate that a rise of temperature of saline water will increase the yield of the system. The maximum yield obtained was about 36 ml/min with a flow rate of 6000 ml/min.

Also a rise in flow rate of hot saline water to the unit produces more steam inside the chamber and thus increases the yield.

The comparison of quality of saline and desalinated water shown that the quality of desalinated water is improved and nearly matches with the BIS standard for drinking water

Overall production can be further improved by giving certain modifications and by considering certain factors. Modifications include

- Use of copper fins in the condenser tube to increase the heat transfer rate.
- Increasing the flow rate
- Increasing the temperature of salt water

REFERENCE

REFERENCES

Abd Elkader, M., 2003. Exprimental Investigation of Multi-Effect Humidification (MEH)- Dehumidification Solar Desalination System, Port-Said Engineering Research Journal, Volume 7, No. 2, September 2003, pp: 385-400.

Abdel-Salam, M.S., M.M. Hilal, A.F. El-Dib, and M.A. Abdel-Monem, 1993, “Experimental study of humidification-dehumidification desalination system,” *Energy Sources* 15 (3): 475–490.

Abu Arabi, M. and K. Reddy, 2003. Experimental Design and Computer Simulation of Multi-Effect Humidification (MEH)- Dehumidification Solar Desalination, Desalination, 156: 281-293.

Borouni K., et al. Water desalination by humidification and dehumidifiation of air: state of the art. Desalination 2001:137, pp. 167-176

Efat Chafic, 2003. A new Type Seawater Desalination Plants Using Solar Energy, Desalination, 156: 333-348

Farid, M. and H. Abd ElWahid, 1996. Desalination with a Humidification-Dehumidification, Cycle, Desalination, 106: 427-429.

Fath H.E.S. Solar distillation: a promising alternative for water provision with free energy, simple technology and clean environment. Desalination 1998:116, pp. 45-56

Goosen, M.F.A., S.S. Sablani, C. Paton, J. Perret, A. Al-Nuaimi, I. Haffar, H. Al-Hinai, and W.H. Shayya, 2003, “Solar energy desalination for arid coastal regions: Development of a humidification-dehumidification seawater greenhouse,” *Solar Energy* 75:413–419.

Sopian, M.A.Alghoul, “Evaluation of thermal efficiency of double pass solar collector with porous-nonporous media,” *Renewable Energy,* vol.34, 2009, pp. 640-64

Klausner, J.F., Mei, R., Li, Y., 2003. Innovative Fresh Water Production Process for Fossil Fuel Plants, U.S. DOE - Energy Information Administration annual report.

Holst, M. Engelhardt, M. Herve. 1998. " Solar Thermal Seawater Desalination Systems for Decentralised Use", The Six Arab International Solar Energy Conference, AISEC-6, 29March – 1 April , Mascat, Sultanate of Oman.

Muller, H., M. Engelhardet, A. Hauer and with W. Scholkopf, 1995. Solar thermal Seawater Desalination using a Multi Effect Humidification temperature System, Bayersches Zentrum fue Angeewandte Energieforschung e.V. (ZAE Bayern).

Narayan, G.P., Sharqawy, M.H., Summers, E.K., Lienhard V, J.H., Zubair, S.M. and Antar, M.A., 2009. The potential of solar-driven humidification-dehumidification desalination for small-scale decentralized water production, Renewable and Sustainable Energy Reviews, 14, No. 4, pp.1187-1201.

Nawayseh, N., M. Farid and S. Hallaj, 1999. Solar Desalination based on Humidification Process-I., Energy Conversion & Management. 40: 1423-1439.

Sandeep Parekh, M.M. Farid, J.R. Selman and Said Al-hallaj, 2004. Solar Desalination with a Solar Humidification-Dehumidification Technique, Desalination, 160: 167-186.

Shafic, E., 2003. A New Type of Seawater Desalination Plants Using Solar Energy, Desalination 156: 333-348.

Voropoulos, K., E. Mathioulakis and V. Belessiotis, 2003. Experimental Investigation of the Behavior of a Solar Still coupled with Hot Water Storage Tank, Desalination, 156: 315-322.

Xiong, R.H., S.C. Wang, L.X. Xie, Z. Wang, and P.L. Li, 2005, "Experimental investigation of a baffled shell and tube desalination column using the humidification-dehumidification process," *Desalination* 180 (1–3): 253–261.

Y.J.Dai,H.F.Zhang,“Experimental investigation of a solar desalination unit with humidification and dehumidification,” *Desalination,* vol.130, 2000, pp. 169-175.

FABRICATION AND TESTING OF SMALL CAPACITY SOLAR DESALINATION SYSTEM USING HUMIDIFICATION-DEHUMIDIFICATION METHOD

By
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ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree of

Bachelor of technology
in
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Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Land & Water Resources & Conservation Engineering

Kelappaji College of Agricultural Engineering & Technology

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2012

ABSTRACT

Water is an essential and unique natural resource that provides life support for plants and animals. The world's water consumption rate is doubling every 20 years, outpacing by two times the rate of population growth. It is projected that by the year 2025 water demand will exceed supply by 56%, due to persistent regional droughts, shifting of the population to urban coastal cities, and water needed for industrial growth. . Lack of fresh water reduces economic development and lowers living standards. Clearly, there is a critical worldwide need to better manage this increasingly valuable resource. Desalination is a water treatment process that converts brackish or saline water to fresh water by removing dissolved minerals from the water.

Solar desalination with humidification - dehumidification process seems to be an efficient means of utilizing solar energy for production of fresh water from saline water.

The study has been conducted in KCAET campus, Tavanur, Malappuram district. It is situated at 10°52'30" north latitude and 76° east longitude. Flat plate solar collector is used as the heat source. The study was conducted during 2011 in successive days to ensure the same climatic conditions for all tests.

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