FABRICATION, EXPERIMENTATION AND ANALYSIS OF AN ECONOMICALLY VIABLE BASIN TYPE SOLAR STILL

BY

D.KEZHIA SUNITHA

(Reg.No.03 MP 55)

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CERTIFICATE

This is to certify that the dissertation entitled "FABRICATION, EXPERIMENTATION AND ANALYSIS OF AN ECONOMICALLY VIABLE BASIN TYPE SOLAR STILL ". submitted to the Avinashilingam Institute for Home science and Higher Education for Women-Deemed University, Coimbatore, in partial fulfilment of the requirements for the award of the degree of MASTER OF PHILOSOPHY IN PHYSICS is a record of original research work done by D.KEZHIA SUNITHA during the period of her study in the Department of PHYSICS, Avinashilingam Institute for Home Science and Higher Education for Women, Deemed University, Coimbatore, under my supervision and guidance and the dissertation has not formed the basis for the award of any Degree / Diploma / Associateship/ Fellowship or other similar title to any candidate of any University and it represents entirely an independent work on the part of the candidate.

Rajammal
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Signature of the Head of the Department.

DECLARATION

I hereby declare that the dissertation entitled "FABRICATION, EXPERIMENTATION AND ANALYSIS OF AN ECONOMICALLY VIABLE BASIN TYPE SOLAR STILL" submitted to the Avinashilingam Institute for Home Science and Higher Education for Women - Deemed University, Coimbatore, in partial fulfilment of the requirements for the award of the degree of MASTER OF PHILOSOPHY IN PHYSICS is a record of original research work done by me under the supervision and guidance of Dr.(Tmt) K.RAJAMMA, M.Sc., Dip.Ed., M.Phil, Ph.D, Department of Physics and that it has not formed the basis for the award of any Degree \ Diploma \ Associateship\ Fellowship or other similar title of any candidate of any University.

D. Keziah Smitha
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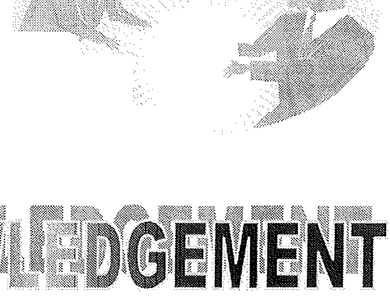
Signature of the candidate



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CONTENTS

III.THEORY

IV.DESIGN AND FABRICATION

V.EXPERIMENTS RESULTS AND DISCUSSION

(i) Experiments undertaken

(ii) Results and discussion

LIST OF TABLES

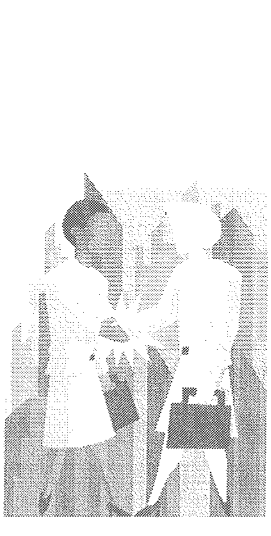
LIST OF FIGURES

LIST OF PLATES

LIST OF NOTATIONS:

α_g	=	Absorbtivity of glass
$\tau_g I(t)$	=	Transmitted radiation
τ_g	=	Transmittance of glass
α_w	=	Absorbtivity of water
α_b	=	Absorbtivity of basin
R_w	=	Portion of radiation reflected by water
d_w	=	Depth of water (m)
μ_j	=	Attenuation factor
m_w	=	Mass of water (kg)
A_s	=	Area of the still (m^2)
q_g	=	The external heat transfer from glass cover to outside atmosphere ($w/m^2\ ^oC$)
q_{rg}	=	The heat transfer due to radiation from glass to ambient air ($w/m^2\ ^oC$)
q_{cg}	=	The heat transfer due to convection from glass to ambient air ($w/m^2\ ^oC$)
h_{rg}	=	Radiative heat transfer coefficient from glass to ambient air ($w/m^2\ ^oC$)
h_{cg}	=	Convective heat transfer coefficient from glass to ambient air ($w/m^2\ ^oC$)
h_{1g}	=	Total heat transfer coefficient due to convection and radiation from glass cover to ambient air. ($w/m^2\ ^oC$)
$\in_g$	=	Emissivity of glass
σ	=	Stefan - Boltzmann constant (5.67 x 10-3 w/m^2)

T_g	=	Temperature of glass (^oC)
T_w	=	Temperature of water (^oC)
T_a	=	Ambient temperature (^oC)
T_b	=	Basin temperature(^oC)
U_b	=	Bottom loss coefficient ($w/m^2\ ^oC$)
h_w	=	Heat transfer coefficient from water to glass($w/m^2\ ^oC$)
h_b	=	Heat transfer coefficient from basin liner to atmosphere ($w/m^2\ ^oC$)
U_e	=	Side heat loss coefficient ($w/m^2\ ^oC$)
q_{rw}	=	The heat transfer due to radiation from water surface to glass cover ($w/m^2\ ^oC$)
q_{cw}	=	The heat transfer due to convection from water surface to glass cover ($w/m^2\ ^oC$)
h_{cw}	=	Heat transfer coefficient from water surface to glass cover ($w/m^2\ ^oC$)
h_{1w}	=	Total internal heat transfer coefficient due to convection, radiation and evaporation from water surface to glass cover
L_i	=	Thickness of insulation (m)
K_i	=	Thermal conductivity of insulation ($w/m\ ^oC$)
C	=	Specific heat capacity of water (4190 J/K)
U_t	=	Top loss coefficient ($w/m^2\ ^oC$)
U_l	=	Over all heat loss coefficient ($w/m^2\ ^oC$)



INTRODUCTION

I. INTRODUCTION

1.1 ENERGY: The changing scene.

The energy situation in the developing world is desperate. Because the developing countries are primarily dependant on fossil fuels, chiefly oil for their industrial growth, they have been hard hit by the oil price increases. Further in rural area where most of the population lives, there are limited supplies of increasingly expensive diesel fuel or kerosene. Noncommercial energy sources such as firewood, dung, and agricultural residues are generally used in rural areas, but under the pressure of growing population the forests are disappearing.

There should be an extensive use of recycled materials and a major shift to greater reliance on renewable energy sources. The introduction of true least cost planning methods and institution of proper consideration for externalities are gradually changing perspectives regarding the genuine economic value of environmentally benign, renewable energy sources. Such an approach is vital if we truly intend to move the world from its present over dependence on fossil fuels. These traditional sources currently supply over 85% of all globally traded primary energy. It is only with such a shift in attitude that we can safeguard the future of the planet for generations yet unborn.

In any developed scenario for the world as a whole we must consider the enormous variation in level of development across different countries. The problems of the developed world pale into insignificance when compared with those of the developing nations. Providing an adequate energy supply to major new populations will become a critical problem. Recent forecasts indicate that 90% of the population is likely to occur in developing nations. It is therefore reasonable to expect, based on current extensive international studies, that the energy growth rate in the developing nations is likely to run at 5% to 6% whilst in the world as a whole it would be stabilizing at 2.5%. Excessive dependence on imported oil in the developing nations can also pose a crippling debt burden and adversely dominate the balance of trade ratios for these countries.

1.2 RENEWABLES FOR SUSTAINABLE ENERGY DEVELOPMENT

Caught unprepared by the OPEC (Oil and Petroleum Exporting Countries) inspired oil crises in 1973, the leading energy consuming nations, hitherto dependent on coal and oil began exploring renewable energy options. Recently for the very first time a major international company **shell** produced forecast which included a 50% contribution by renewables by the year 2050.In the past any such moves had always come from green movements or from Governments in socially aware countries. This seems to be realistic and encouraging if somewhat daunting prospect for the renewable energy industry who will have to cope with annual growth rates of 25% or more to cater to this demand. In Europe and European union, many of its individual members are already planning forward to supply 20 to 30% of their energy from the renewables by the decade 2020-2030.

Major reinforcement of the useful long-term role of renewables has come from the massive environmental degradation and atmospheric pollution, now well catalogued caused by escalation of fossil fuel usage in both stationary and mobile power plant in rapidly developing and industrializing countries.

Estimates for future demand of electrical energy are, inaccurate and subject to major change but China is predicting a shortfall in excess of 86000 MW and India in excess of 28000 MW by the year 2000. Indonesia and Malaysia have had electrical growth running at the rate of 12 to 15% per annum, which is approximately twice the economic annual growth rate of these nations. The renewable energy sector is seen as the mainstay of the India's future power requirements. After initial success in deriving energy from water, sun, wind and biomass ,India is poised for a great leap in making these the energy sources of the future.

Because of India's vast territory, varied geography and different agro climatic conditions, its renewable energy potential is high whilst these growth rates may slow temporarily due to the Asian financial crises this is likely to be only a short-term outcome. The increased use of renewables is therefore seen as an essential prerequisite to sustainable energy development. The future of solar energy is bright. In the last 20 years, the cost of conventional power has been going up, and the cost of solar energy has been coming down.

Apart from solar energy, other important areas of alternative energy development are those of wind power and biogas. Biogas plants have become increasingly prevalent. The present capacity of biomass-based power generation totals 358 MW and 42.8 MW biomass gasifier power has been installed and regarding wind power, India keeps fifth place after Germany, the US, Denmark and the UK with a total wind power generation of 1507 MW (MNES) Ministry of Non conventional Energy Sources, 2002.

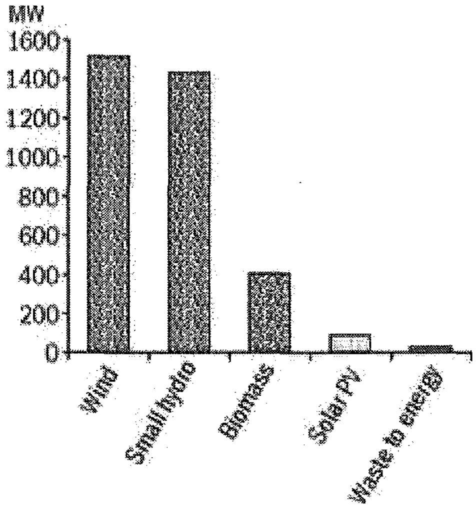


Fig.1. : Megawatts of alternate energy produced through 1999

1.3 RENEWABLES AND ENERGY EFFICIENCY:

There is no doubt that the efficient and proper use of energy is an essential and fundamental prerequisite to the introduction of any new renewable technology into the market place. By implementing effective energy demand management it is possible to substantially reduce the size of the new plant required and makes the new technology more cost effective.

In general the developing countries are less efficient than their industrialized counterparts and their energy use / GDP ratios can be up to 60% more than those normally present in developed economies.India's energy consumption is increasing and it is likely to grow for quite some time as efforts to provide better living standards to her population are made. India's energy consumption more than doubled from 91 million tonnes of oil equivalent (mtoe) in 1980-81 to 189 mtoe in 1991, reaching 219 mtoe in 1994-95. Most of the increased energy consumption has been contributed by coal and oil, the fuels that are also associated with emissions of greenhouse (GHG) gases. As a signatory to the Framework Convention on Climate Change that was adopted at Rio by the international community, India needs to pursue environmentally sound energy development.

Since fossil fuel use contributes the largest share of GHG emissions in the atmosphere, efficient production and use of energy can reduce emissions and put India on a low energy intensive growth path, and thus benefit the environment most in the long term. Equally of concern are the health effects associated with fossil fuel use, and soil and water pollution due to coal based power plants. Thus, one of the best ways to improve quality of life and reduce environmental damage is also by increasing energy efficiency.

1.4 POTENTIAL OF RENEWABLE ENERGY IN INDIA

India is generously endowed with renewable energy sources viz solar energy, wind energy, biomass and small hydro widely distributed across the country, and can be utilized through commercially viable technologies to generate power. Renewable energy technologies fit well into the system that gives due recognition to decentralization and local participation. The potential of various renewable energy technologies in India have been estimated in table 1.

TABLE 1: THE POTENTIAL OF RENEWABLE ENERGY IN INDIA

SNO	SECTOR	POTENTIAL
1.	BIOGAS PLANTS	12 MILLIONS
2.	IMPROVED WOOD STOVES	120 MILLIONS
3.	WIND	45,000MW
4.	SMALL HYDRO	15,000 MW
5.	BIOMASS POWER/CO-GENERATION	19,500 MW
6.	SOLAR PV	20MW/ Sq. Km
7.	WASTE TO ENERGY	1700 Mwe
8.	SOLAR WATER HEATING (COLLECTOR AREA)	140 MILLION

Source: MNES

1.5 SOLAR ENERGY:

1.5 .1HISTORY OF SOLAR ENERGY :

A common form of energy utilized throughout the world is solar energy. Solar energy is radiant energy that is conveyed from the sun to the earth through electromagnetic waves. For thousands of years this form of energy has been used by humans to keep warm and to assist with various activities. "Serious studies of the sun and its potential began in the seventeenth century-when Galileo and Lavoisier utilized the sun in their researches. By 1700 diamonds had been melted and by the early 1800s heat engines were operating with energy supplied by the sun. In the early twentieth century solar energy was used to power distillation plants in Chile and irrigation pumps in Egypt."[Krieder et al, 1999] By the end of the 1930's, solar technology was used to heat the first building with solar water heaters at the Massachusetts Institute of Technology. The conclusions drawn from this project and solar heating experiments in subsequent years, aided in the development of solar hot water systems. Today, approximately one million residential homes (one percent of all residences) and two hundred thousand commercial buildings use solar power to heat domestic water in the United

States.[Davidson et al, 1999] Through the analysis of different solar hot water systems and their components, it can be noted that these systems are energy efficient and cost-effective.

Solar energy research, development, and commercialization in this century have been driven by a variety of different forces. First was the vision and enthusiasm of solar pioneers like Abbot, Robinson, Daniels, and Yellot, to name only a few, who saw in this unlimited natural resource a secular clean energy resource for the post fossil fuel era. Some of these eminent scholars, and others like them, helped to bring together the international solar scientists and engineers in 1955 at Phoenix, Arizona. The gathering led to the formation of the solar energy society.

The second wave of interest broke in the mid-seventies with the advent of the Middle East oil cartel known as OPEC and the overnight quadrupling of the price of crude oil in 1973 and 1979. Prices rose to nearly US$40 per barrel from a base price of US$13 per barrel. Although the international economy adapted rapidly to these price increases, the seeds of doubt have been sown. The possibilities of price instability and supply uncertainty led several nations to implement major renewable energy programs, focused on energy supply security and national independence.

The third and possibly the final wave of this century is the growing emphasis now being placed on minimizing environmental degradation in all its diverse forms; protecting the vital land, water and air resources whilst sustaining economic productivity and attempting to provide useful employment for the workforce. Access to uncontaminated land, to clean water, and to fresh air used to be considered a natural right of citizens in many nations of the world.(Charters W.W.S,1994)

1.6 SOLAR ENERGY AS AN ALTERNATE ENERGY SOURCE:

Dr. M. N. Nahar, principal scientist of the Division of Agriculture and Energy at the Central Arid Zone Research Institute (CAZRI) said

“At the present rate of energy consumption, the reserve of fossil fuels of the entire world can be exhausted in 50 to 100 years,” “There is an urgent need to harness solar energy and other alternative energy sources.”

Unlike natural gas, coal, or nuclear power, solar power requires no fuel, works without polluting the air or leaving behind dangerous radioactive waste, and is extremely plentiful. Researchers estimate that the sun produces enough energy in a single second to meet the needs of all humanity for 2000 years. “The surface of the Earth receives an amount of solar energy equivalent to roughly 10,000 times the world energy demand,” wrote Erik Lysen in the January 2003 issue of Renewable Energy World magazine.

1.7 PROSPECTS OF SOLAR ENERGY

With the fossil fuels inching their way out off the existence within the next century, there is a great need for alternate and renewable energy sources. The sun is an inexhaustible source of energy to mankind. India is ideally located for utilization of the radiant energy of the sun. The country receives solar radiation amounting to over 5 x 1015 kWh per annum with the daily average incident energy varying between 4 and 7 kWh per sq.m. depending on the location.

As forests and fossil fuels diminish, solar energy emerges as one of the most promising sources of alternative energy. Apart from the tiny lights from twinkling stars, all the energy we have on earth ultimately has come from the sun. Even the wood and coal we burn to give us heat was made originally by organic processes that depended on light and heat from the sun. The atmosphere of the earth absorbs some of the energy and the more air the sun’s rays have to travel through to get to the earth’s surface, the weaker they become. When the sun is high in summer and travels through less air it appears stronger and heats more, while in winter the sun is low and much of the energy is absorbed.

Solar energy in its raw form may be pollution-free, but manufacturing the devices that get the energy out of light and heat requires metal and other material, requiring mines and smelters, therein causing pollution. Maybe the most exciting thing about solar energy today is not only that the costs continue to drop and efficiencies continue to rise, but also that clean solar energy is arriving at last. New technologies allow new methods of manufacturing, which pollute much less, and often run on solar energy.

Solar heating and solar electric systems can now generate thermal and electric energy over their service life upto 100 times the energy input during their manufacture. This ratio; the energy it will produce in its lifetime, compared to the amount of energy input to manufacture and maintain an energy system, has doubled in the last 20 years for most solar technologies. The ratio of energy out vs. energy in for solar systems has become so favorable that the economic and ecological viability of solar power is now beyond question.

One reason solar energy still cannot compete financially vs. conventional energy is because the value of future energy output from a photovoltaic system is discounted when calculating, for example, an internal rate of return. These economic models that put a time-value on money, making long-term receipts not worth as much as near-term receipts cannot necessarily be applied to energy. Traditional models of economic analysis for an energy system lasting 50 years treat the free energy in years 11 through 50 as nearly worthless. The underlying assumption when discounting returns beyond 10 years is that BTUs are as fungible as currencies; something that is arguable but not certain. If a society as a whole desires energy independence, a solar energy system's return on investment in year 50 is no less valuable than the return on investment in year one.

Solar radiant energy can be used through thermal as well as photovoltaic routes. Solar energy utilization in India has been growing steadily over the last two decades. A wide variety of technologies have been developed. The efforts made for research & development, demonstration and large-scale promotion during the eighties and nineties have resulted in perfecting many of these technologies. As a result, some of these technologies have reached maturity and a user-friendly status. The technologies are suitable for decentralized applications and have no negative impact on environment. Both solar thermal and photovoltaic applications have a large potential.

1.8 SOLAR THERMAL ENERGY PROGRAMME:

Several solar thermal technologies have been developed. These include solar water heaters, solar cookers, solar air heaters, solar distillation systems etc. A number of these technologies have already percolated widely in both the developed and developing regions of the world. An analysis shows that the primary reason for many of the countries adopting these technologies is not so much the shortage of conventional energy but the recognized multidimensional advantages of these technologies, such as energy security, decentralized energy generation and environmental benefits. In India, there is an additional factor in favour of solar thermal technologies in that these help overcome energy shortage.

1.9.SOLAR PHOTOVOLTAICS:

PV, is the technology that converts light directly into electricity.

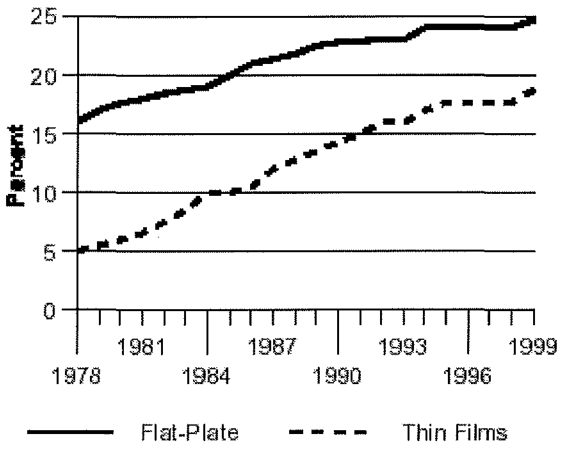


Fig.2. : **Laboratory PV Efficiency Progress**

A photovoltaic panel consists of several connected 0.6-V dc PV cells, which are made out of a semiconducting material, generally mono- or multi-crystalline silicon. The thin layer of silicon is sandwiched between two metallic electrodes, and the cells are usually encapsulated behind glass to make them weatherproof.

Multiple PV panels can be then connected to form an array, capable of providing sufficient power for everything from common electrical applications like single-household electricity to Olympic swimming pools, apartment or industrial buildings. The average lifetime of a PV system is about 20 years, and it can be used in combination with conventional power or alone. The only problem is that, although in some cases it is becoming competitive, solar power is generally still slightly more expensive than tapping into conventional electricity. The process of constructing PV cells is somewhat complicated and delicate, and there is also a considerable loss of materials. Multi-crystalline silicon wafers are obtained from ingots grown by casting liquid silicon in a large container followed by controlled cooling, a technique less complicated than the pulling of single-crystalline rods. Then, in sawing the thin layer of crystalline silicon, about 20% of the material is lost as "sawdust".

Efficiency is also not high, although it has been progressively increasing. A solar cell made of multi-crystalline silicon, which accounts for most of the PV panels currently in use and production, converts sunlight to electricity at about 13.5% efficiency. Mono-crystalline silicon, which is more difficult to produce, can achieve about 15%; in both cases, clouds and night time also rob the cell of a further 65%.

One way to reduce PV costs is to use materials other than silicon as semiconductors, like amorphous silicon and cadmium telluride (CdTe). Although government grants are keeping the fire going, the technology is moving slowly, and thin-film PV panels are hard to mass-produce cost-effectively because of the difficulty of coating large areas of glass. "It is my opinion that crystalline-silicon technologies will dominate for at least the next 10 years," said Jeffrey Mazer of the U.S. Department of Energy (DOE) Office of Solar Energy Technologies in Washington.

In terms of overall installed PV capacity, India comes fourth after Japan, the US and Germany (Indian Ministry of Non-conventional Energy Sources, 2002). "India is the only country which has a separate ministry for alternative energy," Government support and subsidies have been a major influence in the progress of India.

1.10 SOLAR THERMAL ENERGY IN INDIA:

Soaked in abundant sunshine, India offers an excellent opportunity for converting the solar energy to thermal energy for meeting the requirements of heat in different temperature ranges. It is also possible to convert this thermal energy into mechanical or electrical energy.

Arid regions receive plentiful solar radiation. In computed global solar radiation of arid stations in the Indian states of Rajasthan, Gujarat and Haryana, it was found that Jaisalmer, Rajasthan, receives the maximum radiation at 6.27 kWh/m^2 per day; the average daily duration of bright sunshine in Jodhpur, Rajasthan is 8.9 hour. Thermal solar energy can be used for water heating, cooking, drying, water distillation, refrigeration, and space heating and cooling. One of the most crucial of these uses is cooking, as half the total energy consumed in developing countries is used in the domestic cooking sector; there are currently over 500,000 solar cookers in use in India, including the world's largest solar cooking venue in Tirupati, which provides food for over 15,000 people each day.

Solar dryers, for dehydrating vegetables, and solar water heaters are also becoming popular. Conventional water heaters require copper piping . India has developed models using gerberized steel.These water heaters are currently used in hotels and hospitals, providing up to 100,000 litres of water per day; the cost of these is also decreasing steadily.

Another important area of development is that of solar stills, by which the acute drought and shortage of potable water, currently the cause of many physical disorders, can be alleviated.In the latest models of solar stills, presuming the potable limit to be 1500 PPM TDS, as much as 50 litres per day of potable water can be made available from raw water with salinity of 5000 PPM TDS by installing a solar still of capacity 35 litre/day. If the per person requirement for drinking and cooking is 5 litres/day, this is enough for a family of 10.

Income can also be derived from solar stills. Considering the cost of the still, interest and maintenance, solar distilled water costs Rs. 0.98/litre, and the current market rate of distilled water is Rs. 3/litre. A solar still for the production of rose water has also been developed, which can be quite profitable.

1.11.FUTURE ROLES OF SOLAR ENERGY:

- Small-medium and large scale decentralized power generation systems based on solar thermal and photovoltaic supply.
- A range of industrial process heat applications in particular the food processing industries.
- Vital food preservation through drying and refrigeration to minimize post harvest and post processing losses.
- Improved public health services through water purification and supply, water -pumping for drinking, irrigation, and the provision of vaccine cold chain.
- Accelerated production of solar fuels and chemical storage materials such as ethanol, methanol, methane and ultimately hydrogen.(Charters W.W.S,1994)

1.12 POTENTIAL RISKS IN USING BRACKISH WATER:

There are many parts of the world like arid and semi-arid areas and coastal areas where plenty of underground water is available, but this is highly saline (2000 ppm to 35000 ppm) and therefore unfit for human consumption. The ocean covers some 70.8 percent of earth's surface amounting to about 1350 million cubic kilolitres of saline water containing about 30,000 ppm impurities out of which about 28,000 is common salt- sodium chloride- which is also an integral part of our body. The maximum level of the acceptance of salt in fresh water for human consumption is only 500 ppm. Howeever there are communities in the world, which are taking water up to 1500 ppm without visible ill effect. For agricultural purposes a salt content of 1000 ppm is generally thought to be the upper limit but there are many crops grow even in high salinity water. The acceptance of impurities (salinity) level in water for industrial operation varies to a greater extent. For example saline water as such can be used for many cooling operations but frequent cleaning or exchanges is required. In some industries like in modern steam power generation, very pure water with a distilled salt of only 10 ppm can be used. Water standards have been laid down in many countries for drinking , agriculture and industries.

The pure water can be drunk without any problems under normal circumstances. During diets or periods of starvation it should not be the only drink taken due to a possible lack of minerals and salt, which could effect a disturbance of the osmotic cell pressure. Once these abnormal conditions occur, the essential minerals such as calcium and potassium must be added either directly into the pure water or, better, together with other drinks and food. Some US-American studies say that it is possible to drink a lot of demineralized water because the drinking water in civilized countries has too much salt and minerals. The Inuit tribes are perfectly proving that one can live without problems by drinking just rain and snow water. Although potassium is essential it is also creating allergies if one takes too much of it. Calcium rests in the veins and arteries and can be a major reason for heart attacks or problems with bones and kidneys. In the USA and Switzerland fluorides are added to drinking water to avoid medical treatment costs against dental cavities, but the pollution of the environment with this poisonous halogen has not been taken into consideration.

To get "normal" water one can mix 1 ton of condensed water with approximately 3 to 4 gallons of filtered ocean water. The product will be similar to spring water except that strontium and bromide salt can be found additionally at non-toxic amounts of less than 1 mg/litre. It is, however, not necessary to mix the condensate with crude water since the essential minerals and salts are normally taken with the food. Besides, ocean water contains a large amount of bacteria and germs.

1.13 METHODS OF CONVERSION OF THE BRACKISH WATER:

There are many methods of converting brackish water into potable water. Some processes, which are commercially employed, are:

(i)Desalination:

In this method, the brackish or saline water is evaporated using thermal energy, and the resulting steam is collected and condensed as final product.

(ii) Vapour compression:

In this process of distillation water vapour from boiling water is compressed adiabatically and vapour gets superheated. The superheated vapour is first cooled to saturation temperature and then condensed at constant pressure. This vapour is drived by mechanical energy.

(iii) Reverse Osmosis:

In this process of distillation saline water is pushed at high pressure through special membranes allowing water molecules selectively to pass and not the dissolved salts.

(iv) Electro dialysis:

In this method water is passed through a pair of special membranes perpendicular to which there is an electric field. Water does not pass through the membranes while dissolved salts pass selectively.

(v)Distillation:

Distillation process is considered to be one of the simplest and widely adopted technique for converting seawater into fresh water. More than 90 percent of the worldwide installed seawater desalination capacity is based on distillation process. One of the main advantages of the distillation process is that it requires heat only upto 120^0C which can be supplied from solar energy or other cheap fuels, while in reverse osmosis, vapour compression and electro dialysis processes, some mechanical or electrical energy can be used. Distillation devices are divided into four main types of sub processes (a) single effect distillation (b) multiple effect distillation(c) vapour compression distillation (i) single stage (ii) multiple stage and multiple effect multiple stage flash distillation and (d) solar distillation.

1.14 SOLAR DISTILLATION:

Solar energy is an abundant and everlasting one available on site and pollution free energy. However the cost of its collection and utilization becomes high because it is diffuse, of low intensity and intermittent and therefore, requires some kind of thermal energy storage. But for applications like distillation of brackish water, the intermittent nature of solar energy will not limit its use and distilled water will be produced, as and when solar energy is available. Because of the simplicity of apparatus design, the requirement of fresh water and free availability of thermal energy, work in the field of solar distillation is in progress for more than 100 years.

1.15 NEED FOR SOLAR WATER DESALINATION :

Fresh water is a scant 2.5% of the total Global water supply and 69% of that is represented by permanent snow and glaciers. The remaining 97.5% is salt water.

Since 1940, the amount of fresh water used by humanity has roughly quadrupled as world population has doubled. Given the finite nature of the earth's fresh water resources, such a quadrupling of world water use probably cannot be sustained again. In many of the regions where world population is growing most rapidly, the needed water is simply unavailable.

It is obvious that desalination of seawater represents the best source of fresh water, to sustain future requirements. Unfortunately most current methods of desalination use energy sources that produce environmental problems. Upon investigating vast amounts of information of current technologies for converting non-potable water into drinkable water, distillation appears to be the most fool-proof in terms of reliably producing contaminant-free water.

Distillation by heating water to the boiling point is expensive, is not energy efficient, has negative environmental issues, has been reported to have poor taste and is believed to have health risk. But solar desalination offers very low operating and maintenance costs, has excellent taste, no health risks and presents no major negative environmental impact.

The only apparent environmental impact could be the increase of salt content in a localized area if the runoff brine from the stills is spilled back into the ocean. This may be negated by building salt refineries that refine the brine into pure salt for human and animal consumption.

1.16 SOLAR WATER DISTILLATION - a feasible solution!

The principles of solar distillation have been around for centuries. In the fourth century B.C., Aristotle suggested a method of evaporating seawater to produce potable water. However, the first solar still was not produced until 1874, when J. Harding and C. Wilson built a still in Chile to provide fresh water to a nitrate mining community. This 4700 m^2 still produced 24000 litres of water per day. Currently there are large still installations in Australia, Greece, Spain and Tunisia, and on Petit St. Vincent Island in the Caribbean. Smaller stills are commonly used in other countries. Practically any seacoast and many desert areas can be made inhabitable by using sunshine to pump and purify water. Solar energy does the pumping , purification, and controls seawater feed to the stills.

Fresh water is an essential commodity both for developed and developing countries. Many areas depend heavily on water produced by desalination plants for their water supply. Large desalination plants are usually coupled with electric power generating plants .In remote towns, villages and islands, potable water is supplied by trucks, or is transported from the nearest supply source. The utilization of solar radiation as an energy source for desalination plants may offer a valid alternative for supplying potable water.

Solar desalination of brackish water is a practical alternative, which offers life to those regions where the lack of fresh water hinders development. It has been shown that the solar distillation still remains the most favorable; process for the supply of water to small communities where there is considerable solar radiation.

Today, four out of every 10 people worldwide live in areas experiencing water scarcity. By 2025, as much as two thirds of the world's population an estimated 5.5 billion people - may be living in countries that face water shortage. To address this crucial issue, the United Nations General Assembly has declared 2003 the International Year of Freshwater. "Lack of access to water for drinking, hygiene and food security inflicts enormous hardship on more than a billion members of the human family. Access to fresh, clean water has been "a source of tensions and fierce competition between nations that could become even worse if present trends continue," said UN Secretary-General Kofi Annan.Local initiatives involving affordable technologies in the areas of potable water are the key to providing agricultural resources in arid regions globally, as these sustainable agricultural resources rely on potable water to be sustainable.

The availability of safe drinking water and usable water for sustainable agriculture is becoming an increasingly important issue. Expanding populations, enhanced living standards and decreased availability of fresh water has catalyzed much research in the area of obtaining potable water. Since a large majority of the earth's water supply is salt water, desalination methods such as reverse osmosis and electrodialysis have been developed. In addition to the practical limitation of small-scale usage, these methods are energy demanding, and are generally coupled to fossil-fuel sources. Therefore a very feasible alternative is **solar powered desalination.**

Adequate quality and reliability of drinking water supply is a fundamental need. Without potable or fresh water (less than 500 ppm of salt) human life is not possible. Industries and agriculture also need fresh water without which they cannot survive or thrive. Water is therefore, the key to man's prosperity; it is intimately associated with the evolution of civilization and hence it is aptly said that water is everybody's business. Fresh water that was obtained from rivers, lakes and ponds in plenty is becoming scarce because of industrialization and population explosion. Moreover 'these potable water sources are being polluted constantly by industrial wastes and large amounts of sewage. It is said that presently more than 2000 million people are not getting potable water, which leads to many diseases and inhibits development. Looking to the scarcity and large demand of fresh water, the United Nations on November 10, 1980 declared the years 1981-1990, the decade of water supply and sanitation. Many organizations like UNDP, WHO, and the World Bank are now actively involved throughout the world in promoting projects concerning the supply of fresh water for drinking purposes.

In the past also, the shortage of fresh water existed but it was confined to regions where only brackish water is available and arid and semi-arid regions. But now due to the industrialisation and population rise, the shortage has become wide spread. In earlier days when the population was small and people lived near the water sources, used to be 15-25. Liters per person per day, has increased to 75-100 liters per person per day in the twentieth century. Because of large demand of fresh water to big industries and agriculture (increased irrigation of land for growing more food), thc per capita consumption has been increasing rapidly.

1.17 OBJECTIVES OF THE STUDY:

Brackish water unsuitable for human consumption (TDS > 500 mg/L), is readily available from different sources in many of the remote, arid areas of the world. These regions are normally characterised by an abundance of sunshine. This solar radiation is 'free' and can potentially be utilised to distill saline water, thus providing fresh water (TDS < 10 mg/L) for household use. The construction and maintenance cost of such solar distillation units (stills) have in the past been too high for commercial application. With the emergence of new plastic materials, however, new opportunities arise whereby environmentally durable, inexpensive solar stills can be built. Further, a better understanding of the distillation process and the factors that influence it can lead to improvements in efficiency of such stills, also resulting in cheaper distilled water. The aims of this project are therefore to explore developing economically viable solar distillation units for community use by making use of locally available technology and improving still efficiency by enhancing the distillation process. (http://www.sun.ac.za/polymer/solar.htm)

1.18 KEY FEATURES OF A SOLAR STILL:

- Technology available is tested and proven
- Potential applications are worldwide where there is a demand for water and power
- Suited to remote locations
- Economically viable with even low capacity plants of 5,000-10,000 m^3/day
- Produces high quality water for potable and industrial purposes
- Cost effective co-generation of power and steam generation

- Reduces electricity consumption
- Operates 24 hours a day, seven days a week.
- Uses solar energy during the day,and sensible heat storage at night.

In principle, solar energy can be used to separate pure water from most of the natural contaminants, such as dissolved solids (salts) and particles (dirt and algae). Solar distillation is most economically effective when sunlight is allowed to pass through a transparent cover and into a black evaporating pan with little or no concentration of the sun's rays.

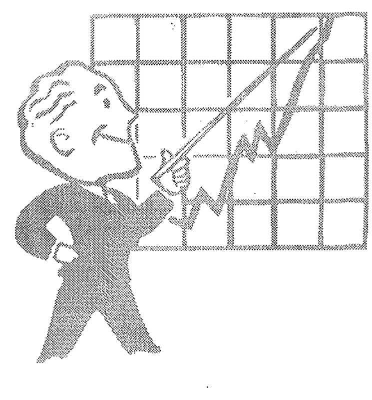
1.19 IMPROVEMENTS IN SOLAR STILL DESIGNS:

Solar stills have got major advantages over other conventional Distillation / water purification /de-mineralisation system as follows:

- Can purify highly saline water (even seawater)
- Produces pure water
- No prime movers required
- No conventional energy required
- No skilled operator required
- Local manufacturing/repairing
- Low investment

1.20 FACTORS TO BE CONSIDERED IN CONSTRUCTING A SOLAR STILL:

- Latitude of installation site.
- Annual sunny days - history.
- Peak annual wind velocity.
- Lowest annual temperature.
- Hurricane history.
- Annual rainfall, hail and snowfall.



REVIEW OF LITERATURE

II . REVIEW OF LITERATURE

2.1 SOLAR STILL BACKGROUND

The population of the world is increasing, and fresh water is the primary requirement for life in the universe. However, while water covers about three-quarters of the earth's surface, only 3% is fresh water from various sources, and not all of this limited quantity is suitable for drinking. Thus, water treatment is usually needed, and desalination is the most efficient method for providing fresh water from brackish and/or seawater. However, desalination is energy intensive, and because of scarce availability of wood and oil and high capital and operational cost; solar desalination based on renewable, safe, free and clean solar energy is the promise for a cost-effective solution. Fortunately, in other arid regions, areas of solar desalination have been practiced for many generations. Solar distillation is a tried and true technology. The first known use of stills dates back to 1551 when Arab alchemists used it. Other scientists and naturalists used stills over the coming centuries including Della Porta (1589), Lavoisier (1862), and Mauchot (1869). Mauchot stated that an Arab alchemist had used polished Damascus mirrors for solar distillation. The great French chemist Lavoisier (1862) used large glass lenses mounted on collaborating supporting-structures to concentrate solar energy on the contents of distillation flasks. Mauchot described the use of silver or aluminum-coated glass reflectors to concentrate solar energy for distillation. In the last century the use of solar concentrators in solar distillation was reported by Pasteur, who used a concentrator to focus solar rays onto copper boiler containing water. The steam generated from the boiler was piped to a conventional water-cooled condenser in which distilled water was accumulated.

Renewal of interest in solar distillation occurred soon after the First World War. Many varieties of new devices and stills such as the basin-type, roof-type, tilted-wick type, inclined-tray, inflated stills, and flash-type systems had been developed and studied for solar desalination systems, but a very small number of the systems were put into practice because of the low efficiency and small amount of fresh water production.

2.2. IMPROVEMENTS IN SOLAR STILL DESIGNS:

The first "conventional" solar still plant was built in 1872 by the Swedish engineer Charles Wilson in the mining community of Las Salinas in northern Chile (Region II). This still was a large basin-type still used for supplying fresh water using brackish feed water to a nitrate mining community. The plant used wooden bays, which had blackened bottoms using logwood dye and alum. The total area of the distillation plant was 4,700 square meters. On a typical summer day this plant produced 4.9 kg of distilled water per square meter of still surface, or more than 23,000 liters per day. Several glass covered stills were constructed in 1952 under the guidance of Maria Telkes (Howe.E.D,1990). This first still plant was in operation for 40 years. The summary of research on solar distillation was given by Howe and Tleimat, (1974), Lof (1955)and Howe (1980).The single effect basin type solar still has been for long time the cheapest way of producing drinking water from sea water using solar equipment. (Howe and Tiwari, 1977) .A project on "Absorption of solar radiations by water in presence of dyes in solar stills" sponsored by Tata Energy research Institute, Bombay was initiated by G.C. Pandey in 1979.

It has been observed that the performance of a conventional solar still is maximum for minimum water depth. In order to achieve this condition, a multiwick solar still was developed in 1979 by Sodha etal. Mousa et al (1980) described a double exposure still in which the water basin evaporator was exposed to the solar radiation at both its upper and lower surfaces. A 10,000 litre solar multistage flash desalination system was tested at Kuwait Institute of scientific Research in 1984. A refrigerator heat pump desalination scheme (RHPDS)was proposed by Reali(1984).

This scheme exploited the difference in vapour pressure between fluids of different salinities and temperatures.

Tamini (1987) confirmed that the installation of the reflectors on the inside walls of a basin type solar still enhances the still production of distilled water. The single and double multiwick fiber re-inforced plastic solar stills were designed and monitored by Yadav and Tiwari (1987). Assouad and Lavan (1988) presented a solar desalination scheme with latent heat recovery. The scheme consisted of a dehumidifier, a solar still, a condenser and a pond. Hegazy in 1987 used two flat booster reflectors in order to increase the quantity of solar radiation incident into the evaporator. The effect of such reflectors on still performance was studied. A solar collector consisting of thin film, inclined, free flow , flat plate has been studied both experimentally and theoretically by Leeson and Bootebila(1987). As their objective was distillation applications, a condensing system was introduced in their experimental rig. Tiwari and Kumar (1988) presented a detailed analysis of a tubular solar still for predicting its nocturnal productivity. An analytical model of an inverted multiwick still was suggested by Tiwari et al (1984).

Solar distillation in a single basin was studied theoretically under the climatic conditions of Alexandria, Egypt in 1991.Solar distillation using a wick type solar still was investigated theoretically (Mahidi, 1992) and experimentally (Mahidi, 1990). Aly (1990) analyzed a central fuel fired, solar assisted dual power plant. In that scheme, solar energy collected at moderate temperatures was used to supplement the fuel in the conventional plant. A tilted flat plate wick-type solar still was designed constructed and a V- trough concentrator solar still combination was investigated in the Mechanical energy department of Brunel University, U.K.in 1992.Systems may be classified into various categories as depicted in fig.3.

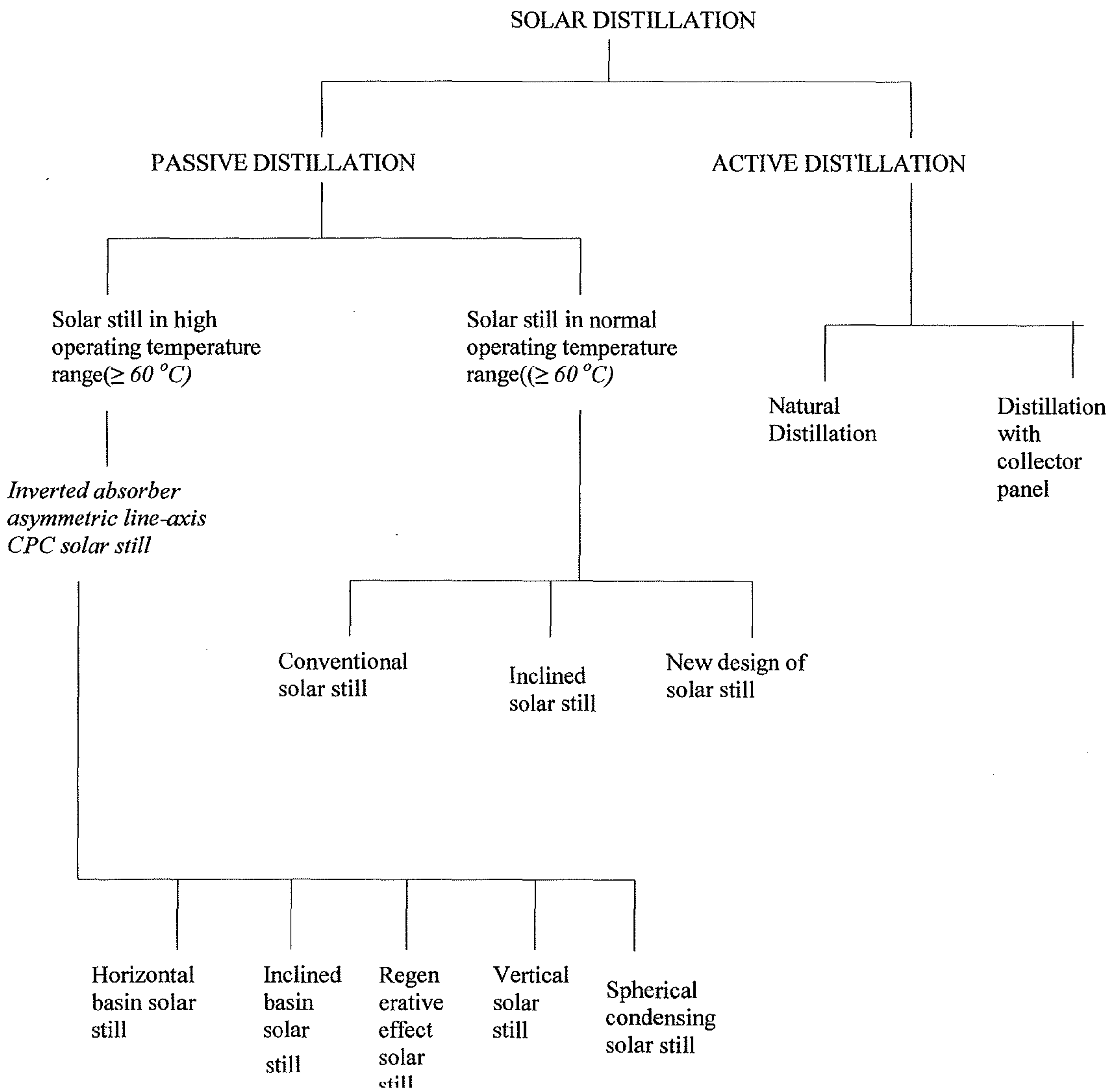


Fig.3 : Various Categories of Distillation Systems.

In 1993, a new design for passive atmospheric multieffect distillation unit was proposed which consisted of inclined metallic surfaces covered with a cotton fabric and placed one over the other in a box were used in Argentina. In 1993, the university of Botswana developed two designs of thermal electric solar stills, which were highly efficient. The yield of the distillate from these stills nearly doubled.

Over the past century, literally hundreds of solar still plants and thousands of individual stills have been built around the world. Several configurations for solar desalination studies have been produced in past studies. The numerical analysis and practical results show the feasibility for such systems for fresh water production. For instance, experimental results and computer simulation of a solar desalination plant located in Abu Dhabi were presented by a El-Baghdadi(1987) and El-Nashar(1990,1992). In that plant , a solar collector field was used to intercept the solar radiation. El-Bahi and D. Inan in Physics Engineering Department, Hacettepe university, Beytepe, Ankara - Turkey, studied a solar still with minimum inclination and coupled to an outside condenser .The effect of adding an outside passive condenser to a single basin- type solar still with minimum inclination (4^0) was investigated experimentally.

A prototype desalination unit operating on the multiple effect principle was built and tested with successful results at the university of Zimbabwe in 1994. Hirschmann and Bloemer et al (1976) have investigated several different solar still models theoretically and experimentally. A single type solar still having optimum effective height (0.24 m) well sealed and with good insulated base was constructed by Soliman (1986). Based on good capillarity of a jute wick, a new type of solar still has been proposed by A.A. Karaghouli and A.N. Minasian of the solar energy research center, Baghdad, Iraq.

2.3 SOLAR DESALINATION IN INDIA

In India work of solar still was started in 1950, at the National physical Laboratory (NPL), New Delhi. At NPL, experiments were conducted on concentrator type and flat basin type stills.

The central salt and Marine chemicals Research Institute (CSRMCRI), Bhavnagar started work on solar stills in 1946. It first started work with a small laboratory model with a basin area of $0.316m^2$. Later a pilot plant solar still of basin area $377m^2$ with an output of about 1990 liters per day was installed. The CSRMCRI has studied the effect of different design variables like depth and cover angles on distilled water output and also the use of indigenous, building materials for solar still construction.

At central Arid zone Research Institute (CAZRI), Jodhpur work on solar distillation was started in 1973. Its specific aim is to design domestic solar stills for Indian Arid zone conditions. A number of single sloped and doubled sloped stills, both on ground and raised platforms were collected over a period of 2 ½ years. The effect of a number of climatic parameters such as solar radiation, ambient air temperature, outside wind velocity, outside air humidity and design parameters such as base insulation, cover glass inclination, orientation of the still, and operating parameters such as water depth in basin, preheating, coloring and output were experimentally studied. Efforts are now being made to optimize the size of the solar still for both domestic and laboratory purposes.

At Indian institute of technologies, New Delhi, Mumbai and Chennai, numbers of experiments were carried out to design and fabricated new types of solar stills suitable for India. At Indian Institute of science, Bangalore and at Annamalai University in Tamilnadu researches on solar still were conducted.

At NPL complex, New Delhi a solar still was built to give 3 liters of distilled water per square metre area on clear summer days. This still can be used to purify locally available water for drinking.

In TamilNadu, the public works department had set up a solar energized desalination plant at Chennai to get potable water.

At Rameswaram in Tamilnadu, the Government had set up a solar desalination plant to obtain potable water from the sea- water. It provides 2200 liters of distilled water per day.(Natarajan.K,1985)

There are various designs of solar stills available, but in India under the MNES programme only single basin solar still are being installed all over the country, and around 11000 sq.m. of solar stills have been installed.(H.P.Garg, 1991)

2.4 IMPROVEMENTS OF THE EFFICIENCY OF DESALINATION TECHNOLOGIES: A REVIEW

In the first stage, attempts were made to design various types of solar stills. The next stage was to improve the operating efficiencies of the various types of solar stills. Collins and Thompson (1961) and Grune et al (1961) made tests on a simple solar still coupled to an external condenser.

Lof et al(1961) showed some decrease in still production with the increase of wind velocity, while others have observed it otherwise (1961). Morse and read (1968) and cooper (1969) have observed a significant increase in the daily production with the increase in ambient temperature. Morse and read (1968) and cooper (1969) have observed a significant increase in the still productivity by reduction the water depth in the still. They have also showed that plastic cover cannot replace glass because of its lower transmittances to short wave radiation and higher values for long wave radiation (1968). Frick and sommerfield (1970)proposed the design of an indorsed single wick type still which suffered from the limitation of having part of the cloth dry at times (1973) .Hirschmannn and Roefler in 1970 have considered periodic insulation in estimating the effect of heat capacity in the performance of the still.

The simple solar still of basin type and several ways to improve its performance have been investigated. Mousa et.al (1978) surrounded the solar still by flat mirrors to heat the water layer from both sides, thus doubling the still exposure. This resulted in a considerable increase in productivity. An investigation of the effect of preheating sea water before it is delivered to the solar still, by pouring it on the outer surface of the glass cover and then heating a solar collector was described by Abd – Rabbo et al(1978). Akinsete and Duru(1979) showed that filling the bottom of the water layer with charcoal increases the productivity. Moustafa and Brusewitz (1979) studied the performance of different types of stills and concluded that the wick type is better than the basin type solar still. Sodha etal(1981) presented a design and performance analysis of multiple wick solar still, in which the wet surface was created by a series of jute cloth pieces of increasing length, separated by the plastic sheets. Conducting an experimental study on a tilted – wick type solar still, Tanaka et al (1982) found an increase in distillate output of 20 – 50% against basin types. The effect of dried and forced air bubbling on the partial pressure of water vapour and the performance of the solar still was analyzed in the school of environmental sciences, JNU India by G.C Pandey(1984). Tiwari et al (1984) studied the performance of a double condensing multiple wick type solar still. In this still introducing an additional G.I sheet just below the blackened wet jute cloth had increased the area of the condensing surface. Tiwari and Selim (1984) suggested a new design of double slope fibre reinforced plastic (FRP) multiwick solar still, which showed improved performance. A method used to improve the performance of a single basin solar still consists of utilizing the latent heat of condensation of water at the bottom face of glass cover. This has been achieved by allowing the feed water to flow over the glass cover prior to its entering the still (1985).Detailed studies of the use of waste hot water and the integration of the panel of collectors with and without the heat exchanger operated in forced circulation mode have been carried out by Tiwari(1985) .Yen and Chen (1986) investigated a effects of climatic,design and operational parameters on the productivity of wick type solar stills .Yadav (1986) has also compared the performance of a solar still coupled with a panel of collectors working under natural, as well as forced, circulation mode without using a heat exchanger in the basin and concluded that the system, working under natural circulation is more efficient and cost effective than in forced circulation mode. Tiwari and Kumar presented a detailed analysis of a tubular solar still for predicting its nocturnal productivity .An analytical model of inverted multiwick solar still was suggested by Tiwari et al (1988). They concluded that the design gives about 20% greater yield than the conventional multiwick solar still. Ahmed (1988) has observed a continuos increase in still production with the increase in total solar radiation. The evaporation area of the still can be increased by using some kind of high contact surface material like sponges or thorn bushes (Joyce et al,1994).

Rai etal (1990) has studied a single basin solar still in the uncoupled and coupled condition with a flat plate collector. It has been observed that the single basin still, coupled with the flat plate collector, having the forced circulation and blackened jute cloth floating over the basin water with a small quantity of black dye in basin water gives the best performance. As an attempt to increase the evaporation area, a fabric where the previously heated salt solution circulates is utilized (Baumgartner et,al.1991).

Several attempts have been made to increase the production, based mainly on the utilization, several evaporation stages using in each stage the latent heat of condensation rejected by the preceding stage (Fernandez and chargoy,1990, Joyce etal, 1991). One of the latest developments in solar still is using forced convection inside the stills and 60% increase in the still was reported

(Ali,1998). The idea to use gravity to create a partial vacuum through hydrostatic pressure, which increases the rate of evaporation is a clever design improvement which resulted in almost twice the efficiency of flat basin stills (Goswamy .Y,2003).

2.5 MODEL FORMULATIONS ON SOLAR STILLS:

Based in part on Sharply and Boelter's experiments with the evaporation of water into quiescent air, Dunkle (1961) first outlined the steady – state thermal model for a solar still. Mathew et al(1982) explained the mathematical development of the model .Experimental results and computer simulation of a solar desalination plant located in Abu Dhabi were presented by E1 – Nashar and El Baghdad (1987) and El – Nashar (1980, 1992). Shariff and Kiss (1987) had introduced a numerical simulation procedure to predict the daily fresh water production of the solar still.

In Iran in 1991, a mathematical model was used to predict the performance of the solar still. Forced convection inside the solar still to enhance the productivity of the still. A simulation program developed for predicting the performance of solar desalination plants was used to optimize the operating conditions of the solar plant at Abu-Dhabi.

2.6 SIMPLE SOLAR STILLS:

As a result of interest in solar distillation, several types of solar stills evolved. Out of the various stills like single effect basin solar stills, multiple effect solar stills ,single or multiple wick stills , inclined tray or stepped stills ,the multiple stage- flash distillation solar film covered stills , and solar concentrator stills, only the basin type stills using single effect distillation have been used for the supply of large quantities of water for isolated communities or for small supplies of water such as for battery charging, analytical purposes, etc.

There are several minor variations in the geometric configuration of single basin stills.A double sloped symmetrical still with continuous basin is made watertight by using heavy asphalt sheets. Glazings are supported on pre-cast concrete pillars placed on the lining. The distillate is collected in stainless steel chamber on the lower side of the glass pane .The average water depth of the basin is about 10 cm. Asphaltic plastic and caulking material is used for sealing all glass joints. This still was used at Las Marinas, Spain and is a modified version of deep basin tried at Daytona Beach, Florida Laboratory.

The solar stills of double-sloped symmetrical design with divided (separate) basins are also being constructed nowadays. The design popularly known as CSIRO Australia Mark IV design consists a basin insulated with 25 mm polystyrene foam and internally lined with 0.76 mm butyl rubber. Concrete side members contain grooves in which the lower edges of the glass cover rests and distillate gets collected. At the top two glasses are sealed using silicon sealant, thus eliminating the need of a rigid support, which is possible only in small width solar stills. These stills are designed for the continuous supply of saline water and therefore, a slope in the basin is required. Shallow depth of water (2 to 3) cm in the basin is maintained by placing dams across the hill after every 1 –1.5 m. Single sloped glass solar stills are used by Brace research Institute of McGill University, Canada at La Gonava, Haiti. The still was installed on a gentle slope hill with each bay arranged like steps of a staircase. The concrete pillar supports the glass and contains two troughs, one for collecting distillate and second the rainwater. In this model, the glass supports and distillate troughs are made of aluminum extrusions. Butyl rubber is used as a basin liner while sidewalls and curbs are made of concrete. The 1.5 cm wide bays are arranged in pairs so that passage is made between the pair.

The V-trough or saw tooth type solar still was developed at the University of California for use on the south pacific islands and is yet to be constructed. Due to the reduced length of distillate trough in this design, it will minimize the re-evaporation of distillate from trough. The plastic inflated solar still uses tedler film 0.1 mm thick, chemically and mechanically treated to make it wettable and is used by McGill University at Petit St Vincent Island in the Caribbean. The edges of Butyl rubber lining and the tedler cover film are clamped against the concrete curbs making an airtight enclosure. The cover is inflated by maintaining an air pressure of about 6 mm of water in the enclosure. In the plain stretched plastic film type solar still the plastic cover is not inflated but stretched. Concrete curbs with castled distillate troughs and Butyl Rubber as basin liner is used in this design. (Garg .H.P & Prakash.J).

2.7 OTHER DESIGNS OF SOLAR STILLS

The daily yield per m^2 / day in single basin solar still mainly depends on the temperature between the evaporating and condensing surfaces. Various scientists have made attempts to maximize the daily yield per m^2 / day in a single basin solar still in a passive mode by changing its design to get maximum temperature difference between the evaporating and condensing surfaces. Some of the developed design will be discussed in the following sections:

2.7.1 SINGLE SLOPE SOLAR STILL WITH CONDENSER (Faith,1998)

In a conventional solar still; the glass cover is used for transmission of solar energy as well as for condensation of water vapor evaporated from the water surface. During the condensation the latent heat is given to the glass cover which raised the glass cover temperature and hence reduces the overall temperature difference between the evaporating and condensing surfaces .In order to increase this difference, the condensing surface is separated form the solar still.

There is little condensation on the sloped surface; mainly condensation takes place in the attached condenser due to the transfer (purging) of vapor from solar still chamber to condensing chamber. Since most of the distillation is taking place in the condensing chamber, the temperature difference between the glass cover and water is more which causes faster evaporation and distillate output is more. In this case the still efficiency is increased by 45 percent further the distillate output can be increased by natural circulation.

2.7.2 HYBRID SINGLE SLOPE SOLAR STILL (Abu-Quadir et al., 1996)

The condensing chamber can be further improved for faster condensation. The proposed change in design uses electrically operated fan and condensing chamber to increase the distillate output. This is referred as hybrid solar distillation system. The active components that are electric blower and condenser can be attached with distillation unit having collector too.

2.7.3 REVERSE ABSORBER SOLAR STILL (Tiwari and suneja, 1998)

In this case the condensing cover is separated from the surface receiving solar energy. Unlike conventional solar still ,the solar radiation is allowed to be absorbed at the bottom of the solar still after transmission through the glass cover.

This design consists of a cylindrical reflector integrated to the solar still and is based on the concept of an inverted absorber flat plate collector. The condensation takes place on inner surface of the metallic condensing cover . The absorbed solar energy is transferred to the water mass by convection. The water gets heated. There is heat loss from the water surface to the inner surface of the metallic condenser by radiation, convection and evaporation. The evaporated water is condensed on the inner surface of the condenser after releasing its latent heat of condensation. The condensed water is trickled down under gravity to the drainage provided at the lower end of the condensing cover. Due to the separation of the condensing cover (cold surface) and receiver of the solar energy surface , the temperature difference between condensing cover and water surface is increased for higher yield.

2.7.4 MULTI-WICK SOLAR STILL (Sodha et al.,1981)

In this design the maximum temperature difference between the condensing cover and water surface can be achieved by reducing the heat capacity of the water mass in the basin. In other words, a water film is maintained on the absorber for fast heating and quick evaporation.

The water film is achieved by using a porous multi-wick (jute cloth). Each jute cloth layer is separated from other by providing a black polythene sheet between them so that each jute cloth can act independently. One end of the jute cloth sheets is dipped in the water reservoir and other ends are spread over the base of solar still. Before spreading the jute cloth over the base of the solar still, it should be properly wetted before better capillary action . Jute cloth sucks the water from reservoir due to capillary to the inclined surface. The surface is inclined to an optimum, angle to receive maximum solar radiation The glass cover is placed over the unit for condensation of the vapor on its inner surface. The solar radiation is absorbed by blackened jute cloth after transmission from the glass cover. The water in the jute cloth gets heated and evaporation takes place. The evaporated water is condensed on the inner surface of the glass cover after releasing its latent heat of condensation to the glass cover. The latent heat of condensation is lost to atmosphere by convection and radiation. The condensed water is trickled down under gravity to the channel, provided at the lower end of the solar still .The body of the solar still is made up of fibre reinforced plastic (FRP) material.

2.7.5 CONICAL SOLAR STILL (Malik et al.,1982)

In the above design of solar tills the areas of evaporating and condensing surfaces are equal. In the present design, the temperature difference between the evaporating and condensing surfaces can be increased by fast cooling the condensing surface.

This can be achieved by increasing heat transfer coefficient from the condensing surface to atmosphere. This can be obtained by increasing the surface area as shown in the figure .In this impure water is enclosed in a transparent two in one arrangement. Solar energy trapped within the enclosure heats up the water, which causes evaporation and then condensation of the inner surface of the transparent upper cone. Condensed water droplets slide down in the water pan and are collected in the bottom cone .

2.7.6 ACTIVE SINGLE SLOPE SOLAR STILL(Kumar and Tiwari, 1996)

In the case of the active solar still, the temperature difference between the evaporating and condensing surfaces are increased by feeding the additional thermal energy from the flat plate collector into the basin of the solar still.

The flat plate collector is integrated to the basin of solar still. The water in the basin is circulated through flat plate collector either in natural circulation mode or a forced circulation mode depending upon the requirement . The connecting pipes are insulated to avoid losses from the hot water in the pipe to ambient during hot water circulation through it. In an active solar still, the water in the basin is heated directly as well as indirectly through a flat plate collector . The collector should be operated only during sunshine hour. The rise of the temperature of water in the basin mainly depends upon number of collectors connected in series.

2.7.7 EPSEA stills

In 1995, EPSEA received funding through the State of Texas, State Energy Conservation Office (SECO), for a solar demonstration project. EPSEA's project demonstrated the feasibility of using solar energy to purify water. The heart of EPSEA's project is a basin solar still. EPSEA's research resulted in a basin still, with emphasis on ease of replication and readily available materials. The still utilizes standard patio replacement glass (34"X76"), and during the summer months produces over 3 gallons/day. Winter production is about 1/2 that amount. The still has no moving parts, uses only solar energy to operate, and is self cleaning.

2.8 Solar desalination units in Bangladesh.

Clean drinking water is one of the most important international health issues today. In many places of the world only brackish or polluted water is available. In West Bengal and Bangladesh, villagers have been seriously affected by drinking water from deep wells containing arsenic. This fact leads to an increasing interest in new water purification technologies. (Desalination technologies respectively).

For this purpose two systems were developed in Munich.

Together with CASE, GmbH MUNICH, and the Austrian company MOIK, HALLIEN, THE TECHNICAL UNIVERSITY OF MUNICH developed the aquasol single- stage flash evaporation unit.

The GOR multi-effect humidification unit has been developed and optimized by the T.A.S.GmBh. Experiments on the plants have shown satisfactory results.(Palaniappan et al, 2001)

2.9 Solar desalination units in Australia

The need for potable water in remote areas of Western Australia is widely known with many communities in rural areas suffering from scarce and often-marginal quality drinking water resources. This situation led to the investigation of appropriate technologies suitable for small scale desalination in such communities in co-operation with G.P and G.F. Hill Pty Ltd as the industrial partner , the reverse osmosis solar flow unit was developed by the Remote area development Group(RADG).Due to portability, low maintenance and an output which matches with the demand solar power was selected. This unit was capable of producing upto

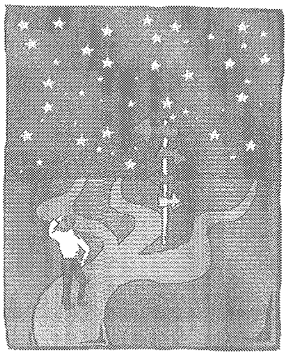
400 L/ day from brackish water of upto 5000 PPM total salinity from a 120 watt photovoltaic array. Harrison Mathew K.G.E.(1992)

2.10 Scope of the project

Distillation of water is the #1 preferred method of purifying water in the entire world. It is the ONLY method which eliminates ALL salts, sand, sediments, rust, heavy metals, bacteria (such as coliform which causes cholera, etc.), micro-organisms (such as E-coli, giardia, chryptosporidium, etc.), heavy metals, arsenic, chlorine taste, fluoride, and other toxins and chemicals from the water. Contaminated water sources from lakes, streams, ponds, puddles, old water tanks, stagnant water, sea water, bad well water, rain water, etc. can all be used in a still. A still coupled with a cheap and simple silver-impregnated carbon filter will also remove volatiles (such as gasoline, kerosene, pesticides, etc. which have a faster evaporation rate than water does).... something that even an R.O. (reverse osmosis) system cannot do.

There are some reasons why solar distilled water is preferred above forced-distillation (distillation via boiling the water). One is the pH of the water is higher (neutral 7.0 to alkaline 7.1-9.0+) and is considered by health professionals to be better for the body (alkalines in the body, acids outside of the body). Boiled distilled water actually lowers the pH to acid levels. Taste is another reason for choosing solar distilled water above force-distilled water. The natural slow process of evaporation/condensation via the sun's energy causes the water vapor to pick up oxygen/carbon dioxide molecules which make the water taste much sweeter than the flat, metallic taste of boiled-distilled water.

The present work is an endeavour to fabricate a shallow depth basin type solar still of area 0.7040 m^2 and study its thermal performance, economic analysis , to study the thermal and heat balance of the still , study of the effect of various climatic parameters and the chemical analysis of the distillate collected from the still .The economic viability makes the still more adaptable for use by the complete range of the population spectrum, from urban to remote rural (Nijegorodov et al, 1994).



THEORY

III. THEORY

3.1WORKING PRINCIPLE :

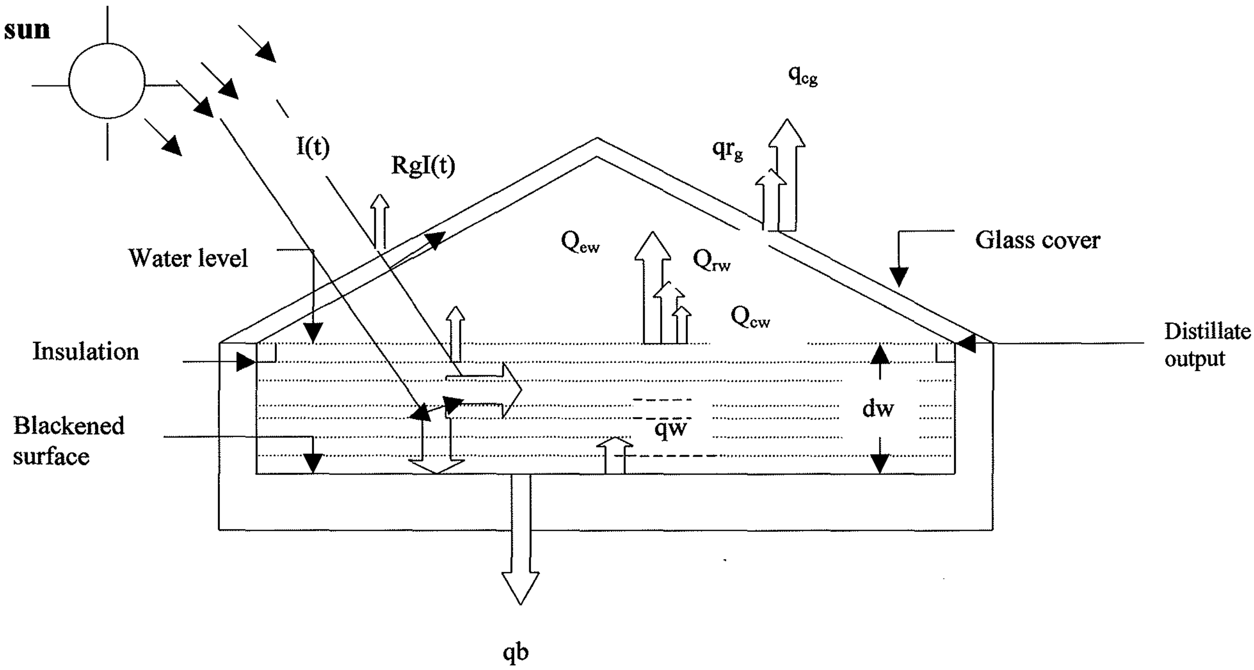


Fig:4. Energy Flow Diagram in a Conventional Solar Still

Figure.4 shows various components of energy balance and thermal energy loss in a conventional solar distiller unit. It is an airtight basin, usually constructed out of concrete/cement, galvanised iron sheet (GI) or fibre reinforced plastic (FRP) with a top cover of transparent material like glass, plastic etc. The inner surface of the rectangular base is blackened to efficiently absorb the solar radiation incident at the surface. There is a provision to collect the distillate at lower end of the glass cover. The brackish or saline water is fed into the basin for purification. The working principle of the distiller unit is described here in.

The solar radiation, after reflection and absorption by the cover is transmitted inside an enclosure of the distiller unit. This transmitted radiation [$\tau_g I(t)$] is further partially reflected [$R'_w I(t)$] and absorbed [$\alpha'_w I(t)$] by the water mass. The attenuation of solar flux in water mass depends on it's absorptivity and depth. The solar radiation finally reaches the blackened surface where it is mostly absorbed. After absorption of solar radiation at the blackened surface, generally known as the basin liner, most of the thermal energy is convected to water mass and a small quantity is lost to the atmosphere, by conduction. Consequently the water gets heated, leading to an increasing difference of water and glass cover temperatures. There are basically three modes of heat transfer, radiation (q_{rw}), convection (q_{cw}) and evaporation (q_{ew}) from the water surface to the glass cover. The evaporated water gets condensed on the inner surface of the glass cover after releasing the latent heat. The condensed water trickles into the channels provided at the lower ends of glass cover. Under gravity, the collected water in the channel is taken out of the system for further use. The thermal energy received by the glass cover, through radiation, convection and latent heat, is lost to the ambient by radiation and convection.

The fraction of solar flux, at different components of the distiller unit is shown in Figure.4. (Tiwari et al., 1989) and can be mathematically expressed as,

Solar flux absorbed by the glass cover.

$$\alpha'_g = (1 - R_g)\alpha_g \quad \text{---------------} \quad 1a$$

Solar flux reflected by the water mass

$$R'_w = (1 - R_g)(1 - \alpha_g)R_w \text{-----------------} \quad 1b$$

Solar flux absorbed by the water mass

$$\alpha'_w = (1 - \alpha_g)(1 - R_g)(1 - R_w)\alpha_w \quad \text{--------------------} \quad 1c$$

Solar flux absorbed by the basin liner

$$\alpha'_b = \alpha_b (1 - R_g)(1 - \alpha_g)(1 - R_w)(1 - \alpha_w) \quad \text{----------} \quad 1d$$

Solar flux lost to the ambient, through water and glass cover, will be

$$(1 - \alpha_b)(1 - R_g)(1 - \alpha_g)(1 - R_w)(1 - \alpha_w) \quad \text{------} 1e$$

If, however attenuation of solar flux within the water mass is considered, then the Equations (1c to 1 e) becomes, Solar flux absorbed by the water mass

$$\alpha'_w = (1 - R_g)(1 - \alpha_g)(1 - R_w)[(1 - \Sigma\mu_j \exp(-\eta_j d_w)] \quad -2$$

Solar flux absorbed by the basin liner

$$\alpha'_b = \alpha_b (1 - R_g)(1 - \alpha_g)(1 - R_w) \Sigma\mu_j \exp(-\eta_j d_w)] \quad -3$$

and the energy lost to the ambient, through water mass and glass cover, will be

$$(1 - \alpha_b)(1 - R_g)(1 - \alpha_g)(1 - R_w) \Sigma\mu_j \exp(-\eta_j d_w)] \quad -4$$

3.2 THERMAL EFFICIENCY

The thermal efficiency of distiller unit can be defined as the ratio of the amount of thermal energy utilised to get a certain amount of distilled water to the incident solar energy within a given time interval.

3.2.1 INSTANTANEOUS EFFICIENCY

If the evaporation process inside the distiller unit can be considered as an isobaric atmospheric process at thermal equilibrium, then all the absorbed solar radiation is utilised for evaporation and thermal losses. An energy balance for steady state around the water basin can be written as [Tamini. 1987]:

$$[\alpha'_w + \alpha'_b] I(t) A_s = Q_{ew} + Q_{losses} \quad -5$$

[Rate of energy in] = [Rate of energy out]

where, $Q_{ew} = m_w L$ and $Q_{losses} = U'_L (T_w - T_a) A_s$. U'_L is the overall heat transfer coefficient from water to the ambient through top, bottom and sides of the distiller unit and it is assumed that,

$$(\alpha'_w + \alpha'_b) = (\alpha\tau)_w \quad .6$$

Here, in the Tamini model, Q_{losses} does not include the evaporative heat loss. The analysis has been compared with that of flat plate collector. However it may be noted that whereas in a flat plate collector, the upward losses should be minimum. In the conventional solar distiller the radiative, convective and evaporative losses from the water to the condensing cover (glass) are grouped together and taken as the total heat transfer coefficient from water to glass.

Equation (5) can be rewritten as,

$$Q_{ew} = m_w L = (\alpha\tau)_w I(t) A_s - U'_L (T_w - T_a) A_s \qquad -7$$

The expression for instantaneous efficiency (η_i) can be given as,

$$\eta_i = \frac{m_w L}{I(t) A_s} = (\alpha\tau)_w - U'_L \frac{(T_w - T_a)}{I(t)} \qquad -8$$

The plot of η_i versus (Tw – Ta)/I will represent a straight line with ($\alpha\tau$)w and – U'L as the intercept and the slope respectively, where U'L can be taken as a constant. The expression for η_i is similar to that for a conventional flat plate collector except for the heat removal factor. Thus, according to Tamini (1987) the distiller unit can be considered as a special type of flat plate collector except for the heat removal factor. Thus, that collects the solar energy and produces distilled water.

3.3 Overall Thermal Efficiency

The overall thermal efficiency of the distilled unit in the passive and active modes of operation can be mathematically expressed as,

$$\eta active = \frac{\Sigma m_w L}{[A_s \int I(t)dt + N A_c \int I'(t)dt]} \times 100 \qquad -9$$

$$\eta\ passive = \frac{\Sigma m_w L \times 100}{A_s \int I(t)dt} \qquad -10$$

Where N is number of collectors connected either is series or parallel.

Here, the latent heat of vaporisation (L) in Joule/kg can be considered temperature dependent, and can be given as : (Fernandez and Chargoy, 1990 and Toyama, 1972).

$$L = 3.1615 \times 10^6[1 - 7.6160 \times 10^{-4}T] \qquad -11$$

For temperature higher than 70°C; and

$$L = 2.4935 \times 10^6[1 - 9.4779 \times 10^{-4}T + 1.3132 \times 10^{-7}T^2 - 4.7974 \times 10^{-9}T^3] \qquad -12$$

For operating temperatures less than 70°C.

3.4 HEAT TRANSFER

The heat transfer in solar distillation system can be classified in terms of external and internal modes. The external heat transfer mode is primarily governed by conduction, convection, and radiation processes, which are independent of each other, these heat transfer occur outside the solar distiller, form the glass cover and the bottom and side insulation. Heat transfer within the solar distiller is referred to as internal heat transfer mode which consists of radiation, convection, and evaporation. In this case, convective heat transfer occurs simultaneously with evaporative heat transfer and these two heat transfer processes are independent of radiative heat transfer. The classification of element of heat transfer in a solar distiller is given below.

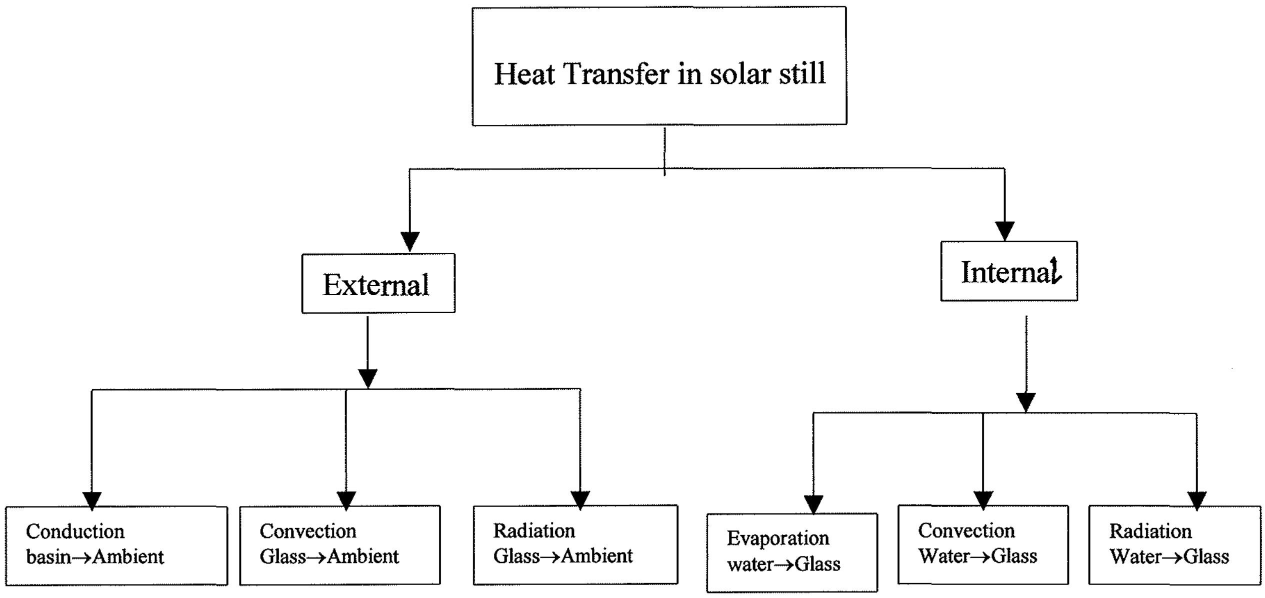


Fig : 5. Heat Transfer in Solar still

3.5 EXTERNAL HEAT TRANSFER

3.5.1 Top Loss Coefficient

Due it the small thickness of the glass cover, the temperature in the glass may be assumed to be uniform. The external heat transfer, radiation, and convection losses from the glass cover to the outside atmosphere q_g can be expressed as

$$q_g = q_{rg} + q_{cg} \qquad -13$$

$$q_{rg} = \in_g \sigma [(T_g + 273)^4 - (T_{sky} + 273)^4] \qquad -14$$

$$q_{rg} = h_{rg} (T_g - T_a) \qquad -15$$

and

$$q_{cg} = h_{cg} (T_g - T_a)] \qquad -16$$

with

$$h_{rg} = \frac{\in_g \sigma [(T_g + 273)^4 - (T_{sky} + 273)^4]}{(T_g - T_a)} \qquad -17$$

On substitution the expressions for q_{rg} and q_{cg} in equation(13), we get

$$q_g = h_{1g}(T_g - T_a) \qquad - 18$$

$$h_{1g} = h_{rg} + h_{cg} \qquad -19$$

The empirical relation for h_{1g} can be discussed for the following conditions:
Case(I): The expression for h_{1g} is given by:

$$h_{1g} = 5.7 + 3.8V \qquad -20$$

Where V is the wind velocity in m/s. This expression includes the effect of free convection and radiation from the glass cover as discussed by watmuff et al (1977).

Case(ii): Incase the radiation and convection losses are to be evaluated separately, the radiative heat transfer coefficient (h_{rg}) can be obtained from equation and the convective heat transfer coefficient. h_{cg}, can be obtained from the relation.

$$h_{cg} = 2.8 + 3.0V \qquad -21$$

There is, however, no significant change in the performance of the distillation system by considering h_{1g} as represented either by case (I) or case(ii).

3.5.2 BOTTOM AND SIDE LOSS COEFFICIENT

Heat is also lost from the water in the basin to the ambient through the insulation and subsequently by convection and radiation from the bottom or side surface of basin. The bottom loss coefficient (U_b) can be written as

$$U_b = [1 / h_w + 1 / h_b]^{-1} = [1/ h_w + 1/ [ki/Li + 1/ h_{cb} + h_{rb}]^{-1} \qquad -22$$

The side heat loss coefficient (U_e) can be approximated as

$$U_e = U_b A_{SS} / A_S \qquad -23$$

If A_{ss} is very small in comparison to A_s, for small water depth, Ue can be neglected. Here, Ass is the surface area in contact with water and A_s is the area of the basin of the distiller.
The rate of heat loss per m^2 from basin liner to ambient can be written as,

$$q_b = h_b (T_b - T_a) \qquad -24$$

Where $h_b = [Li /ki + 1 / h_{cb} + h_{rb}]^{-1}$ - 25

3.6 INTERNAL HEAT TRANSER

The internal heat transfer mode, that is, the heat exchange from water surface to the glass cover inside the distillation unit is governed by radiation, convection, and evaporation and hence these heat transfer modes are discussed separately.

3.6.1 Radiative Loss coefficient (h_{rw})

In this case, the water surface and the glass cover and for large width of the distiller unit, the rate of radiative heat transfer (q_{rw}) from the water surface to the glass cover for these infinite parallel planes is given by

$$q_{rw} = \in_{ef}\sigma\,[\,T_w + 273)^4 - (T_g + 273)^4] \quad -26$$

$$q_{rw} = h_{rw}\,(T_w - T_g) \quad -27$$

Where h_{rw} is the radioactive heat transfer coefficient from the water surface to the glass cover and is given by

$$h_{rw} = \in_{eff}\,\sigma\,[(T_w + 273)^2 + (T_g + 273)^2][T_w+T_g+546] \quad -28$$

It is to be noted that water and glass are considered to be parallel surfaces and thus the radiation shape factor is 1 in this case.

3.6.2 Convective Loss coefficient (h_{cw}):

Heat transfer occurs across humid air in the distillation unit by free convection, which is caused by the effect of buoyancy, due to density variation in the humid fluid, high occurs due to the temperature gradient in the fluid. Hence, the rate of heat transfer from the water surface to the glass cover (q_{cw}) by convection in the upward direction through humid fluid can be estimated by

$$q_{cw} = h_{cw}\,(T_w - T_g) \quad -29$$

The convective loss coefficient from water surface to the glass cover

$$h_{cw} = 0.884 \left(\frac{(T_w - T_g + (P_w - P_g)(T_w+273)}{268.9 \times 10^3 - P_w} \right)^{1/3} \qquad - 30$$

3.63 Evaporative loss coefficient (h_{ew})

The evaporative loss coefficient from water surface of glass cover (h_{ew}) is give by the eqn

$$h_{ew} = 16.273 \times 10^{-3} h_{cw} \frac{[P_w - P_g]}{[T_w - T_g]} \qquad \text{(cooper, 1973)} \qquad - 31$$

$$q_{ew} = h_{ew} (T_g - T_a) \qquad - 32$$

3.6.4.Formula to obtain P_w and P_g:

The values of P_w and P_g (for the range of tempeature 10°C) can be obtained from the expression.(Ref.Femandez and chargoy 1990):

$$P(T) = \exp (25.317 - 5144 / T+273) \qquad - 33$$

3.7 OVERALL HEAT TRANSFER

3.7.1 Top Loss coefficient

The top loss coefficient (U_t) from the water surface to the ambient air can be written as

$$U_t = [1/h_{1g} + 1/h_{1w}]^{-1} \qquad - 34$$

Hence the rate of heat lost in upward direction of distillation system is

$$q_t = U_t (T_w - T_a) \qquad - 35$$

Now h_{lw} , total internal heat transfer coefficient is given by $h_{lw} = h_{rw} + h_{cw} + h_{ew}$ - 35a

3.8 DETERMINATION OF DISTILLATE OUTPUT

The hourly distillate output per m^2 from a distiller unit can be obtained as

$$M_{ew} = \frac{q_{ew}}{L} x\ 3600 = \frac{h_{ew}(T_w - T_g)}{L} \ x\ 3600 \qquad -36$$

Where M_{ew} is hourly distillate output

L is the latent heat of vaporization

q_{ew} is the heat loss due to evaporation

h_{ew} is the evaporative heat loss coefficient

T_w is the water temperature

T_g is the glass temperature.

3.9 Thermal Analysis of Conventional solar still

Energy Balances: The following assumptions have been made in writing the energy balance in terms of joules per sec per m^2.

i. Inclination of the glass cover is very small
ii. The heat capacity of the glass cover, the absorbing material and insulation (bottom and sides) is negligible, and
iii. The solar distiller unit is vapor - leakage proof.

The energy balance for different components of the still are as follows:

Glass Cover

$$\alpha'_g I(t) + [\, q_{rw} + q_{cw} + q_{cw}] = q_{rg} + q_{cg} \qquad .37$$

Rate of energy absorbed	Rate of energy received from water surface by radiation convection and evaporation	Rate of energy lost to air

Water Mass

$$\alpha'_w I(t) + q_w = (MC)_w \frac{dT_w}{dt} + q_{rw} + q_{cw} + q_{ew} \qquad -38$$

Rate of energy absorbed	Rate of enery convected for basin liner	Rate of energy stored	Rate of energy transferred to glass cover

Basin Liner

$\alpha'_b I(t) \;=\; q_w \;+\; [q_b + q_b\,(A_{ss}/A)]$ - 39

Rate of Energy Absorbed	Rate of energy transferred	Rate of energy lost by conduction through bottom/sides

Where α'_g,α'_w and α'_b are given by quotations (1,a,c,d). The various q's in terms of respective heat transfer coefficients, are given in the preceding sections. The side area A_{ss} being very small in comparison to the basin liner area of the solar distiller, the term A_{ss}/A_s can be neglected.

On substitution of the expressions for all q's Equations (38) to (40) can be rewritten as

$$\alpha'_g I(t) + h_{lw}(T_w - T_g) = h_{1g}(T_g - T_a) \qquad - 40$$

$$\alpha'_w I(t) + h_w(T_b - T_w) = T_w(M\,C)_w \frac{d\,T_w}{dt} + h_{1w}(T_w - T_g) \qquad - 41$$

$$\alpha'_g I\,(t) = h_w(T_b - T_w) + h_b\,(T_b - T_a) \qquad - 42$$

Substitution the values of T_g and Tb from Equations (41) and (42) in Equation (42) and simplifying , we get

$$\frac{dT_w}{dt} + aT_w = f(t) \qquad - 43$$

$$\text{Where } a = \frac{U_l}{(MC)_w} \qquad - 44$$

$$f(t) = \frac{(\alpha\tau)_{eff} I(t) + U_l T_a}{(Mc)_w} \qquad - 45$$

$$(\alpha\tau)_{eff} = \alpha'b\,\frac{h_w}{h_w + h_b} + \alpha'w + \alpha'g\,\frac{h_{1w}}{h_{lw} + h_{1g}} \qquad .46$$

$$\text{and } U_l = U_b + U_t;\; U_b = \frac{h_w h_b, H_t}{h_w + h_b},\; U_t = \frac{h_{1w} h_{1g}}{h_{1w} + h_{1g}} \qquad - 47$$

3.10. Approximate solution for (T_w)

In order to obtain an approximate solution of equation (43), the following assumptions have been made:

i. The time interval $\Delta y(0<t<\Delta t)$ is small
ii. The function f(t) is constant, i.e.$f(t) = \overline{f(t)}$ for the time interval Δt
iii. a is constant during the time, interval Δt.

The value of h_{1w} can be determined by considering known values of water and glass temperatures at

$$t = 0, \text{ i.e. } T_w / t = 0 = Two \text{ and } T_g/t = 0 = T_{go}$$

The solution of equation (43) can be written as

$$T_w = \frac{\overline{f(t)}}{a} [1 - \exp(- a\Delta t)] + T_{wo} \exp(-a\Delta t) \qquad - 48$$

Where T_{wo} is the temperature of basin water at t = 0 and $\overline{f(t)}$ is the average value of f(t) for the time interval between 0 and t.

The average temperature of water, T_w is given by

$$\overline{T_w} = \frac{1}{t} \int_0^1 T_w \, dt = \frac{f(t)}{a} \left(1 - \frac{(1- e^{-a\Delta t})}{a} + \right) \frac{Two(1-e^{-a\Delta t})}{a} \qquad - 49$$

The average glass temperature in terms of the water temperature can be obtained from equation (40) and is given as,

$$T_g = \alpha_g I(t) + \frac{h_{1w} T_w + h_{1w} T_a}{h_{1w} + h_{1g}} \qquad - 50$$

The calculated values of T_w and T_g are used to evaluate the internal heat transfer coefficient h_{1w}.

DESIGN AND FABRICATION

IV. DESIGN AND FABRICATION

4.1 SOLAR POWERED DISTILLATION

The solar distillation method is fairly simple and is pretty much self-operating. Saline water is supplied either continuously or intermittently to a pool ranging in depths of approximately 1 inch to 1 foot. The bottom of the pool has a black surface which absorbs solar energy. The discarded salts exit through a drain. A transparent cover composed of glass sheets or plastic film is supported above. These are arranged so that the surfaces slope downward into small troughs at their lower edges. These troughs are connected to channels or piping which transport the condensate to storage. The inclined surfaces and enclosing box are designed so that the box can be easily opened.(Franco and Saravia.L,1994).

A majority of the solar energy is absorbed in the basin bottom with a small amount being absorbed by the salt water itself. Heat is absorbed by the salt water from the basin bottom, raising the temperature and vapor pressure of the water. Partial vaporization occurs and these vapors are transported upward to the transparent cover by convection covers. The cover is generally 10 to 30 degrees F cooler than the vapors and therefore condensation occurs. The condensation flows down the slope and collects in the troughs. The heat of condensation is transported through the cover and into the atmosphere. Only about half of the original feed is evaporated to prevent salt deposition on the bottom of the tank. The rest goes to waste. Some design and other considerations on which the distillate output depends are given in the following section.

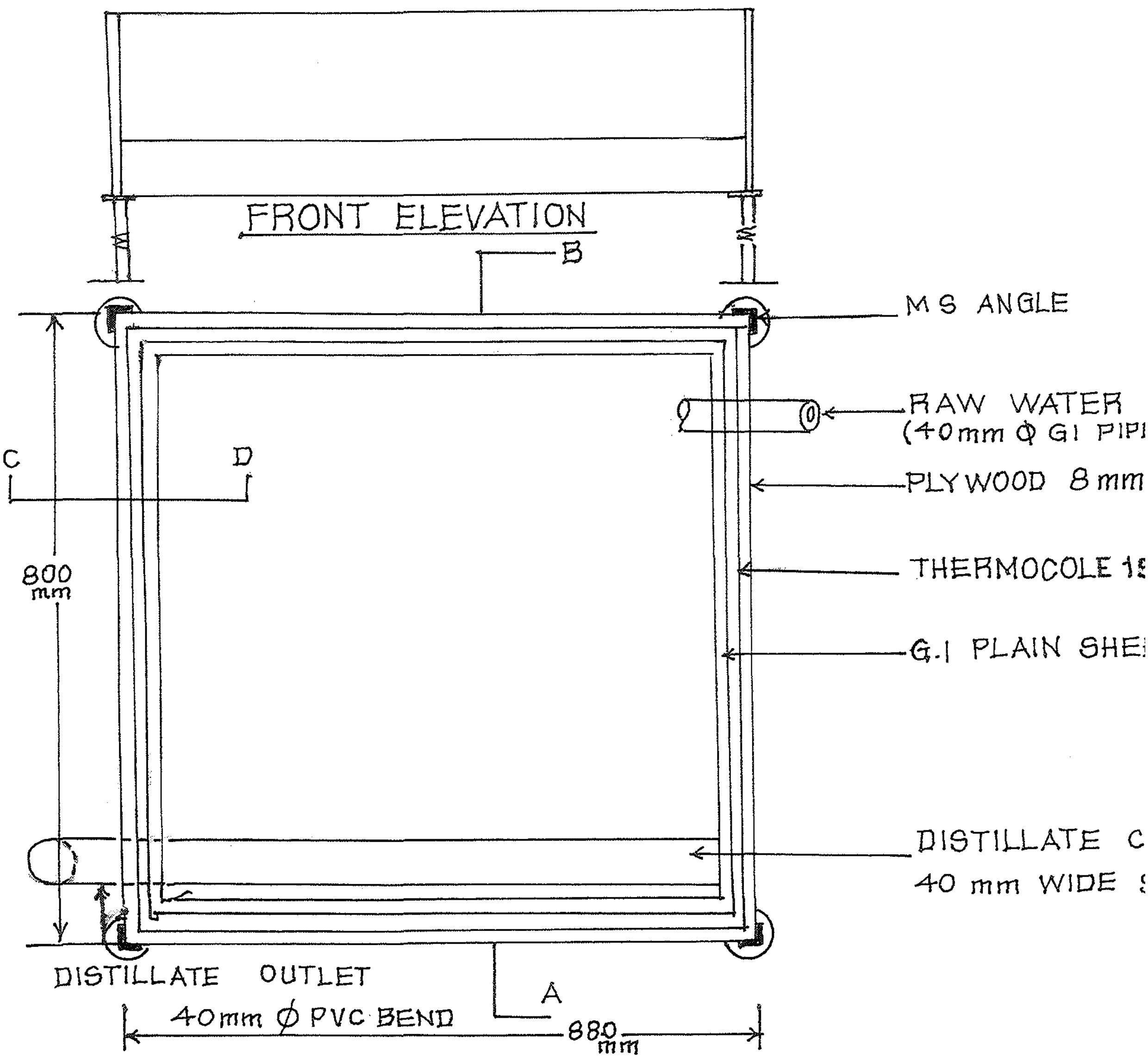
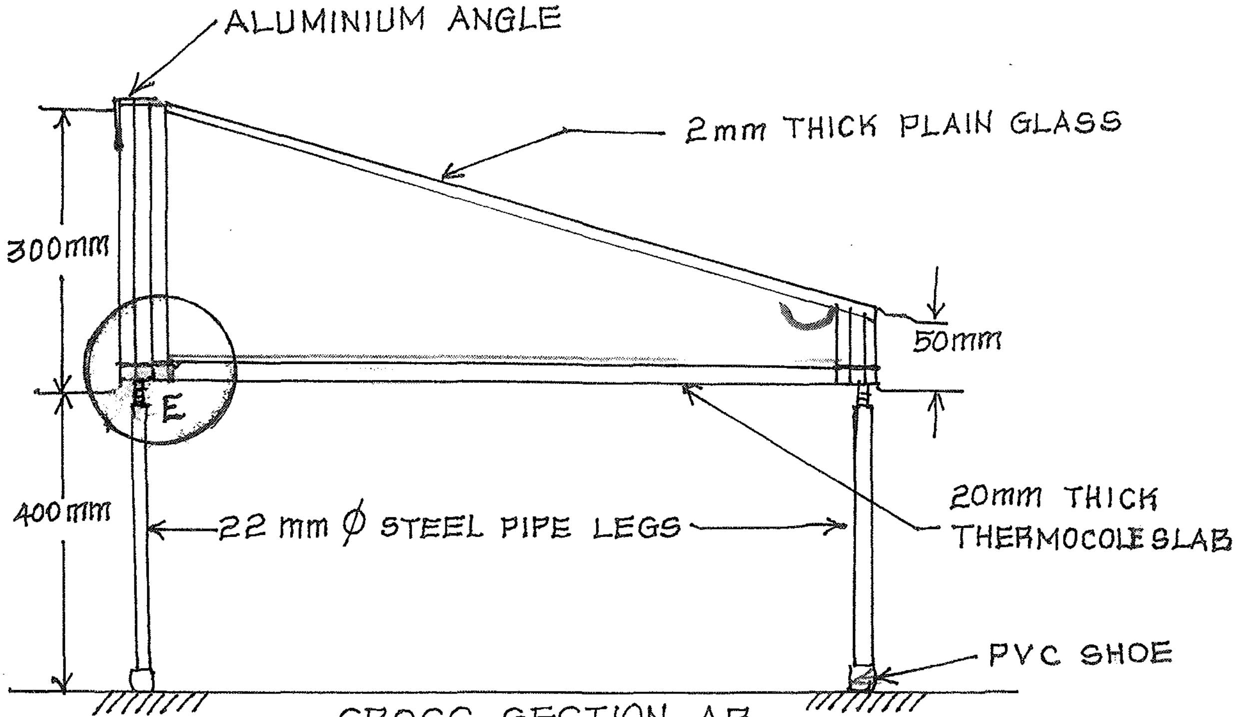


FIGURE-6: PLAN



CROSS SECTION AB

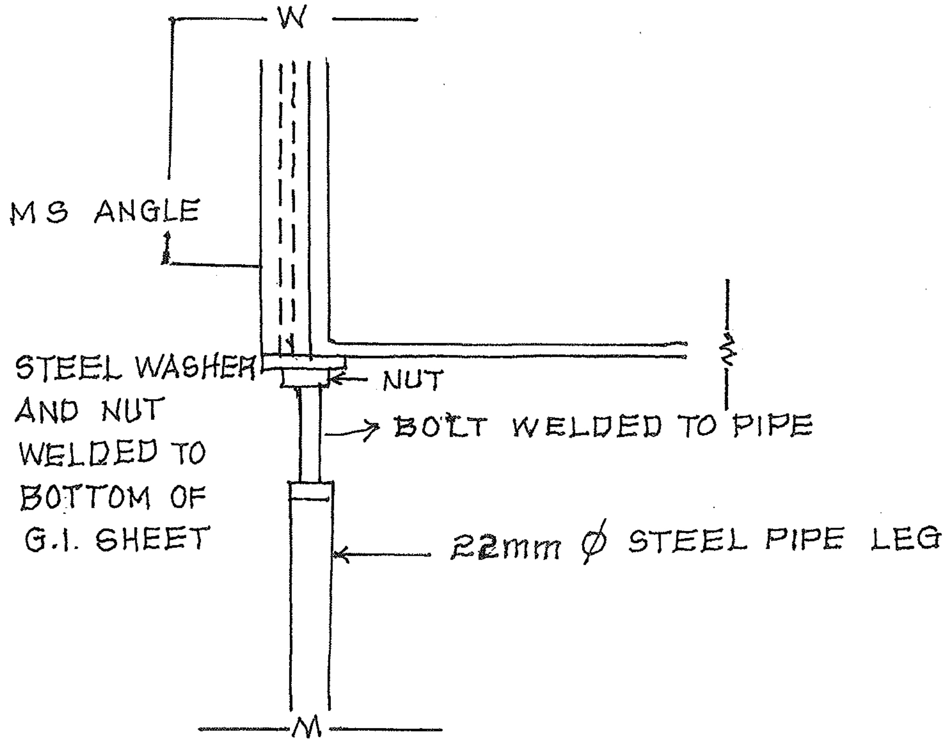


FIGURE : 7 DETAILS AT (E)

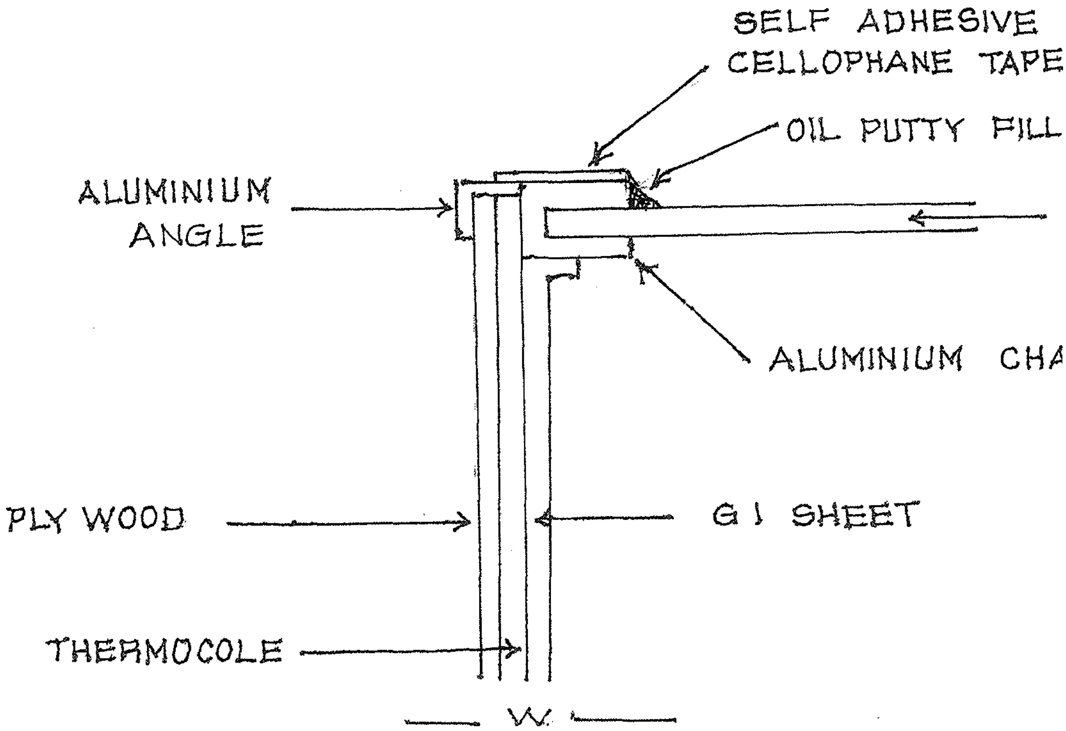


FIGURE-8 SECTION AT CD

4.2.CONSIDERATIONS:

- The solar still output (distillate) is a strong function of solar radiation on a horizontal surface. The distillate output increases linearly with the solar insolation for a given ambient temperature. If the ambient temperature increases or the wind velocity decreases, the heat loss from solar still decreases resulting in higher distillation rate. It is observed for each 10 °C rise in ambient temperature the output increases by about 10 percent.
- The depth of the water in the basin also affects the performance considerably. At lower basin depths, the thermal capacity will be lower hence the increase in the water temperature will be large resulting in higher output. However it also depends on the insulation, increase in water temperature will also increase the bottom loss. It is observed that if the water depth increases from 1.2 cm to 30 cm the output of still decreases by about 30 percent.
- Increase in the number of transparent covers in a solar still do not increase the output since it increases the temperature of the inner cover resulting in lower condensation of water vapour.
- Lower cover slope increases the output but from practical considerations a minimum cover slope of 10 degrees is suggested.
- The maximum possible efficiency of a single basin solar still is about 60 percent.
- For higher receipt of solar radiation and resultant higher yield, the long axis of the solar stills should be placed in East-west direction if the still is installed at a high latitude station. At low latitude stations the orientation has no effect on solar radiation receipt.

4.3.DESIGN DETAILS:

Basin of the solar still for this study has been fabricated out of galvanized iron plain sheet 0.6mm thick and of size 88 cm x 80 cm. Heights are 5 cm at the distillate collecting end and 30 cm at the other end which gives an angle of inclination of 16 degrees to the glass cover.

The still is mounted on four steel pipe legs (22 mmϕ) 40 cm high with PVC shoes and fixed to the bottom of the still (at the four corners) with a nut welded on a circular disc washer. Bolts are welded to the leg top. This arrangement enables setting up of the still at level by adjusting the nuts and bolts. Two vertical angle stiffeners are also welded to the disc at corners of 30 cm high side.

Aluminium channel is fixed at both the sloping sides of the still at top to facilitate sliding in of the glass cover- 2mm thick plain sheet glass .Gap between the aluminium channel and the glass is filled with oil putty and finally sealed with self adhesive cellophane tape.

Aluminium angles are fixed on all sides at top so as to close the gaps between the external wall face of the still, thermocole and plywood to prevent possible heat loss.

All the four vertical sides of the still are insulated with 15 mm thick thermocole slab fixed to the basin with fevicol and 8 mm thick plywood externally. Bottom of the basin is insulated with 20 mm thick thermocol slab fixed with fevicol.

A semicircular G I sheet channel 40 mm wide is fixed inside at the bottom sloping end of the still to collect the distillate trickling down the glass cover and a PVC bend 40 mm provided at the left end to drain out the distillate to the collecting vessel. 40 mm thick G I pipe bend with suitable metal plug is fixed at the right side for feeding raw water into the still as and when required. The arrangements are shown in the sketch of the still at Figs: 6- 8.

Internal surfaces – walls and floors of the basin are painted with black paint mat finish, to ensure maximum absorption of heat.

EXPERIMENTS, RESULTS AND DISCUSSION

V. EXPERIMENTS, RESULTS AND DISCUSSION:

(i) EXPERIMENTS UNDERTAKEN

5.1 ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:

Experiments for this study were conducted at the terrace on the third floor of the physics laboratory building of Avinashilingam Deemed University, Coimbatore, where the solar still fabricated was positioned for the purpose.

5.1.1 EVALUATION PROCEDURE:

The solar still designed and fabricated as described in chapter IV was placed facing south in the upstairs open space of Physics laboratory of Avinashilingam Deemed University with the glass cover at an inclination of 16° from the horizontal to receive maximum solar radiation (Morcos V.H,1994). The still was evaluated for condensate output, thermal and mass balance and economic analysis of desalination costs. Chemical analysis of the distillate is also done.

Temperatures of the basin, glass cover and that of the ambient air were recorded at different intervals using thermometers and a sensitive digital multimeter. A thermocouple measuring the condensate temperature was found to represent well the average temperature of the glass cover. (Farid .M, 1983). Distillation rate and wind velocity were also measured at the same intervals. Solar radiation was continuously measured with pyranometer. The amount of condensate obtained was measured hourly using a measuring jar graduated in millilitres.

The ambient temperature (T_a) was measured using a thermometer, which was fixed near the still. The evaluation covered field tests conducted on the still during sunny days of June 2004.

5.2 MEASUREMENT OF VARIOUS PARAMETERS:

a) TEMPERATURE MEASUREMENTS:

The ambient temperature was noted continually from 9-30 A. M.to 4-30 at P.M. at an interval of half an hour with the help of a thermometer fixed close to the still. The temperature values are noted in degree Celsius.

Two digital multimeters with probes are used to measure the basin and the cover glass temperatures of the still. The temperatures are obtained in celsius scale. All these readings are given in the tables 6-11.

b) SOLAR INSOLATION MEASUREMENT

The solar insolation incident on the glass cover was measured at an interval of one hour from 9:30 A.M. to 4:30 PM using a pyranometer. These pyranometer readings are measured in milli volts and then converted to watts/m^2 as given in the table.

The conversion factor to convert the value of solar insolation in mv to watts/m^2 is by multiplying the solar insolation values in mv with the conversion factor

$$\frac{1000}{12.64}$$

c) MEASUREMENT OF WIND VELOCITY:

The speed of the wind is also an important climatic parameter that affects the efficiency of the solar still. Wind velocity is measured with the help of a digital anemometer, which is mounted at a specific height near the still. The readings are measured in m/sec at an interval of half an hour and tabulated.

d) MEASUREMENT OF THE DISTILLATE OUTPUT:

The volume of distilled water collected from the solar still was measured using the measuring jar graduated in milliliters and the readings are given in the table. The readings in ml are converted to kg by multiplying it with a conversion factor of 0.8315. Then the readings are divided by the area of the solar still and the values obtained in kg/m^2 h.

5.3 SYSTEM EFFICIENCY:

Extensive field tests were conducted to study and evaluate the performance of the still .The experiments were conducted on clear, sunny days of June 2004.

There are several means of assessing the thermodynamic performance of still .One among them is computing the daily thermal efficiency of the system. The daily thermal efficiency of a still is defined as the ratio of useful heat (increased enthalpy of air) to the solar radiation incident on the glass cover of the still. The hourly performance of the still was studied. Maximum temperature rise is expected between 10 A. M and 2 P.M on clear sky days.

The still efficiency was calculated by measuring condensate production obtained hourly. Heat gained by the still and the temperature rise inside the basin increases steadily till noon and drops gradually afterwards. The distillate produced and their respective efficiencies are given in the tabulations 6-11.

An example of the calculation for the experiment of 4^{th} June 2004 between 1:30 - 2:30 h is given here under.

If the solar insolation on horizontal surface is H_t and Q is the amount of heat (WIM^2) utilized by the solar still for evaporating Me Kg of water per m^3 per hour, then the efficiency of the solar still is

$$\eta = \frac{\text{USEFUL HEAT}}{\text{TOTAL HEAT INPUT}} \quad (\%)$$

Daily distilled output of the still is Me(Kg/m^2)

Then,

$$Me = Qe/L$$

Where L is the latent heat of evaporation of water (2.43×10^6 J/kg)

Therefore

$$\eta = \frac{M_e L}{A.H_T}$$

Total area of the still exposed = length x breadth(m^2)

= $88 \times 10^{-2} \times 80 \times 10^{-2}$

= $0.7040\ m^2$

Hourly distillate output
Of the Still (1:30 - 2:30 hrs) = 300 ml

= 0.3 litre

= 0.300 x 0.8315

= 0.24945 kg

Hourly distillate output per unit area of the still

$$= \frac{0.24945}{0.7040}$$

$$= 0.35433\ kg/hr.m^2$$

Hourly solar insolation = $672.46\ w/m^2$

Efficiency of the System

$$= \frac{M_e L}{A.H_T}$$

$$= \frac{0.35433 \times 2.43 \times 10^6}{0.7040 \times 672.46 \times 3600} \times 100$$

$$= \frac{861021.9}{1704282.6} \times 100$$

$$= 50.52\%$$

5.4 THERMAL ANALYSIS OF BASIN TYPE SOLAR STILL

The thermal analysis of the newly constructed basin type solar still is done by the equations given in chapter III.

READING AT 10.00 A.M

DATE : June :3rd 2004

$T_w = 40^oC = 313K$; $T_b = 44\,^oC$

$T_g = 34\,^oC = 307K$; $\alpha = 1.04$

$T_a = 30\,^oC = 303K$; $\tau = 0.62$

$T_w - T_g = 40 - 34 = 6^oC$

$T_g - T_a = 34 - 30 = 4^oC$: $T_b - T_a = 44 - 30 = 14$

$\sigma = 5.67 \times 10^{-8}$

$\in_1 = 0.9$ $(Mc)_w = 15 \times 4190 = 62850\ J / ^oC$

$$P(T) = \exp\left[25.317 - \frac{5144}{T+273}\right] \quad \text{(From eqn. 33)}$$

$$P(40^oC) = \exp\left[25.317 - \frac{5144}{40 + 273}\right]$$

$$= \exp\left[25.317 - \frac{5144}{313}\right]$$

$$= \exp(25.317 - 16.434)$$

$$= \exp(8.883)$$

$$P_w = 7208.38\ p_a$$

$$P(34^oC) = \exp\left(25.317 - \frac{5144}{307}\right)$$

$= \exp(25.317 - 16.755)$

$= \exp(8.562)$

$P_g = 5229.128\ p_a$

$P_w - P_g = 7208.38 - 5229.13$

$P_w - P_g = 1979.25$

$h_{rw} = \in_{eff} \sigma\ [(T_w + 273)^2 + (T_g + 273)^2]\ [T_w + T_g + 546]$

Since

$$e_{ff} = \left(\frac{1}{0.9} + \frac{1}{0.9} - 1 \right)^{-1}$$

$=0.82$

For $\in_g = \in_w = 0.9$

$h_{rw} = 0.82 \times 5.67 \times 10^{-8}\ [313)^2 + (307)^2]\ [40 + 34 + 546]$

$= 0.82 \times 5.67 \times 10^{-8}\ [97967 + 94249]\ [40 + 34 + 546]$

$= 0.82 \times 5.67 \times 10^{-8} \times 192216 \times 620$

$h_{rw} = 5.54\ W/m^2$

$q_{rw} = h_{rw}(T_w - T_g)$ (from eqn. 27)

$q_{rw} = 5.54 \times 6$

$q_{rw} = 33.24\ W/m^2$

$$h_{cw} = 0.884 \left(T_w - T_g + \frac{P_w - P_g (T_w + 273)}{268.9 \times 10^3 - P_w} \right)^{1/3}$$ (from eqn. 30)

$$= 0.884 \left(6 + \frac{(1979.25)(313)}{268900 - 7208.38} \right)^{1/3}$$

$$= 0.884\left(6 + \frac{61950525}{261691.62}\right)^{1/3}$$

$$= 0.884\,[\,6+2.367\,]^{1/3}$$

$$= 0.884\,[(8.367)]^{1/3}$$

$$h_{cw} = 2.465 w/m^2$$

$$q_{cw} = h_{cw}\,(T_w - T_g) \quad \text{(from eqn. 29)}$$

$$= 2.465 \times 6$$

$$= 14.79\ w/\ m^2\ {}^oC$$

$$q_{cw} = 14.8\ w/\ m^2\ {}^oC$$

$$h_{ew} = 16.273 \times 10^3\ hcw\ \frac{P_w - P_g}{T_w - T_g} \quad \text{(cooper, 1973) (from eqn. 31)}$$

$$= 16.273 \times 10^{-3} \times 2.465 \times \frac{1979.25}{6}$$

$$= 16.273 \times 10^{-3} \times 2.465 \times 329.87$$

$$h_{ew} = 13.23\ w/\ m^2\ {}^oC$$

$$q_{ew} = h_{ew}\,(T_w - T_g) \quad \text{(from eqn. 32)}$$

$$= 13.23 \times 6$$

$$q_{ew} = 79.392\ w/\ m^2\ {}^oC$$

Now h_{lw}, total internal heat transfer coefficient is given by

$$h_{lw} = h_{rw} + h_{cw} + h_{ew} \quad \text{(from eqn. 35a)}$$

$$= 5.54+2.465+13.23$$

$$= 21.23\ w/\ m^2\ {}^oC$$

$$h_{lw} = 21.23\ w/\ m^2\ {}^oC$$

The radiative heat transfer coefficient is given by

$$h_{rg} = \epsilon_g \sigma \left(\frac{(T_g + 273)^4 - (T_{sky} + 273)^4}{T_g - T_a} \right) \quad \text{(from eqn. 17)}$$

Where $T_{sky} = T_a - 6$

$T_{sky} = 30 - 6 = 24^{o}C = 24+273 = 297K$

$T_g = 34^{o}C$; $T_g - T_a = 4^{o}C$

$$h_{rg} = 0.9 \times 5.76 \times 10^{-8} \left(\frac{(307)^4 - (297)^4}{4} \right)$$

$$= 0.9 \times 5.67 \times 10^{-8} \left(\frac{(8882874001 - 7780827681)}{4} \right)$$

$$= 0.9 \times 5.67 \times 10^{-8} \left(\frac{(1102046320)}{4} \right)$$

$$= 0.9 \times 5.67 \times 10^{-8} \times 275511580$$

$$h_{rg} = 14.05 \text{ w/ m}^2$$

$$q_{rg} = h_{rg}(T_g - T_a) \quad \text{(from eqn. 15)}$$

$$= 14.05(4)$$

$$= 56.2 \text{ w/m}^2\,{}^{o}C$$

$h_{cg} = 2.8 + 3.0V$ (from eqn. 21)

$V = 1.5$ m/sec

$h_{cg} = 2.8+3.0(1.5)$

$= 2.8+4.5$

$= 7.3$

$h_{cg} = 7.3$ w/ m^2 °C

$q_{cg} = h_{cg}(T_g - T_a)$ (from eqn. 16)

$= 7.3 \times 4$

$= 29.2$ w/m^2 °C

The total heat transfer coefficient from glass to ambient (h_{lg}) is given by

$h_{lg} = 14.05 + 7.3$

$h_{lg} = 21.35$ W/ m^2 °C

The combined radiative and convective heat transfer coefficient is

$h_{lg} = 5.7+3.8$ V (from eqn. 20)

$= 5.7 + 3.8 \times 1.5$

$= 5.7 + 5.7 = 11.4$ w/ m^2 °C

$h_{lg} = 11.4$ w/ m^2 °C

$$U_t = \left(\frac{1}{h_{lg}} + \frac{1}{h_{lw}}\right)^{-1}$$

$$= \left(\frac{1}{11.4} + \frac{1}{21.23}\right)^{-1}$$ (from eqn. 34)

$= (0.08771 + 0.04710)^{-1}$

$= (0.13481)^{-1}$

$= 7.417 W/m^2 \, ^oC$

5.5 DETERMINATION OF THE DISTILLATE OUTPUT:

The predicted distillate output at 10:00 h is given as

$$m_{ew} = \frac{q_{ew} \times 3600}{L} = \frac{h_{ew} (T_w - T_g) \times 3600}{L} \qquad \text{(from eqn. 36)}$$

$h_{ew} = 13.23 \; w/m^2 \, ^oC$

$T_w - T_g = 6 \, ^oC$

$L = 2.43 \times 10^6$ J/Kg

$m_{ew} = 13.23 \times 6 / 2.43 \times 10^6 \times 3600$

$m_{ew} = 0.117617 \; kg/m^2 h$

The observed distillate output at 10:00 hrs

$m_{ew} = .100$ litre

$= .100 \times .8315$

$= .08315$ kg

$$m_{ew} / \text{unit area} = \frac{0.08315}{0.7040}$$

$= 0.118110 \; kg/m^2$

$m_{ew} = 0.118110 \; kg/m^2$

5.6 (i) OBSERVED EFFICIENCY (η)

$$\eta = \frac{m_e/A \times L}{A \times H_t \times 3600}$$

$$= \frac{0.118110 \times 2.43 \times 10^6}{0.7040 \times 714.06}$$

$$= \frac{= 287007.3}{1809713.66} \times 100$$

$$= 15.8\%$$

(ii) Predicted Efficiency (η):

$$\eta = \frac{0.117617 \times 2.43 \times 10^{6}}{0.7040 \times 714.06 \times 3600}$$

$$= \frac{285809.31}{1809713.66} \times 100$$

$$\eta = 15.79$$

$$q_b = h_b (T_b - T_a)$$

$$h_b = \left(\frac{Li}{Ki} + \frac{1}{hcb + hrb} \right)^{-1}$$

Predicted efficiency η_{pre} = 15.79%

Observed efficiency η_{obs} = 15.8%

(since hlg = 5.7 + 3.8 V hlg = hrg + hcg)) & v = 0

$h_{cb} + h_{rb}$ = 5.7 W/m^2 °C

Thickness of insulation = 8 mm

Thermal conductivity of Insulation = 0.04

$$h_b = \left(\frac{0.8 \times 10^{-2}}{0.04} + \frac{1}{5.7} \right)^{-1} \quad \text{(from eqn.25)}$$

$$= [\,0.2 + 0.1754\,]^{-1}$$

$$= [0.3754]^{-1}$$

$$h_b = 2.66 \ W/m^2\,^{o}C$$

$$q_b = h_b\,(T_b - T_a) = 2.66 \times 14 = 37.24 \ W/m^2\,^{o}C \quad \text{(from eqn. 24)}$$

5.7 THEORETICAL ANALYSIS: (To compute T_w & T_g)

The theoretical analysis of the newly fabricated solar still is given:

The equations given in the chapter 3 are used. The theoretical values for T_w and T_g are computed

$$a = \frac{U_L}{(Mc)_w} \quad \text{(from eqn. 44)}$$

$$f(t) = \frac{(\alpha t)_{eff}\, I(t) + U_l T_a}{(MC)_w} \quad \text{(from eqn. 45)}$$

$$U_b = \frac{h_w h_b}{h_w + h_b} \quad ; U_t = \frac{h_{1w} h_{1g}}{h_{lw} + h_{1g}}$$

$$U_L = U_b + U_t \quad \text{(from eqn. 47)}$$

$$(\alpha t)_{eff} = \alpha'_b \frac{h_w}{h_w + h_b} + \alpha'_w + \alpha'_g \frac{h_{1w}}{h_{1w} + h_{1g}} \quad \text{(from eqn. 46)}$$

$\alpha'_{(b)}$ (G.I sheet) = 0.77

$\alpha'_{(w)}$ (Water) = 0.1966

α'_{g} (Glass) = 0.0935

τ = 0.8362

h_w = 100 $w/m^2\,^oC$

h_b = 2.66 $w/m^2\,^oC$

h_{1w} = 21.23 $w/m^2\,^oC$

h_{1g} = 21.35 $w/m^2\,^oC$

$$\alpha\tau_{(eff)} = 0.77 \times \frac{100}{102.66} + 0.1966 + 0.0935 \times \frac{21.25}{42.58}$$

$$= 0.77 \times 0.974 + 0.1966 + 0.0935 \times 0.4985$$

$$= 0.75004 + 0.1966 + 0.04661$$

$$= 0.993$$

$$\alpha\tau_{(eff)} = 0.993$$

$$U_b = \frac{100 \times 2.66}{102.66}$$

$$= \frac{266}{102.66}$$

$$= 2.595$$

U_b = 2.6 $w/m^2\,^oC$

$$U_t = \frac{h_{1w}\,h_{1g}}{h_{1w} + h_{1g}}$$

$$= \frac{21.23 \times 21.35}{21.23 + 21.35}$$

$$= \frac{453.26}{42.58}$$

$$U_L = 10.6\ W/m^2\ {}^oC$$

$$U_L = U_b + U_t$$

$$U_L = 2.6 + 10.6$$

$$U_L = 13.2\ W/m^2\ {}^oC$$

$$f(t) = \frac{(\alpha\tau)_{eff}\, I(t) + U_L T_a}{(Mc)_w}$$

$$\alpha\,\tau_{eff} = 0.993$$

$$I(t) = 575.56 W/m^2$$

$$U_L = 13.2\ W/\ m^2\ {}^oC$$

$$T_a = 32.8\ {}^oC$$

$$(Mc)_w = 12 \times 4190$$

$$= 50280 J/{}^oC$$

$$f(t) = \frac{0.993 \times 575.56 + 13.2 \times 32.8}{50280}$$

$$= \frac{571.531 + 432.96}{50280}$$

$$= \frac{1004.491}{50280}$$

$$f(t) = 0.019977$$

$$a = \frac{U_L}{(Mc)_w}$$

$$= \frac{13.2}{50280}$$

$$= 0.0002625$$

$$a = 2.6 \times 10^{-4}$$

$$t = 1\ h = 3600\ s$$

$$T_w = \frac{f(t)}{a}\left[1 - \exp(-a\Delta t) + T_{wo}(\exp(-a\Delta t)\right] \quad \text{(from eqn.48)}$$

$$= \frac{0.01990}{0.0002625}\left[1 - \exp(-0.9451)\right] + 40\ \{(\exp(0.9451)\}$$

$$= 75.8\ (1 - 0.3886) + 40\ (0.3886)$$

$$= 75.8(0.6114) + 40\ (0.3886)$$

$$= 46.3 + 15.5$$

$$T_w = 61.8 = 62\ ^0C$$

$$T_g = \frac{\alpha'(I(t) + hl_w T_w + hl_w T_a}{hl_w + hl_g} \quad \text{(from eqn. 50)}$$

$$= \frac{0.0935 \times 609.17 + 21.23 \times 61.8 + 21.23 \times 30}{42.58}$$

$$= \frac{56.95 + 1312.10 + 636.9}{42.58}$$

$$= \frac{2005.86}{42.58}$$

$$= 47\ ^0C$$

5.8 TECHNO- ECONOMIC ANALYSIS

The simple techno-economic analysis (Tiwari and Yadav,1989), of the effectiveness of solar distillation systems considers the capital cost of the system, P, and the rate of capital recovery C. The first annual cost of the system, A, can be determined by the following formula,

$$A = P \frac{r(1+r)^n}{(1+r)^n - 1} \qquad - (51)$$

Where r is the rate of interest and n is the life of the system (Years)

The salvage value of the systems is considered as the cost of usable material saved even after the system's life is over. The first annual salvage value V can be determined by

$$V = S \times F \qquad - (52)$$

Where F, a depreciation factor is given by

$$F = \frac{r}{(1+r)^n - 1} \qquad - (53)$$

If M is the annual maintenance cost of the system then the total annual cost is A+M-V. The calculation of this analysis for the newly designed still of area $0.7040m^2$ is given below.

CALCULATION:

Principal	= Rs.2000/-
Expected life span of the system	= 5Years
Rate of Interest@7%	= 0.07

Annual maintenance cost M_1 = Rs. 300/-

Scrap Value = Rs. 800/-

FIRST YEAR

The first annual cost of the system, A_1

$$=2000\left\{\frac{0.07\{1+0.07\}^5}{(1+0.07)^5-1}\right\}$$

$$= \frac{[\{2000\,[0.07\,(1.07)^5\}]}{[(0.07)^5-1]}$$

$$= 2000\left\{\frac{[0.07 \times 1.4025]}{1.4025-1}\right\}$$

$$= 2000 \times 0.2439$$

$$= 487.8$$

$$A_1 = \text{Rs.}488/-$$

The first annual cost of the system = Rs.488/-

Depreciation factor, F

$$= \frac{0.07}{(1+0.07)^5-1}$$

$$= \frac{0.07}{0.4025}$$

F_1 = 0.17391

V_1 = S x F

= 800 x 0.17391

= Rs.139/-

Total annual cost (First Year) = $A_1 + M_1 - V_1$

= 488 + 300 - 139

= 649.

Total annual cost (First year) = Rs.649/-

SECOND YEAR

Principal = 2000 – 488

P_2 = Rs.1512/-

N = 4

I = 0.07

The Second annual cost of the system = $\left\{1512 \frac{[\, 0.07\,(1+0.07)^4]}{(1+0.07)^4 - 1}\right\}$

$$= \left\{1512 \frac{[0.07\,(1.07)^4}{(1.07)^4 - 1}\right\}$$

$$= \left\{1512 \frac{[0.07 \times 1.31079]}{1.31079 - 1}\right\}$$

$$= \left\{ \frac{1512 \times 0.09175}{0.31079} \right\}$$

$= 1512 \times 0.2952$

$= 446.39$

= Rs.446 (approximately)

Depreciation factor F_2 $$= \frac{0.07}{(1+0.07)^4 - 1}$$

$$= \frac{0.07}{1.31079 - 1}$$

$$= \frac{0.07}{0.31079}$$

F_2 $= 0.22523$

V_2 $= S \times F_2$

$= 800 \times 0.22523$

= Rs.180/-

M_2 = Rs.300 x 10/100+300

= 30 +300 =330

M_2 = Rs.330

Total annual cost $= A_2 + M_2 - V_2$

$= 446 + 330 - 180$

= Rs.596

THIRD YEAR

Principal = 1512 – 446 = 1066/-

P_3 = R.1066/-

N_3 = 3

I = 0.07

The third annual cost of the system $= \{1066 [0.07 (1+0.07)^3 / (1+0.07)^3 - 1\}$

$= \{1066[(0.07)(1.07)^3 / (1.07)^3 - 1]\}$

$=\{ 1066 [0.07 \times 1.2250 / 1.2250 - 1]\}$

$= 1066 [0.08573] / 0.2250$

$= 1066 \times 0.38112$

= 406.27

A_3 = Rs.406/-

Depreciation factor F_3 $= \dfrac{0.07}{(1+ 0.07)^3 - 1}$

$$= \frac{0.07}{1.2250 - 1}$$

F_3 $$= \frac{0.07}{0.2250} = 0.31111$$

F_3 $= 0.31111$

V_3 $= S \times F_3$

$= 800 \times 0.31111$

$= 248.8/-$

V_3 $= Rs.249/-$

M_3 $=330 \times 10 + 330/100= 363$

M_3 $= 363$

Total annual cost

(third year) $= A_3 + M_3 - V_3$

$= 406 + 363 - 249$

$=$ Rs. 520/-

FOURTH YEAR

Principal $= 1066 - 406$ $=$ Rs.660/-

P_4 $=$ Rs.660/-

N $= 2$

I $= 0.07$

The fourth annual cost of the system A_4 $= \{ 660 [0.07 (1+0.07)^2 / ((1+0.07)^2 - 1)] \}$

$= 660 [0.07 \times (1.07)^2 / ((1.07)^2 - 1)]$

$= 660 [0.07 \times 1.1449 / (1.1449 - 1)]$

$= 660 \times 0.080143 / 0.1449$

A_4 $= 660 \times 0.5530$

A_4 $= 365/-$

Depreciation factor F_4 $= \dfrac{0.07}{(1 + 0.07)^2 - 1}$

$= \dfrac{0.07}{(1.07)^2 - 1}$

$= \dfrac{0.07}{0.1449} = 0.48309$

V_4 $= S \times F_4$

$= 800 \times 0.48309$

V_4 $= Rs.386/-$

M_4 $= 363 + 363 \times 10/100$

$= 363 + 36.3 = 399.3$

M_4 = Rs.399/-

Total annual cost (fourth year) $= A_4 + M_4 - V_4$

$= 365 + 399 - 386$

= Rs. 378/-

FIFTH YEAR

Principal P_5 $= 660 - 365 = 295$

P_5 = Rs.295/-

No of years N = 1

I = 0.07

The fifth (final) annual cost of the system $A_5 = \left\{ 295 \left[\frac{0.07\,(1+0.07)^1}{(1+0.07)^1 - 1} \right] \right\}$

$= \left\{ 295 \left[\frac{0.07\,(1.07)}{(1.07) - 1} \right] \right\}$

$= 295 \times 1.07$

$= 315.6$

A_5 = Rs.316/-

Depreciation factor $F_5 = \frac{0.07}{(1 + 0.07)^1 - 1}$

$F_5 = \frac{0.07}{0.07} = 1$

$V_5 = S \times F_5 = 800 \times 1$

$= Rs.800/-$

The total life span of the system is assumed as five years. Hence at the end of the life span of the system the scrap value of Rs.800/- is realized. The amount towards the maintenance of the system is calculated and found as Rs.439/- and the annual cost of the system (fifth year) is found to be Rs. 316/-Hence a total amount of Rs.755/- has to be spent on the system towards the end of the fifth year. Now by deducting the amount spent from scrap value we obtain Rs. 45/- . This amount and the cost incurred from the distilled water is the profit obtained towards the life span of the system.

5.9 ANNUAL PRODUCTION OF DISTILLED WATER USING THE PROCESS OF SOLAR DISTILLATION

The amount of distilled water produced annually by the process of solar desalination is calculated and given here under.

SOLAR PARTICULARS FOR A YEAR:

Total number of solar days in a year = 200 days

Average number of operating hours per day = 6 hours

Total solar working hours in a year = 200 x 6

= 1200h

Amount of distilled water produced per hour = 500 ml

(approximate value) = .5 l

Amount of distilled water produced in a year = 1200 x .5

	=	600 litres
Cost of distilled water		
per litre	=	Rs 3/-
Total cost of distilled		
water obtained in a year	=	600 x 3
	=	Rs 1800/-

5.10. COST – BENEFIT ANALYSIS

The cost –benefit analysis of the newly fabricated system for five years is given

(1st Year)

Annual cost spent for the system	= Rs.649/-
The total cost of distilled water obtained in the year	= Rs.1800/-
Profit (or benefit) incurred in first year	= 1800 – 649
	= Rs.1151/-

(2nd Year)

Annual cost the system	= Rs.596/-
Total cost of distilled water obtained in 2nd Year	= Rs.1800/-
Profit (or benefit) incurred in 2nd Year	= 1800 – 596
	= Rs.1204/-

(3rd Year)

Annual cost spent for the system	= Rs.520/-
Total cost of distilled water obtained in 3rd year	= 1800-520
Profit (or benefit) incurred in 3rd Year	= Rs.1280/-

(4th Year)

Annual cost spend for the system	= Rs.378/-

Total cost of distilled water obtained in the 4th Year = 1800-378

Profit (or benefit) incurred in 4th Year = Rs.1422/-

(5th Year)

Towards the end of the 5th Year we have

Scrap value - Amount spent = Profit

Rs.800 - Rs.755 = Rs.45/-

Total cost of the distilled water obtained in 5th Year = 1800/-

Total profit incurred in 5th year = 1800 + 45 = Rs.1845/-

S.NO.	YEAR	PROFIT INCURRED(Rs.)
1.	1	1151
2.	2	1204
3.	3	1280
4.	4	1422
5.	5	1845

Table No.2 : Profit obtained from distilled water.

From this table we observe that the profit increases gradually year by years. The cost obtained by marketing the distilled water in the first year is Rs.1800/-. This is taken as a constant value for all the years although there may be slight variation (the cost of distilled water may increase in the years) The amount of distillate may increase or decrease depending upon climatic parameters. But the amount of Rs.1800/- is taken as a constant for all the five years.

The above techno economic analysis reveals that the newly fabricated solar still is economically viable and profitable.

5.11 CHEMICAL ANALYSIS OF WATER AFTER AND BEFORE SOLAR DESALINATION

Table .3

S.NO	TEST	RAW WATER SAMPLE	SOLAR DISTILLED WATER SAMPLE
	A) PHYSICAL EXAMINATION		
1.	Appearance	Clear	Clear
2.	Color (pt - co scale)	Colorless	Colorless
3.	Turbidity N.T. units	None	None
4.	Total dissolved solids mg/L	1055	86
5.	Electrical conductivity (micro mho/cm)	1509	123
	B) CHEMICAL EXAMINATION		
1)	Ph	7.95	6.9
2)	Alkalinity ph	0	0
3)	As $Caco_3$ total	420	18
4)	Total hardness as $Caco_3$	210	14
5)	Calcium as ca	56	4
6)	Magnesium as Mg	17	1
7)	Manganese as Mn	0	0
8)	Free Ammonia as Ni_3	0	0
9)	Nitrite as No_2	0	0
10)	Nitrate as No_3	21	3
11)	Chloride as Cl	68	27
12)	Fluoride As F	1.0	0.2
13)	Sulphate as So_4	198	0
14)	Phosphate as Po_4	0	0

The objective of carrying out a chemical analysis was to determine the effectiveness of the desalination technique employed. Samples before and after desalination were tested for the total dissolved solutes, and for the concentrations of some common chemical contaminants (Saghafi.M,1994).

The solar still, when properly constructed and operated, produces water of very high quality. Firstly, particulate matter (mud), will be filtered out, so there will be none of it in the distillate.Dissolved solids are reduced to non-detectable levels. The incidence of organic substances, such as pesticides, fertilizers, solvents etc; is greatly reduced in the operation of the solar distiller. Polluted water is also purified in a solar still. (Mc Cracken,1990)

The saline water and the distilled water collected from the solar still were tested at the regional laboratory of Tamilnadu Water Board (TNWB), Coimbatore. The samples were tested for colour, odour, turbidity, Ph, electrical conductivity, total dissolved solids, alkalinity, chloride, total hardness, calcium, magnesium, sulphate, phosphate, nitrate, fluoride and manganese. (Palaniappan,2004)The results are given in the table.

5.12. GRAPHICAL ANALYSIS

The following graphs are plotted.

i. Time (hours) Vs Condensate production (ml)
ii. Time (hours) Vs Basin and glass temperature (^{o}c)
iii. Ambient temperature (^{o}c) Vs Basin and glass temperature (^{o}c)
iv. Total solar radiation (w/m^2) Vs Distillate production (ml)
v. Ambient temperature (^{o}c) Vs Distillate production (ml)
vi. Time (hours) Vs Solar insolation (w/m^2)
vii. Time (hours) Vs Observed efficiency (%)

A column chart giving the amount of distillate output in all the days of experimentation was also plotted.

All these graphs are plotted for a sunny day (ie June 4 th 2004) and a cloudy day (ie June 5 th 2004). This is done in order to study the variation of the different parameters influencing the distillate output at different climatic conditions. The characteristic curve of the basin type solar still is also plotted ($T_W - T_a$/ I Vs η)

(ii) RESULTS AND DISCUSSION

The overall performance of the solar desalination system is dependent on the performance of the heat collection, thermal storage, wind velocity, insolation, thermal storage and various climatic parameters especially the cloud cover.

1. EFFECT OF CLIMATIC PARAMETERS ON THE EFFICIENCY OF THE STILL.

The performance and operating conditions of a solar desalination plant (SDP) are strongly affected by the solar radiation, ambient temperature, water temperature, and other parameters like water salinity and depth . Most of these parameters are extremely unstable and are normally subject to continuous changes both on a daily and seasonal basis. In addition to these uncontrollable parameters, the plant is normally designed with some degree of control over other operating parameters such as temperature and flow rate. These controllable parameters also influence the plant performance in a fundamental manner and usually results in substantial change in the plant distillate production.(El-Nasher,1992)

a. EFFECT OF SOLAR RADIATION ON DISTILLATE OUTPUT

The effect of solar radiation on the daily output has been experimentally studied. It is found that in determining the output of a still, solar insolation is the single most important parameter. It depends to some extent upon how the radiation is distributed through out the day. On the seven days of experimentation the least value of distillate output is obtained on June 5th 2004, since the average solar radiation value was found to be minimum on that day. From the values obtained on these days, it is obvious that solar insolation is the most significant parameter upon which the daily distillate output depends.

TABLE.4 : EFFECT OF SOLAR RADIATION ON DISTILLATE OUTPUT (9:30 A.M.- 10:30 P.M.)

S.NO.	DATE	AVERAGE SOLAR RADIATION (W/M^2)	DISTILLATE OUTPUT (Ml)
1.	03-06-2004	576.56	1220
2.	04-06-2004	713.715	1620
3.	05-06-2004	549.26	1050
4.	23-06-2004	598.44	1460
5.	24-06-2004	633.47	1280
6.	25-06-2004	564.53	1140
7.	26-06-2004	683.2	1460

b. EFFECT OF AMBIENT TEMPERATURE ON DISTILLED WATER OUTPUT

The productivity of the solar still increases as the ambient temperature increases. The increase in the productivity is about 0.871 lit/day/m^2 for $5^{o}c$ rise in ambient temperature. Morse and Read have shown that the ambient temperature change from 26 $.7^{o}c$ to $37.8^{o}c$ causes an increase of 11% in the output.

In the seven days of experimentation, higher values for distillate output was obtained on 4^{th} June 2004 which has recorded a maximum average ambient temperature of $33.2^{o}c$ and lesser values of distillate output is obtained on 5 th June 2004 since the ambient temperature was found to be only $30.3^{o}c$ on that day. This shows the dependence of the daily distillate output on the ambient temperature of that day.

TABLE.5 : EFFECT OF AMBIENT TEMPERATURE ON DISTILLATE OUTPUT (9:30 A.M.- 10:30 P.M.)

S.NO.	DATE	AVERAGE AMBIENT TEMPERATURE (°C)	DISTILLATE OUTPUT (Ml)
1.	03-06-2004	32.7	1270
2.	04-06-2004	33.2	1620
3.	05-06-2004	30.3	1050
4.	23-06-2004	31.4	1460
5.	24-06-2004	32.2	1280
6.	25-06-2004	32.4	1140
7.	26-06-2004	33.1	1460

c. VARIATION OF DISTILLATE OUTPUT WITH TIME:

The amount of distillate output is found to vary during different hours of the day. It is found to be maximum from 11:30 A.M to 1:30 P.M. The ambient temperature and solar insolation are high during this period. Hence maximum distillate output is obtained during this time period of the day where as a decrease in the distillate output is observed before and after this time interval.

d. VARIATION OF THE BASIN AND GLASS TEMPERATURE:

The observed temperature values of the basin and cover glass are given in tables. It is noted that the basin temperature is always greater than the cover glass temperature, which is in agreement with the theory, otherwise there will not be any condensation.

From the tables it is noted that as the solar insolation values increases with the time of the day, the temperature values of basin and glass also increases steadily reaching a maximum value of 69°c at 1:30 P.M when the solar insolation is also maximum (Day 5).

It was reported by Cooper that there was some doubt about the validity of Dunkle's equation used to estimate the convective and evaporative heat transfer at elevated temperatures. The peak basin temperature recorded at 1:30 P.M on 24th June 2004 was 69°c. Dunkle has indicated that some of the assumptions made in the derivation for q_{cw} and q_{ew} may not be valid at the temperature achieved in the experimental still.

2. EFFICIENCY OF THE SYSTEM:

The daily thermal efficiency was found to be in the range of 20 – 60% and the distillate output was found to vary between 1300-1700 ml (excluding nocturnal contribution). Ambient temperatures were found to vary between 28 – 35°c. The solar insolation was found to vary between 500 – 750 w/ m^2. The thermal performance of the still can be further increased if the suggestions and recommendations given in chapter 6 are implemented. Maximum efficiency is observed during peak time interval of 12:30 – 1:30 P.M.

3. THERMAL ANALYSIS:

The thermal analysis is done on the newly constructed basin type solar still is done and results are obtained.

i. Partial Vapour pressure at water temperature P_w = 7208.38 pa

ii. Partial Vapour Pressure at glass temperature P_g = 5229.129 pa

iii. The radiative heat transfer coefficient from the water surface of the glass cover h_{rw} = 5.54 w/m^2

iv. The heat transfer due to radiation q_{rw} = 33.24 w/m^2

v. Convective loss coefficient from the water surface to the glass cover, h_{cw} = 2.465 w/m^2

vi. The heat transfer from water surface to the glass cover by convection q_{cw} = $14.8 w/m^2 \, ^oC$

vii. Evaporative loss coefficient from water surface to glass cover, h_{ew} = $13.23 \, w/m^2 \, ^oC$

viii. The rate of evaporative loss from water surface to glass cover q_{ew} = $79.392 \, w/m^2 \, ^oC$

ix. Total internal heat transfer coefficient h_{lw} = $21.23 \, w/m^2 \, ^oC$

x. The radiative heat transfer coefficient (h_{rg}) = $14.05 \, w/m^2 \, ^oC$

xi. The heat loss, due to radiation (q_{rg}) = $56.2 \, w/m^{2o}C$

xii. The convective heat transfer coefficient (h_{cg}) from glass cover to outside = $7.3 \, w/m^{2o}C$

xiii. The heat transfer due to convection from glass cover to outside q_{eg} = $29.2 \, w/m^{2o}C$

xiv. The total heat transfer coefficient from glass to ambient (h_{1g}) = $21.35 \, w/m^{2o}C$

xv. The top loss coefficient from water surface to ambient air (U_T) = $7.417 \, w/m^{2o}C$

4. DETERMINATION OF THE DISTILLATE OUTPUT AND EFFICIENCY:

The predicated and the observed value of the distillate output are calculated values of the distillate output are calculated and the values are given as follows.

(According to reading at 10.00 h on June 3rd 2004)

i. Predicted distillate output Me p_{re} = $0.117617 \, Kg/m^2 \, h$

ii. Observed distillate output Me_{obs} = $0.118110 \, Kg / m^2 \, h$

Using these values the predicted and observed efficiencies are calculated and the results are obtained as follows.

i. Predicted efficiency ηpre = 15.79%
ii. Observed efficiency η obs = 15.8%

The values of predicted and observed efficiencies are found to coincide well with each other.

5. THEORETICAL ANALYSIS:

Theoretical analysis was undertaken to compute the theoretical values of T_w & T_g and these are compared with the experimental values.

Theoretical values of T_W = 62 ^oC
Experimental values of T_W = 60 ^oC
Theoretical values of T_g = 47 ^oC
Experimental values of T_g = 44 ^oC

These values are found to be close to each other

6. TECHNO ECONOMIC ANALYSIS:

Techno economic analysis is done on the system to compute the total annual cost of the newly fabricated solar desalination system. The economic analysis is performed by assuming the life span of the constructed solar still to be five years. The first annual cost of the system is computed and found to be Rs .488/-. The first annual salvage value was found to be Rs .139/-.The total annual cost is calculated by adding the first annual cost of the system and the maintenance cost of the system and by deducting the salvage value from it. The total annual cost of the fabricated solar still was calculated and found to be Rs. 649/-. (first year) and similarly the analysis is done for five years and the results are obtained.

7. COMPUTATION OF THE ANNUAL DISTILLATE PRODUCTION USING SOLAR DESALINATION PROCESS:

The amount of distilled water produced annually by the process of solar desalination is computed and the results are obtained. There are approximately 200 solar days in a year and 6 hours of bright sunshine in a day. Nearly 500 ml of distilled water is produced per hour. Based on the above data, the total cost of distilled water obtained in a year was found to be Rs 1,800 /-. This figure is expected to increase by proper handling and maintenance of the system.

8. COST - BENEFIT ANALYSIS

The cost- benefit analysis of the system is done and the annual profit of around Rs 1500/- is obtained. Hence the capital investment of Rs.2000 can be recovered in a period of less than two years.

9. PHYSICAL AND CHEMICAL ANALYSIS OF THE DISTILLATE

The samples were physically and chemically analyzed before and after solar distillation, in the Tamilnadu Water Board, Regional laboratory, Coimbatore. The solar distilled water was found to be superior in all respects when compared to the saline water. The analysis shows clearly, that the total dissolved solids were reduced to very low values and Ph was found to be 6.9, which is the normal Ph of distilled water and the values of calcium, magnesium, nitrate, chloride, fluoride and sulphate are found to be negligible. Electrical conductivity is also reduced but it has a slightly higher value than the specified value. This discrepancy in the electrical conductance is due to the contamination of the product water since it is permanently in contact with the welded G.I. sheet. Hence the solar distilled water was found to be superior to the saline water in physical as well as chemical analysis of the water samples.(El-Kassaby.M.M,1991)

10. GRAPHICAL ANALYSIS OF THE CLIMATIC PARAMETERS

The following inferences are obtained from the graphs plotted between the various climatic parameters such as solar insolation, ambient temperature, wind velocity etc during a sunny day (4^{th} June 2004) and cloudy day (5^{th} June 2004) of experimentation.

For sunny day, the basin and glass temperatures increase gradually with time and then decreases. During the cloudy day the values do not increase to maximum value (fig. 11 a & b).

It is observed that the distillate output is maximum at 1:30 P.M during a sunny day where as during a cloudy day, the sudden drop in distillate output is observed at 1:30 P.M due to the drop in ambient temperature and solar insolation (fig. 10 a & b).

It is found that the values of basin and glass temperatures are maximum during a sunny day where as there is no notable increase is observed during a cloudy day (fig.9 a & b)

It is obvious that the amount of distillate output is maximum on sunny day where as the amount of distillate output decreases substantially on a cloudy day (fig.14 a & b).

It is observed that on a sunny day, as the ambient temperature increases gradually with time, the amount of distillate output also increases and decreases as ambient temperature decreases with time, whereas on a cloudy day the distillate output decreases when ever there is a decrease in ambient temperature (fig15 a & b).

It is found that the solar radiation steadily increases with time during a sunny day whereas on a cloudy day, due to the presence of clouds, there is a variation in the amount of solar radiation throughout the day (fig. 13 a& b).

The variation of efficiency with time can be noted. Usually the efficiency is found to be maximum at the time interval of 12:30 - 1:30 P.M. The efficiencies are found to be maximum when the solar insolation values are maximum at other periods of the day also (fig.12 a & b).

In the column chart, the distillate output during different days of experimentation can be observed. It is found to be high (that is 1620 ml) on Day 2, since the solar insolation and ambient temperatures are maximum on that day. The output is found to be low (that is 1050ml)on Day 3 since the solar insolation and corresponding ambient temperatures are minimum on that day (fig.16).

From the above graphical analysis, it is obvious that the distillate output is maximum when the ambient temperature and solar insolation values are maximum (at the peak hours of the day). The presence of clouds has a negative impact on the distillate output since the distillate output gets substantially reduced during a cloudy day. All these observations are obtained from the figures 9 to 16. The characteristic curve of the basin type solar still is given in fig. 17.

PLATE 1. BASIN TYPE SOLAR STILL WITH MEASURING INSTRUMENTS

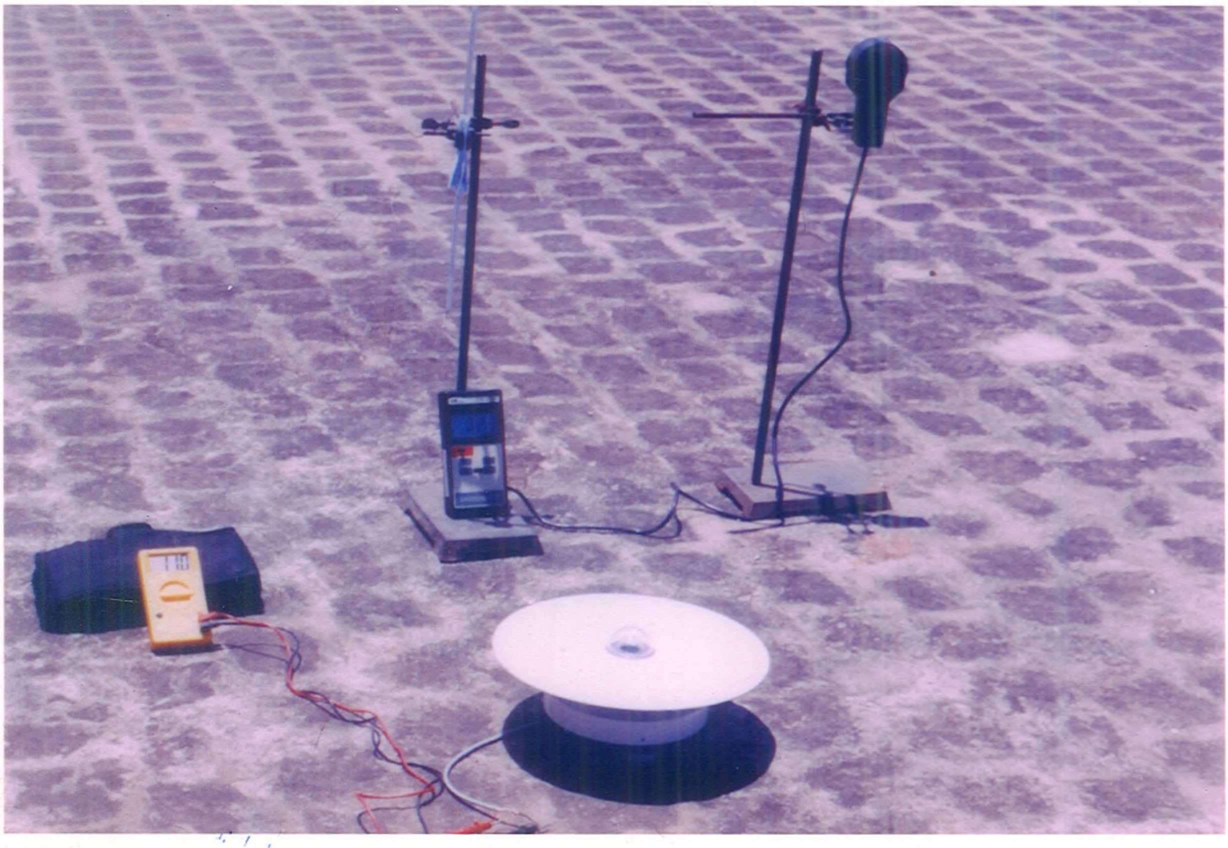


PLATE 2. INSTRUMENTS TO MEASURE THE CLIMATIC PARAMETERS

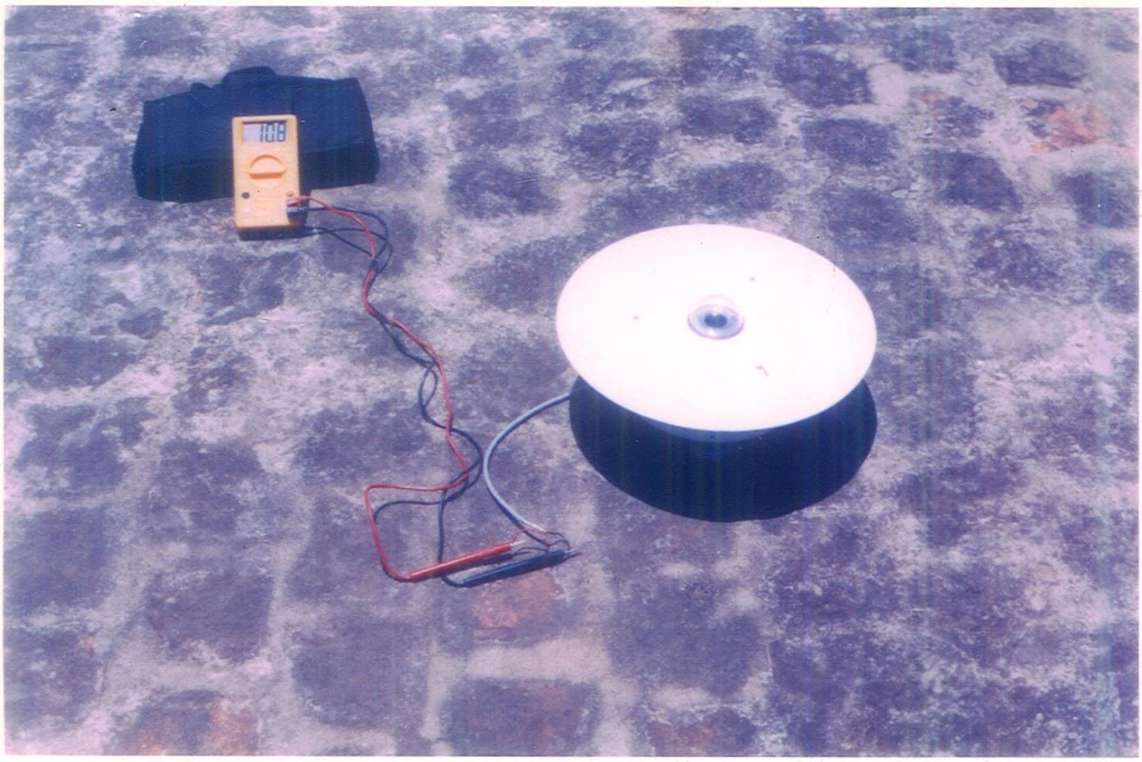


PLATE 3 (i). PYRANOMETER
TO MEASURE SOLAR INSOLATION

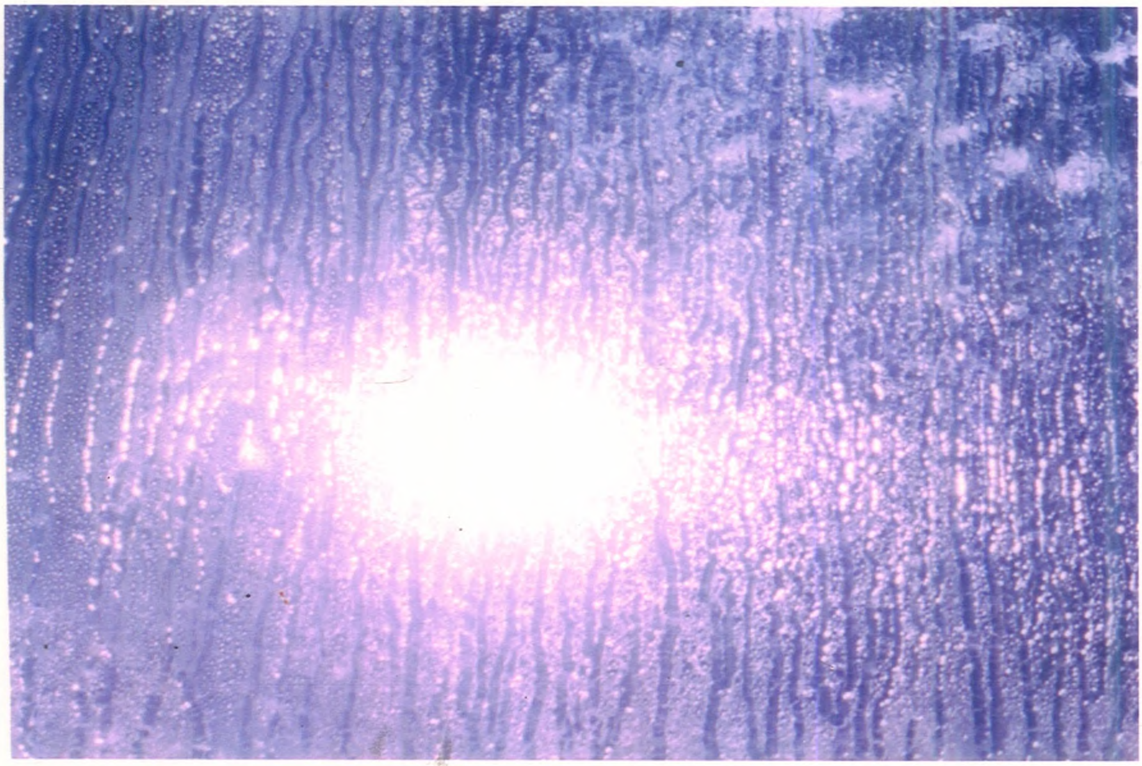


PLATE 3 (ii). IMAGE OF THE SUN
INSIDE THE SOLAR STILL

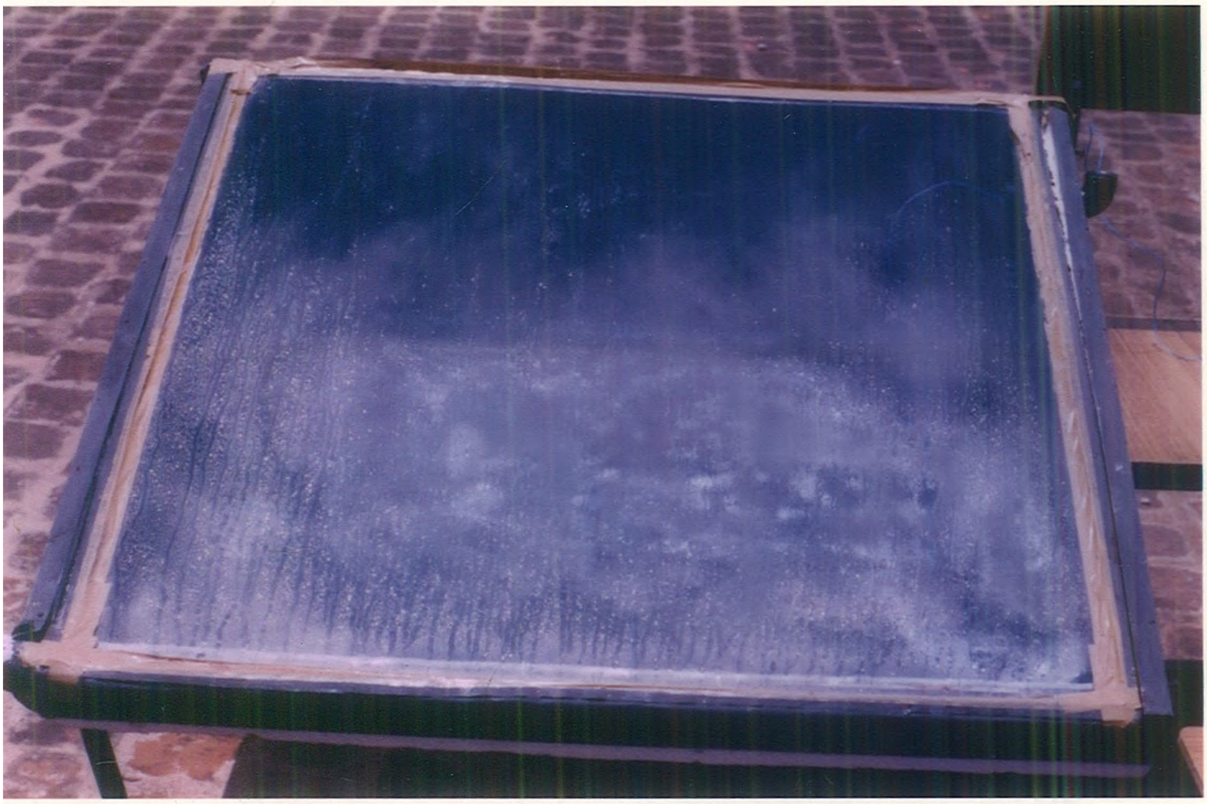
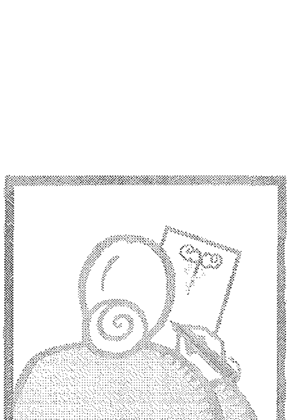


PLATE 4. TOP VIEW OF THE SOLAR STILL



SUMMARY AND CONCLUSION

6.SUMMARY AND CONCLUSION

6.1 LIMITATIONS:

- The device may have the problem of algae growth, which decreases the absorption capacity of the basin. This may be averted if frequent cleaning of the basin is undertaken.

- The black paint used to enhance the solar absorption at the basin gets leached after about one month into the excess water accumulated during off sunshine hours. This can be prevented by avoiding water accumulation in the basin when the still is not in operation.

- The absorbing capacity of the absorber deteriorated due to the salt deposition in it. This can be avoided by filling the basin every day before sunshine and leaving it to work for 24 hours after which it is drained and refilled again. This method gets rid of the saline water before its concentration increases to the limit where the salt badly affects the basin.

- The deposition of dust on the glass cover reduces the transmittance of the glass cover. Glass covers should be frequently cleaned to avoid it.

- The leakage of water vapor occurs from the joints between the glass cover and the sides of the still. This can be avoided by using a sealant of good quality (Tiwari et al,1994).

- Normally, basin type solar stills have the drawback of rejection of latent heat of condensation to the atmosphere which results in the reduction of the operating efficiencies (Joyce et al ,1994).

- The nocturnal contribution increase with the increase in water depth and decrease in the solar insolation. But since the newly fabricated solar still is a shallow basin type still, it is not possible to increase the depth of the still above a certain limit.

6.2 SUGGESTIONS AND RECOMMENDATIONS FOR FUTURE WORK

- The water productivity in the solar still can be enhanced by using vacuum inside the still. This is mainly due to the absence of convection heat transfer loss from the water and also the absence of non-condensable gases inside the still when complete vacuum is applied (Al-Hussaini and Smith. I.K,1994).

- The construction material should be corrosion resistant and they should be able to withstand temperature unto 80°c(Saghafi.M,1994).

- For simplicity, good productivity and limited operation requirements with no problems, floating wick type stills can be used in remote and isolated areas. (Al-Karaghouli et al,1995).

- The nocturnal productivity can be increased by increasing the water depth of the still (El-Sherbiny et al,1993).

- Tubular multiwick type solar still can be used to yield high distillate output, even under typical cold climatic conditions (Kumar.A and Anand J.D, 1992). It has been experimentally reported that tilted wick type solar stills have some advantages over basin type stills (Talbert et al, 1970,Hirschman.J and Rheinlaender.J,1976 and Moustafa.S.and Brusewith. G, 1976).

- To increase the productivity, the still can be integrated with external systems as metal condensers, external reflectors, heat pipes, waste heat source, flat plate collectors (or) concentrators.(Zaki etal,1993)

- The efficiency of the still can be increased to a considerable extent by providing arrangements for simultaneous dry air bubbling and glass cooling. In this system wind energy can be used for bubbling.(Pandey.G.C,1984)

- Multiflash evaporation may offer a good potential when it is used in a solar desalination system.(Moustafa et al,1985).

- The absorption system of the still can be powered by a renewable energy source (or) by a hybrid method (e.g. solar energy and natural gas). It has several attractive features including a high performance ratio, no pretreatment required, extraction of water at low temperatures, absence of scaling and minimal corrosion(Riffat.S.B,1985).

- The idea of using gravity to create a partial vacuum through hydrostatic pressure, which increases the rate of evaporation, can be investigated. Tests on small prototypes have resulted in almost twice the efficiencies of solar stills (Goswami, 2003). A complete vacuum in solar still was also used by Abbot(1934)

- Selective coatings can be used in the still to increase the absorption capacity and hence the productivity of the still

The daily yield of a conventional solar still can be increased by passive methods like:

- Use of good insulating material
- Lowering heat capacity of basin water
- Use of water flow over the glass cover

and active methods like:

- Use of waste hot water(Tiwari.G.N,1985)
- Integration of panel of collectors to the basin with or without heat exchanger (Lawrence etal,1990).

- Normally, solar still use solar energy on a single stage basis. Multi-effects of energy can be achieved by passing the condensing vapor through a heat exchanger so that latent heat is transferred to incoming feed water. (Fernandes & Chargoy, 1990)
- In order to utilise the latent heat of condensation at the bottom face of the glass cover feed water can be allowed to flow over the glass cover prior to its entering the still. (Tiwari et al, 1985)

6.3.CONCLUSION

In the coming decades, as the environmental degradation takes it's toll on available, potable water resources, low-cost environmentally benign methods of purifying, restoring or desalinating water will become increasingly valuable (Mc Cracken, 1990). Hence the utilization of solar radiation as the energy source for desalination plants like the present fabricated one may offer a valid alternative.

The conclusions of the experiments conducted in the newly designed $0.7040m^2$ area solar still are as follows:

- The efficiency of the newly fabricated, low cost solar still was found to be in the range of 20 - 60% and the distillate was found to vary between 1340 - 1800 ml for a solar insolation of 500 - 750 W / m^2. The efficiency was found to be maximum during the peak sunshine hours of the day.

- Techno-economic analysis is performed on the newly fabricated still and the annual cost of the system computed is found to be Rs 1849/-

- The annual distilled water production by the process of solar desalination is calculated and found to be 600 litres. The total cost of distilled water obtained in a year was found as Rs 18,00/- for 200 solar days. Hence the amount spent on the system could be recovered in a year.

- Cost- benefit analysis is performed on the system and the system is found to be profitable.

- The water samples (distillate) were physically and chemically analyzed and the quality of water was found to be superior to saline water obtained from bore well.

- Thermal analysis is done on the newly constructed basin type still and the various parameters are calculated.

- Theoretical analysis of the solar still is done to compute the values of T_w and T_g. These values are compared with the experimental values. They are found to be in close agreement.

- The observed and the predicted values of distillate output and the efficiencies are calculated. These values are also found to be in close agreement.

- The graphical analysis of the various climatic parameters revealed the fact that the presence of clouds had a negative influence on the efficiency of the still.

It was also obvious from the analysis and tabulations that the still efficiency has a strong bearing on climatic parameters like solar insolation, ambient temperature, wind velocity etc.

Table 6. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA
June 3rd 2004

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	W\m^2
10:00	30	01.5	40	34	7.7	609.17
10:30	33.4	0.01	48	37	9.6	741.88
11:00	33.7	0.03	60	44	10.0	791.13
11:30	33.8	01.6	61	46	10.2	806.96
12:00	34.0	00.5	65	47	10.7	846.51
12:30	33.0	00.2	62	40	9.2	727.84
1:00	33.8	00.5	65	41	10.2	806.96
1:30	33.6	00.9	65	41	9.8	775.31
2:00	33.0	01.8	62	38	9.3	735.75
2:30	31.5	01.8	52	36	5.8	458.86
3:00	31.0	01.2	51	36	5.5	435.12
3:30	30.0	02.0	47	33	1.5	118.67
4:00	30.0	01.8	43	32	2.5	201.61

Table 7. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA
June 4th 2004

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	W\m^2
9:30	32.0	0.03	49	30	7.4	585.44
10:00	32.5	0.07	50	32	8.4	664.55
10:30	33.0	0.13	53	35	9.8	775.31
11:00	34.0	00.5	57	37	10.1	799.05
11:30	34.1	00.6	60	39	10.6	838.6
12:00	34.2	00.7	62	40	10.7	846.51
12:30	34.0	01.4	63	42	10.6	838.60
1:00	34.0	00.5	64	43	10.5	830.69
1:30	33.8	00.4	66	43	10.2	806.96
2:00	33.4	00.8	62	38	9.7	767.40
2:30	33.0	01.8	58	35	9.2	727.84
3:00	32.5	00.3	55	35	7.8.	617.08
3:30	32.2	00.6	55	35	5.8	458.86
4:00	32	01.8	54	34	5.5	435.12

Table 8. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA
June 5th 2004

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	W\m^2
9:30	32.0	01.2	42	33	7.7	609.17
10:00	32.0	0.01	48	34	8.7	688.29
10:30	31.5	00.5	54	35	8.8	696.20
11:00	31.0	01.6	56	36	8.9	704.11
11:30	30.5	00.6	56	37	7.2	569.62
12:00	30.2	00.4	58	37	12.3	973.10
12:30	30.1	00.5	53	35	5.9	466.77
1:00	30.0	00.8	49	34	4.5	356.01
1:30	30.0	00.3	50	35	6.9	545.88
2:00	29.8	00.6	51	36	6.6	522.15
2:30	29.5	01.8	50	36	5.0	395.56
3:00	29.5	01.2	51	35	5.1	403.48
3:30	29.0	00.5	50	35	4.9	387.65
4:00	29.0	00.3	49	33	4.7	371.83

**Table 9. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA'
June23rd 2004**

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	w\m^2
9:30	31.0	00.4	43	33	8.0	632.91
10:00	31.2	0.02	48	34	8.1	640.82
10:30	31.4	01.2	49	37	8.4	664.55
11:00	31.5	00.1	53	39	8.6	680.37
11:30	31.8	00.3	58	38	8.8	696.2
12:00	32.4	00.4	64	40	10.2	806.96
12:30	32.5	00.2	67	42	10.4	822.78
1:00	32.3	00.3	64	43	10.2	806.96
1:30	32.0	00.4	63	43	9.8	775.31
2:00	31.9	00.5	60	41	7.1	561.70
2:30	32.1	00.4	62	41	9.3	735.75
3:00	30.0	01.4	47	37	2.1	166.13
3:30	30.0	01.6	46	36	2.5	197.78
4:00	29.8	02.4	44	34	2.4	189.87

Table 10. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA
June 24th 2004

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	w\m^2
9:30	31.0	00.5	38	35	7.5	593.35
10:00	32.0	0.03	45	38	8.5	672.46
10:30	34.0	00.0	52	39	9.0	712.02
11:00	34.2	00.7	58	40	9.8	775.31
11:30	32.0	00.4	58	40	9.0	712.02
12:00	31.0	00.6	49	36	4.0	316.45
12:30	31.5	00.8	53	37	7.5	593.35
1:00	32.0	00.4	69	38	9.0	712.02
1:30	32.5	00.6	69	41	9.7	767.4
2:00	32.8	00.0	68	41	9.5	751.58
2:30	32.5	01.8	60	38	9.2	727.84
3:00	31.8	01.4	56	38	6.4	506.32
3:30	31.7	00.4	55	38	6.0	474.68
4:00	32.0	00.6	54	39	7.0	553.79

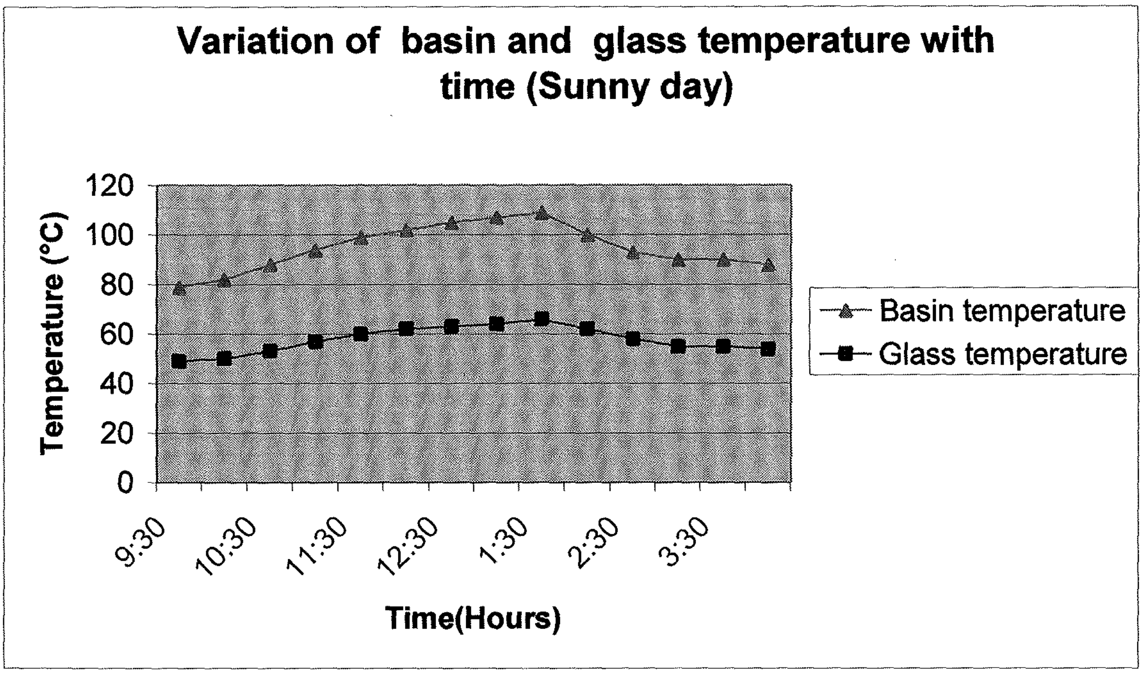
Table 11. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA June 25th 2004

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	w\m^2
9:30	32.3	00.4	43	35	7.0	553.79
10:00	33.0	0.02	53	40	8.5	672.46
10:30	33.1	00.3	57	41	8.8	696.2
11:00	32.8	00.0	59	41	8.7	688.29
11:30	33.1	00.4	62	42	9.8	775.31
12:00	32.0	00.3	60	45	5.4	421.2
12:30	33.5	00.3	63	46	10.2	806.96
1:00	32.0	00.3	60	42	6.5	514.24
1:30	32.5	00.3	61	42	6.6	522.15
2:00	31.8	01.6	48	37	3.7	292.72
2:30	32.0	01.9	54	38	5.6	443.03
3:00	32.2	00.3	56	38	6.6	522.15
3:30	32.0	00.5	55	37	6.5	514.24
4:00	31.8	01.4	53	37	6.0	474.68

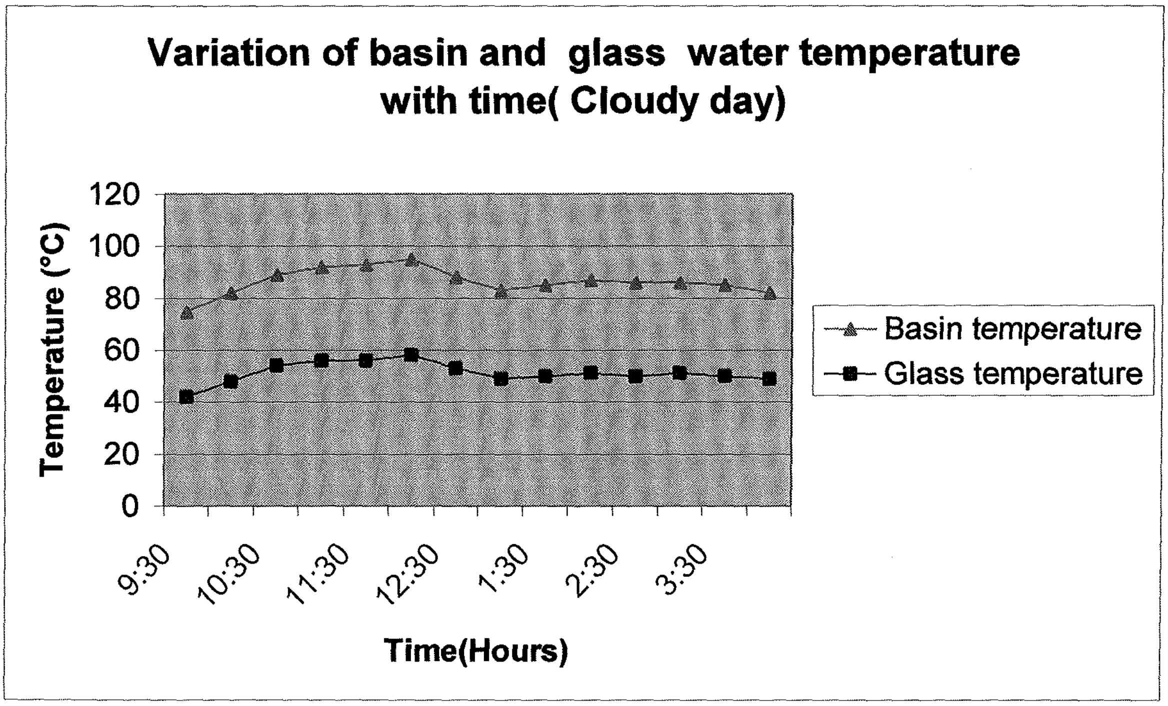
Table 12. ESTIMATION OF THE EFFICIENCY OF THE SYSTEM:DA June 26th 2004

LOCAL TIME	AMBIENT TEMP (°C)	WIND SPEED (m/sec)	BASIN WATER TEMP (°C)	COVER GLAZING TEMP (°C)	INTENSITY OF SOLAR RADIATION	
					mv	w\m^2
9:30	32.0	00.2	45	34	7.7	609.17
10:00	34.0	0.04	51	35	9.6	759.49
10:30	34.1	01.0	55	41	9.7	767.40
11:00	33.8	00.3	60	41	9.6	759.49
11:30	34.4	00.5	63	42	10.5	830.69
12:00	34.4	00.2	65	43	10.5	830.69
12:30	34.6	00.8	65	43	10.6	838.60
1:00	34.4	00.2	65	44	10.4	822.78
1:30	33.5	00.9	62	42	10.0	791.13
2:00	33.0	00.5	60	39	9.4	743.67
2:30	32.8	00.4	59	39	8.3	656.64
3:00	32.7	00.3	58	38	8.5	672.46
3:30	30.9	00.3	51	36	3.9	308.64
4:00	30.0	01.8	45	34	2.2	174.05

Figure : 9 a & b

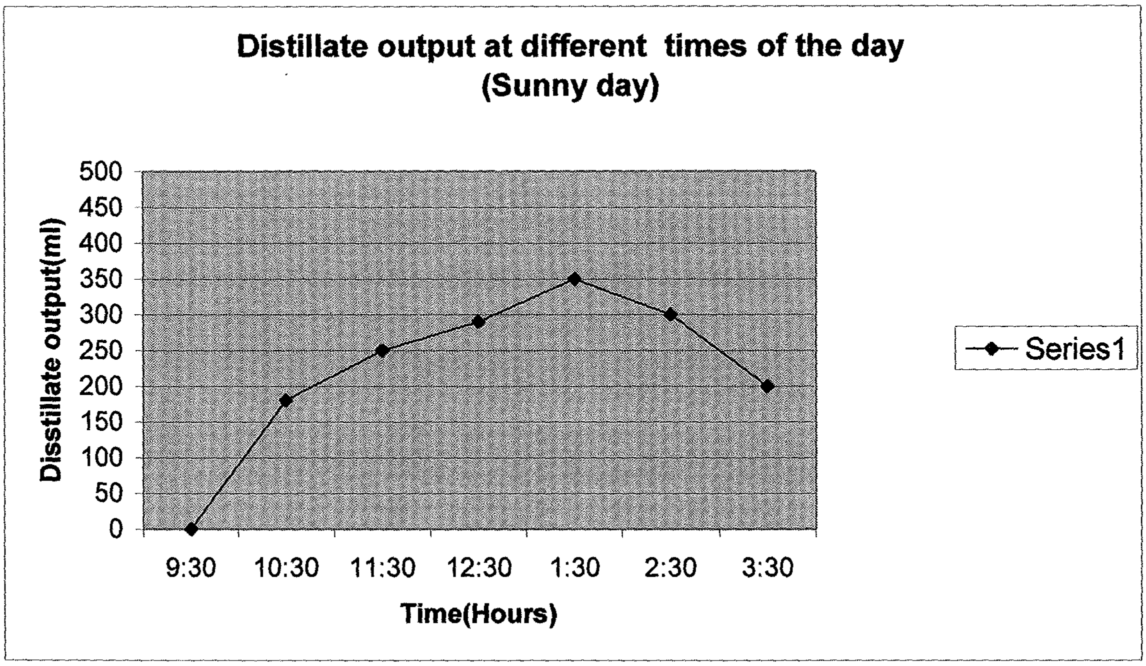


Variation of basin and glass temperature with time (Sunny day)
120
100
80
60
40
20
0
Temperature (°C)
Basin temperature
Glass temperature
9:30
10:30
11:30
12:30
1:30
2:30
3:30
Time(Hours)

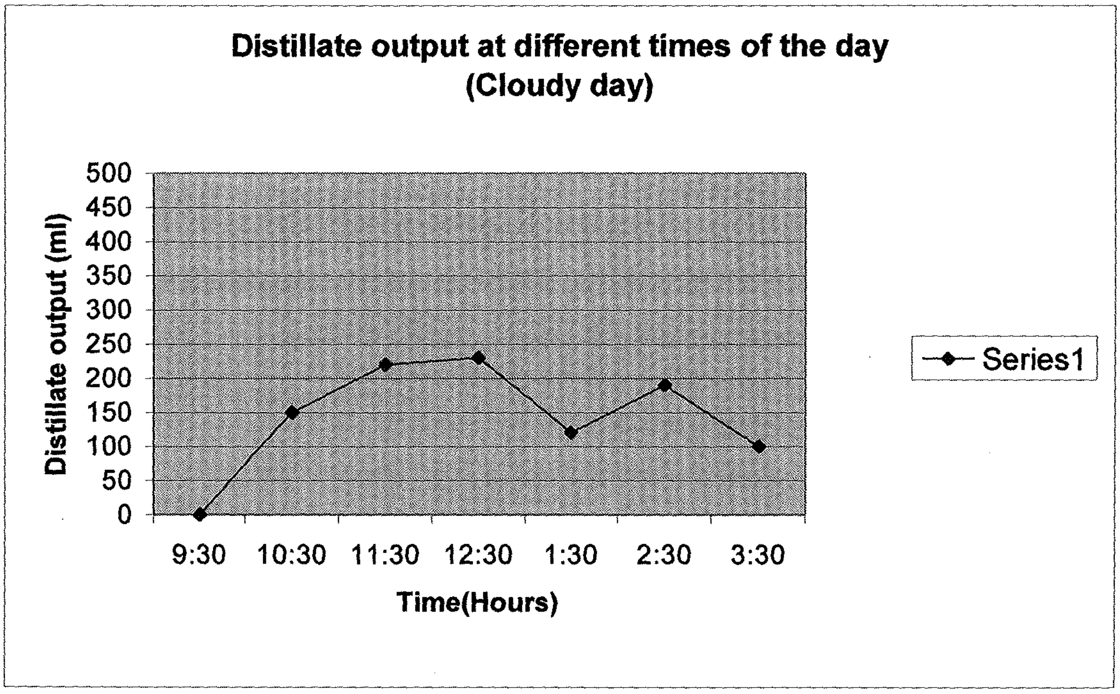


Variation of basin and glass water temperature with time(Cloudy day)
120
100
80
60
40
20
0
Temperature (°C)
Basin temperature
Glass temperature
9:30
10:30
11:30
12:30
1:30
2:30
3:30
Time(Hours)

Figure 10 a & b

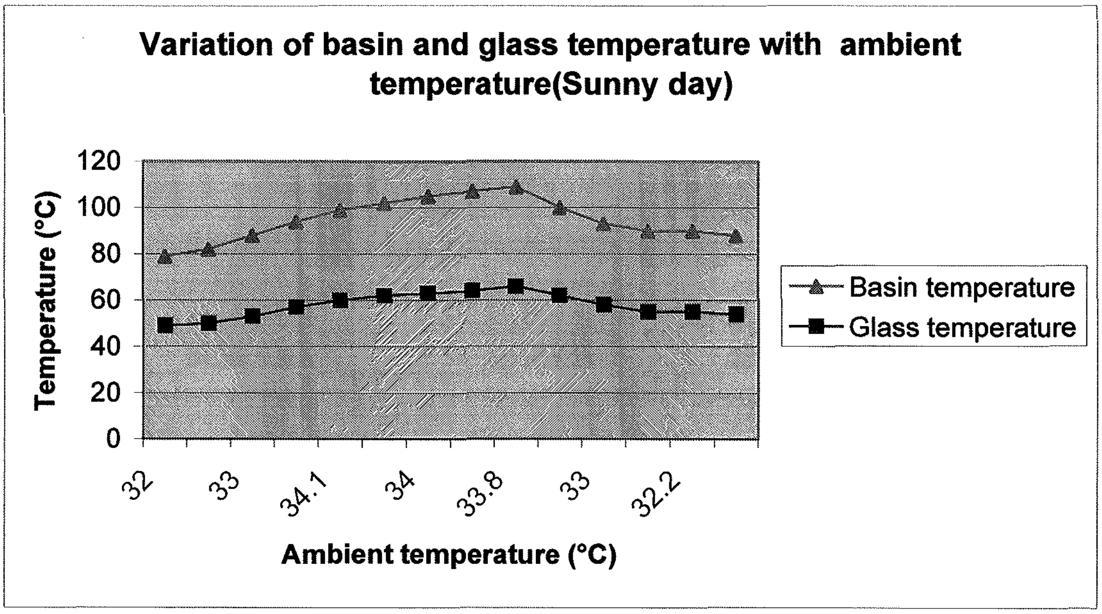


Distillate output at different times of the day
(Sunny day)
500
450
400
350
300
250
200
150
100
50
0
Disstillate output(ml)
9:30
10:30
11:30
12:30
1:30
2:30
3:30
Time(Hours)
Series1



Distillate output at different times of the day
(Cloudy day)
500
450
400
350
300
250
200
150
100
50
0
Distillate output (ml)
9:30
10:30
11:30
12:30
1:30
2:30
3:30
Time(Hours)
Series1

Figure 11 a & b


Variation of basin and glass temperature with ambient temperature(Sunny day)
Temperature (°C)
120
100
80
60
40
20
0
32
33
34.1
34
33.8
33
32.2
Ambient temperature (°C)
Basin temperature
Glass temperature

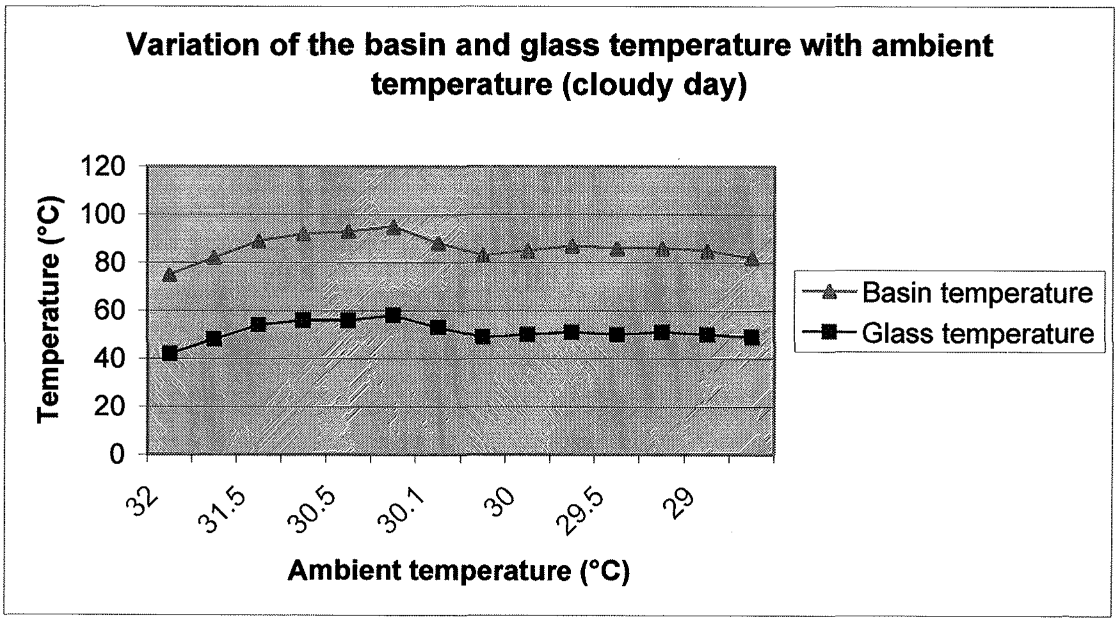

Variation of the basin and glass temperature with ambient temperature (cloudy day)
Temperature (°C)
120
100
80
60
40
20
0
32
31.5
30.5
30.1
30
29.5
29
Ambient temperature (°C)
Basin temperature
Glass temperature

Figure : 12 a & b

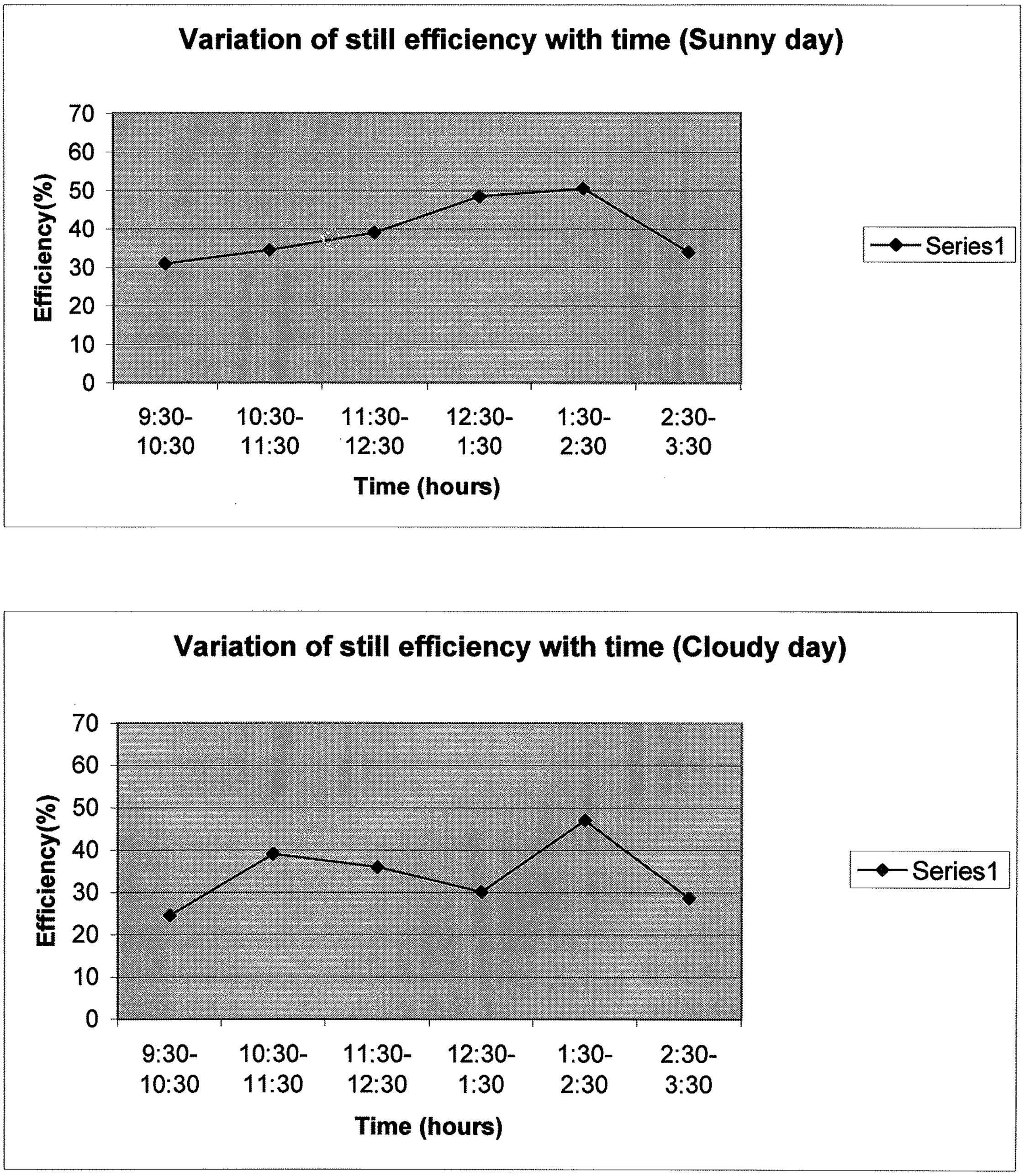
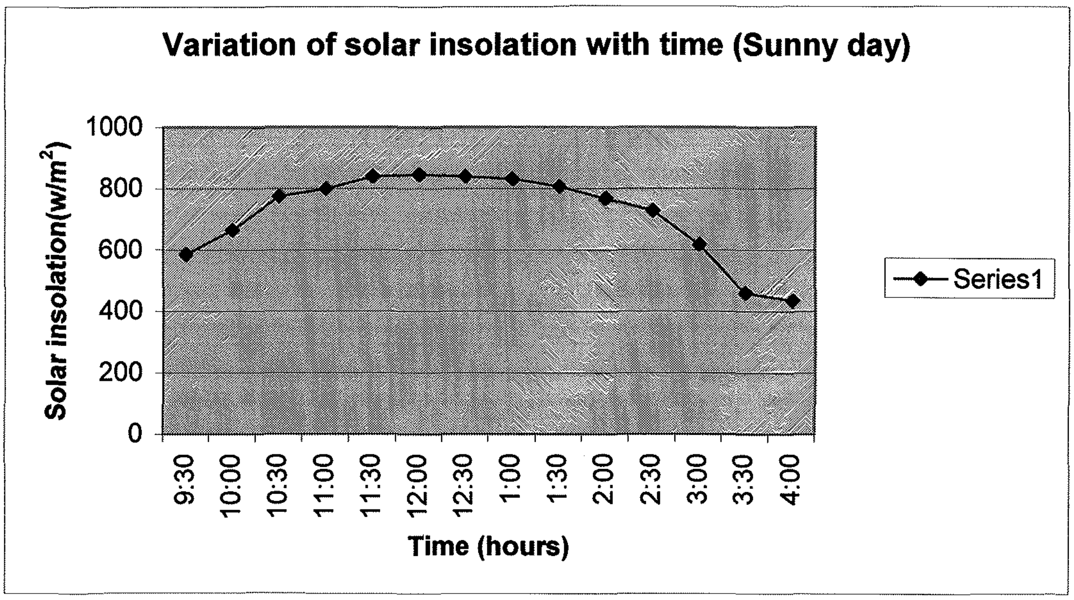

Variation of still efficiency with time (Sunny day)
70
60
50
40
30
20
10
0
Efficiency(%)
9:30-10:30
10:30-11:30
11:30-12:30
12:30-1:30
1:30-2:30
2:30-3:30
Time (hours)
Series1
Variation of still efficiency with time (Cloudy day)
70
60
50
40
30
20
10
0
Efficiency(%)
9:30-10:30
10:30-11:30
11:30-12:30
12:30-1:30
1:30-2:30
2:30-3:30
Time (hours)
Series1

Figure : 13 a & b


Variation of solar insolation with time (Sunny day)
Solar insolation(w/m2)
1000
800
600
400
200
0
9:30
10:00
10:30
11:00
11:30
12:00
12:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
Time (hours)
Series1

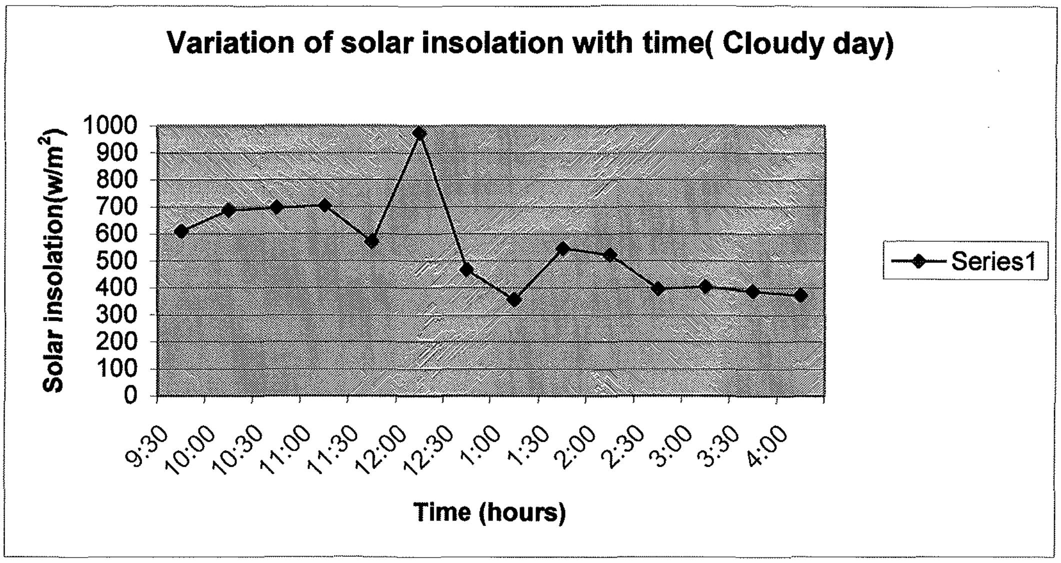
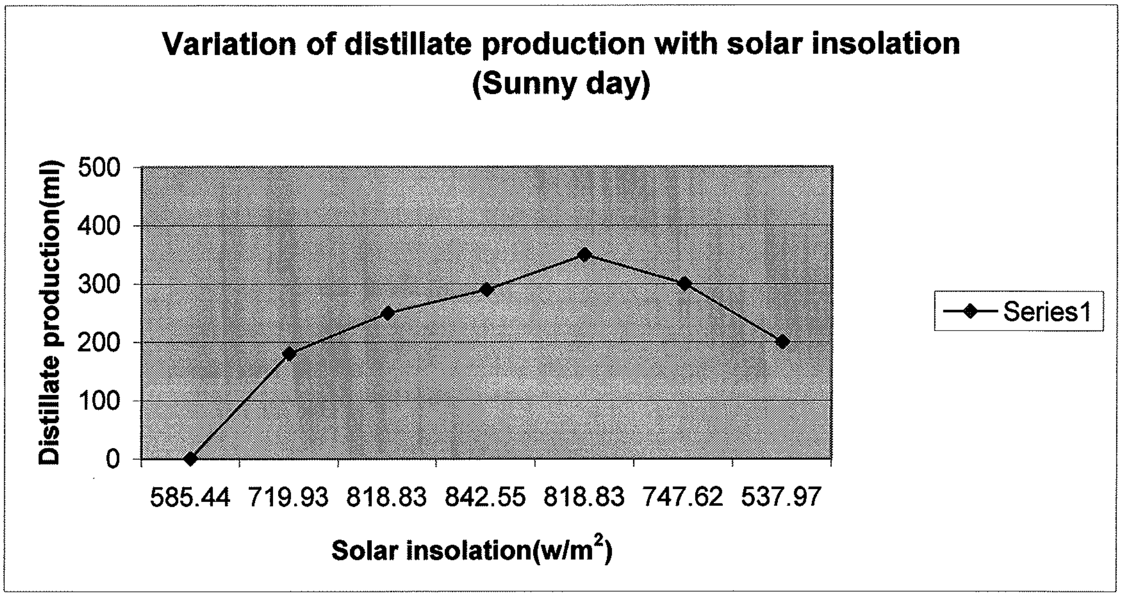

Variation of solar insolation with time(Cloudy day)
Solar insolation(w/m2)
1000
900
800
700
600
500
400
300
200
100
0
9:30
10:00
10:30
11:00
11:30
12:00
12:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
Time (hours)
Series1

Figure : 14 a & b


Variation of distillate production with solar insolation (Sunny day)
Distillate production(ml)
500
400
300
200
100
0
585.44 719.93 818.83 842.55 818.83 747.62 537.97
Solar insolation(w/m2)
Series1

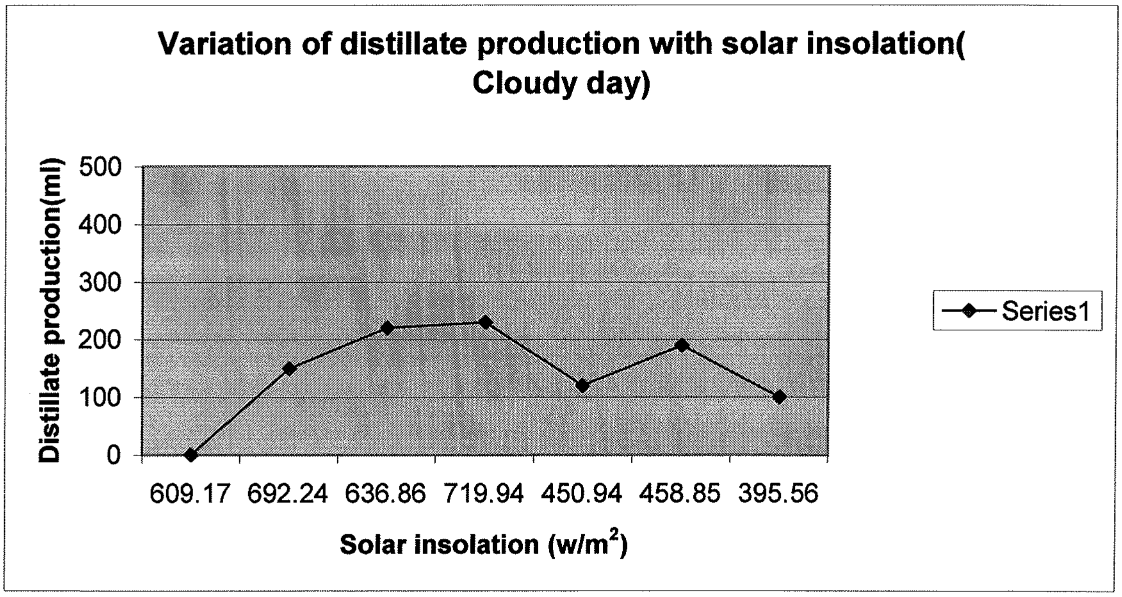
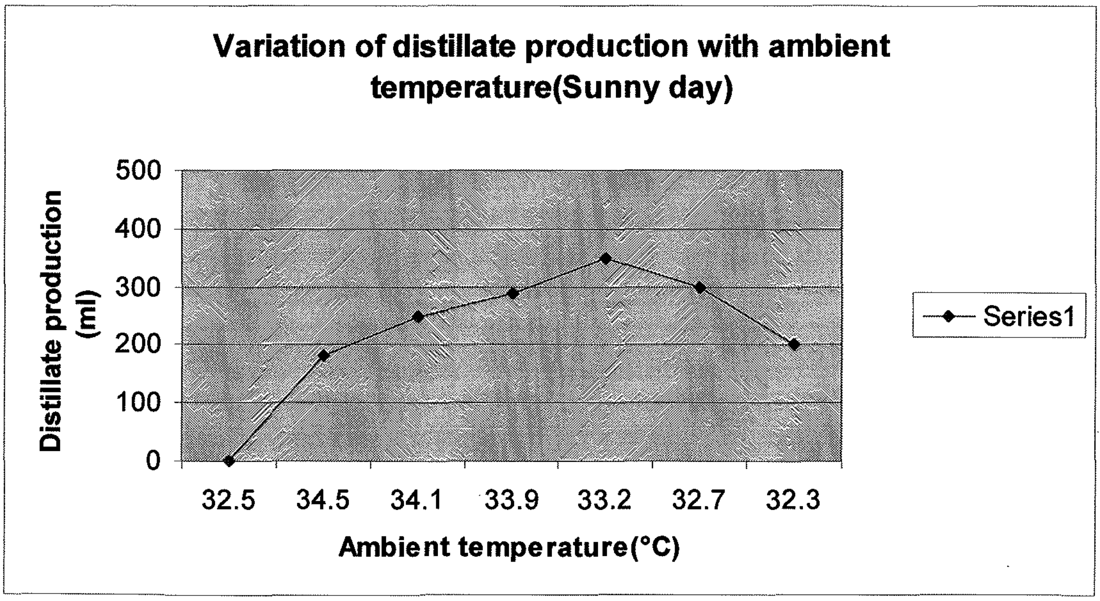
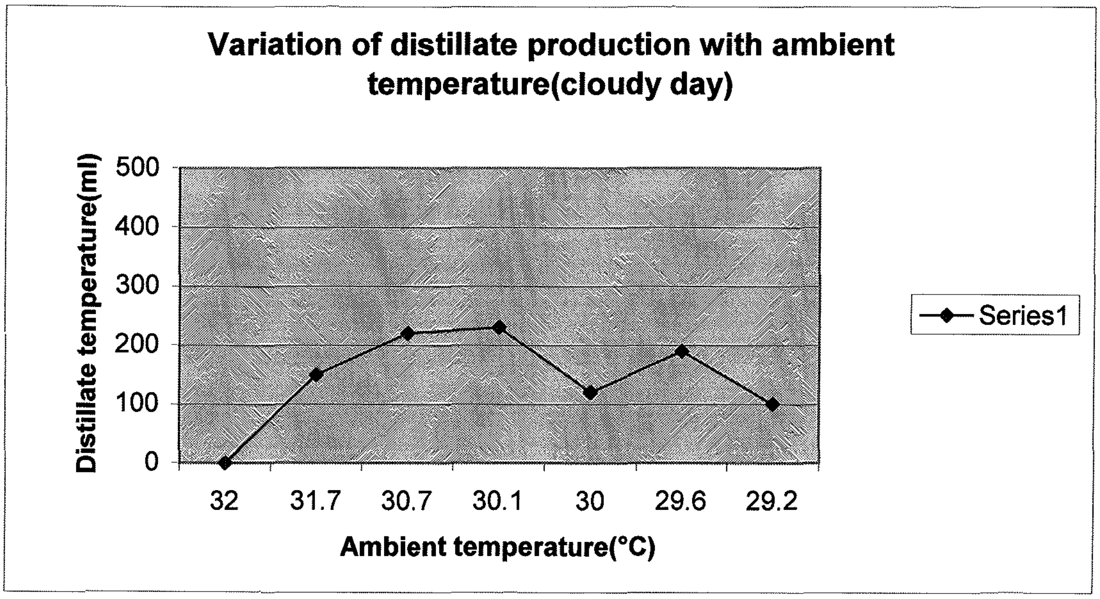

Variation of distillate production with solar insolation(Cloudy day)
Distillate production(ml)
500
400
300
200
100
0
609.17 692.24 636.86 719.94 450.94 458.85 395.56
Solar insolation (w/m2)
Series1

Figure : 15 a & b



Variation of distillate production with ambient temperature(Sunny day)
Distillate production (ml)
500
400
300
200
100
0
32.5
34.5
34.1
33.9
33.2
32.7
32.3
Ambient temperature(°C)
Series1



Variation of distillate production with ambient temperature(cloudy day)
Distillate temperature(ml)
500
400
300
200
100
0
32
31.7
30.7
30.1
30
29.6
29.2
Ambient temperature(°C)
Series1

Figure : 16

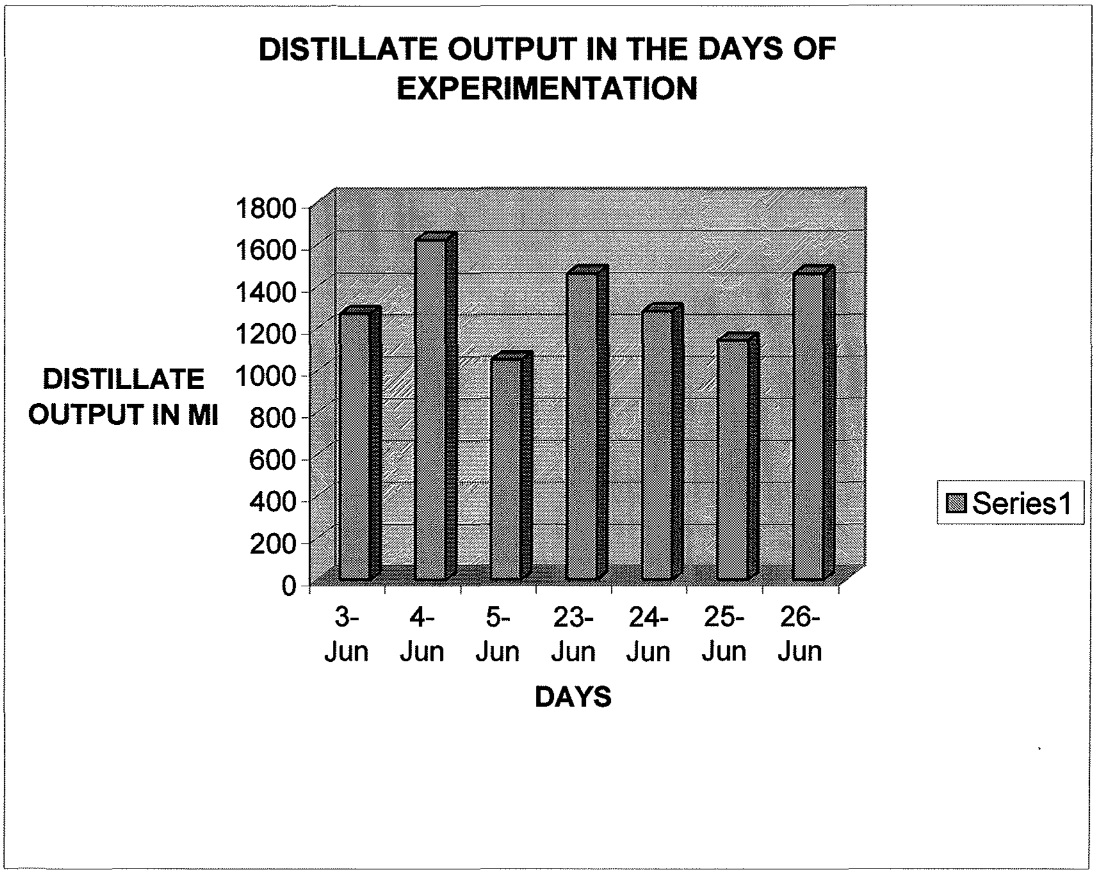
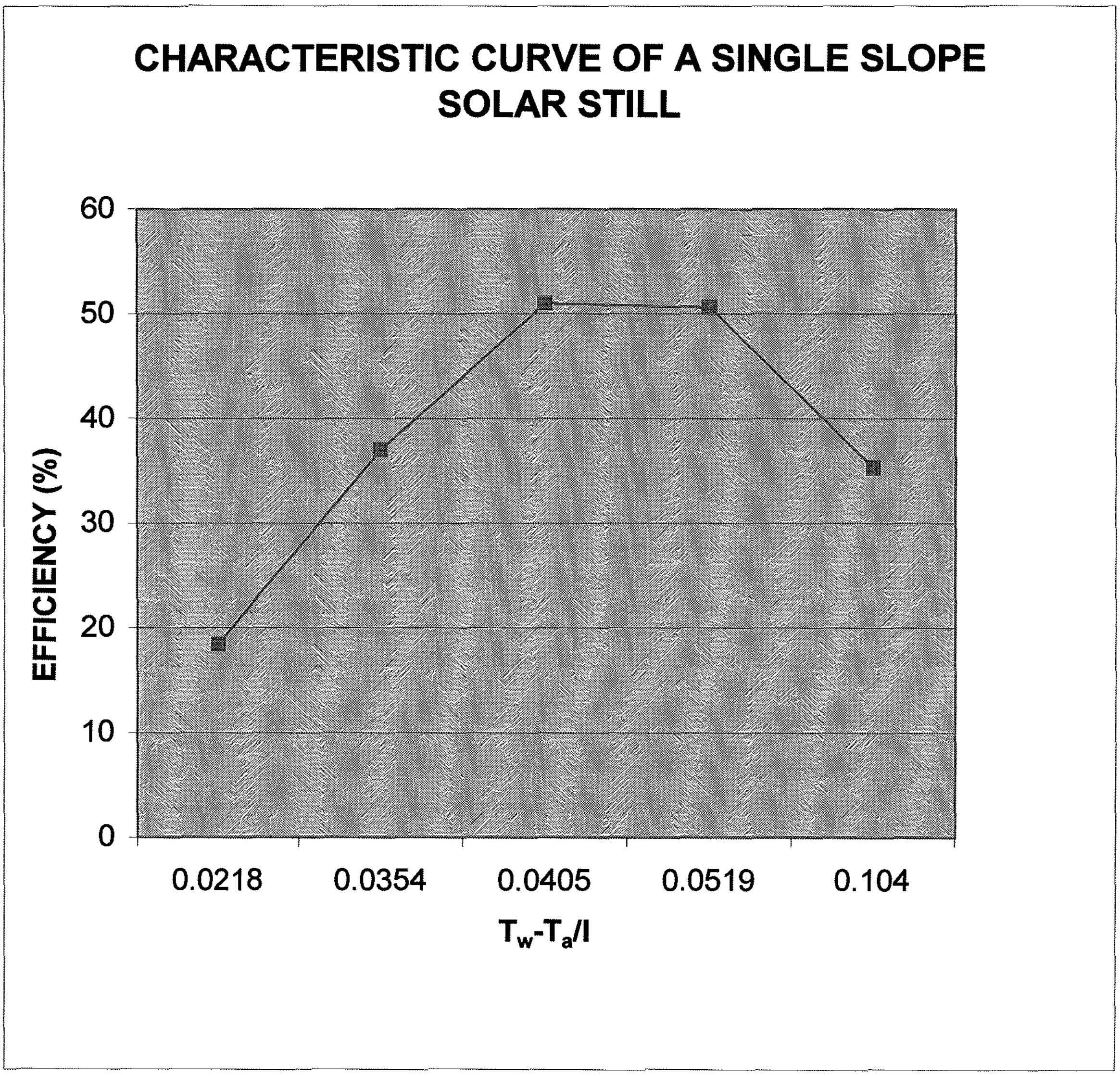
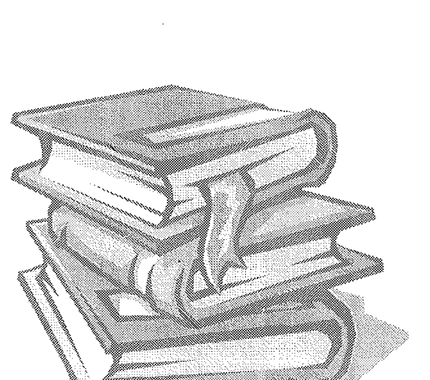

DISTILLATE OUTPUT IN THE DAYS OF EXPERIMENTATION
DISTILLATE OUTPUT IN Ml
1800
1600
1400
1200
1000
800
600
400
200
0
3-Jun
4-Jun
5-Jun
23-Jun
24-Jun
25-Jun
26-Jun
DAYS
Series1

Figure : 17



CHARACTERISTIC CURVE OF A SINGLE SLOPE SOLAR STILL
60
50
40
30
20
10
0
EFFICIENCY (%)
0.0218
0.0354
0.0405
0.0519
0.104
Tw-Ta/I



REFERENCES

REFERENCES:

- Abbot, C.G (1934). The sun and the welfare of man, Smithsonian scientific services.
- Abd – Rabbo M.F, Aly A.A and Zahran M.Z, 1978, preheated solar water distiller, I: Indoor simulation, proc of the solr energy and conservation symposium, (edited by T.N.Verziroglu), Pergamon press, Oxford, pp 557 – 581.
- Abu-quadir, 1996,Experimental study and numerical simulation of a solar still using external condenser, Energy ,21,851.
- Ahmed .S.T.,1988, Study of single solar still with internal condenser, Solar wine technology5 637-64.
- Akinsete. V.A and Duru C.U, 1979, A cheap method of improving the performance of roof type solar still, Solar energy 23,271.
- Ali. H.M, 1991,Mathematical model of the solar still performance using forced convection with condensation process outside the still, Renewable energy, Vol.1,No.516, Pergamon press, 709-12.
- Ali H.M (1998), Experimental study on air motion effect inside solar still on the still performance, Proceedings of the north sun conference, Borlange, Sweden.
- Aly S.E.1990, Analysis of a fuel – solar assisted central dual purpose plant, Desalination 78, 363-379.
- AL – Karaghouli A.A and Minasian A.N, 1995, A floating wick type solar still, Renewable energy, vol. 6, No.1 Pergamon press 77 – 79.
- Al – Hussaini and Smith I.K, 1994, Enhancing the solar still productivity using vacuum technology ,Renewable energy, Vol. 5, part I, Pergamon press, pp 532 – 536.

- Assouad Y and Lavan z, 1988, Solar desalination with latent heat recovery, ASME J. Solar energy engrg 110, pp 14-16.
- Baumgartner, T.D, Jung D, Kossingir F. and Sizman R, 1991, Multi- effect low temperature process of solar desalination, New Technologes for the used of renewable energy sources in water desalination, thermie seminar in Athens.
- Bemporad G. A, 1995, Basin hydrodynamic aspects of a solar energy based desalination process, solar energy Vol 54, No.2, Pergamon Press, PP-125-134.
- Charters W.W.S., 1994, Solar energy, A viable pathway towards ecologically sustainable development ,Solar energy, Vol.52, No.5, Pergamon press, 367-37 .
- Charters W.W.S, 2000, Developing markets for renewable energy technologies, " pro. of the millennium International conference on Renewable energy technologies.
- Clark J.A, 1990, The steady state performance of a solar still ,Solar energy, Vol-44, No.1, Pergamon press, pp-43-49.
- Collins.R.A. and Thompson .T, 1961, Forced convection multiple effect solar still for desalting sea and brackish water, Proc . of the U.N.conf. on new sources of energy, Rome 6,205-217.
- Cooper P.I. 1969,Digital simulation of transient solar still processes, Solar energy 12, 313-331.
- Davidson, Jane and wood Byard,1999 Solar hot water for the home, Mechanical engineering , p1.
- Down to Earth, 1993, Vol 1 News No-24. Pp 5-8.
- Dunkle R.V, 1961, solar water Distillation, The roof type still and a multiple effect diffusion still, International Heat Transfer Conference, Part V, Boulder, co. pp 895 – 902.

- EL- Kassaby, 1991, Parabolic type solar still, Renewable energy, Vol.1, No3/4, Pergamon press, 449 – 454.
- El – Nasher M. and El Baghdadi A. M, 1987, Seawater distillation by solar energy, Desalination 61,49 – 66.
- El Nashar A.M, 1992, Optimizing the operating parameters of a solar desalination plant, Solar energy, Vol 48, No 4 pp 207-213, Pergamon press.
- ELsherbiny S.M and Faith. H.E.S, 1993, Solar distillation under climatic conditions of Egypt, Renewable energy, Vol.3, Nio.1, pp 61-65.
- Faith H.E.S, 1998 ,Solar distillation, Mech. Engg., Faculty of engg. Alexandria university, Alexandria, Egypt.
- Farid.M.,1983, Performance of a single basin solar still, Renewable energy, Vol.3, No.1, 75-76 Fernandez, J.L, Chargoy N. 1990, Multi-stage indirectly heated solar still, Solar energy, Vol. 44, n.4, pp 715.
- Fernandez, J.L, Chargoy N. 1990, Multi-stage indirectly heated solar still, Solar energy, Vol. 44, n.4, pp 715.
- Franco G. and Saravia. L., 1994, A new design for a passive atmospheric multistage still, Renewable energy, Vol.4, No.1, Pergamon press,199-122.
- Frick G. and Sommerfeld J.V, 1973, Solar still of an inclined evaporating cloth, Solar energy 14, 427-431.
- Garg H.P and Prakash J. ,2000 ,Solar energy fundamentals and applications, Tata MC Grawhill publishing company limited.
- Garg H.P, Overview of solar thermal processes, Center for energy studies IIT, Hauz khas, New Delhi – 110 016, 161.
- Goswami Y.D, Al-Kharadbshen. S, 2003, Analysis of innovative water desalination system using low grade solar heat, Desalination, Elsevier science pub, Vol 156, pp 323 – 332.
- Grune W.N. Hughes .R.B, 1961, Operating experiences with natural and forced convection solar stills, Water and sewage works 108, 378-383.

- Harrison D.G, Mathew K. and Ho G.E, 1992 " Solar desalination" in Kutay.C and Ho G.E (eds), Appropriate technology fore remote Communities RADG, Murdoch University, 21-24.
- Hirschman J. and Rheinlaender J, 1976, 5 th Int .Symp. on fresh water from the sea, Vol.2, pp.447 – 456.
- Hegazy. A., 1988, Experimental and theoretical study of solar still thermal performance with periodically adjustable reflectors, North Sun'88, Solar Energy at High latitudes Conf., Borlange, Sweden.
- Hoover.A, 2003, Here comes the sun: Engineers develop solar desalination system, university of Florida news.
- Howe E.D and Tleimat B.W, 1974, Twenty years of wick of solar distillation at the university of California, Solar energy 16,97.
- Howe. E.D, 1980, Distillation of seawater, In solar energy Technology Handbook (edited by W.C Dickenson and P.N cheremisinoff). Ch .33, pp-205-237. Marcel Dekkar, Newyork.
- Howe E.D, 1990, Classic papers in solar energy: Solar distillation, Sunworld, Volume 14, Number 2 ,pp 59 – 61.
- Joyce A, Lovreiro D, Collares pereira. M, Moreira M, 1994, A spray evaporation type solar still, Renewable energy, Vol – 5 , part I, Pergamon press, pp 517-519.
- Kanbour S.I. and I.S. Matloob,1985, Simple solar still performance synthesis and predictions , JSER 3, 11-33.
- Kreider, Jan.F., and Kreith, Frank,1999 Solar heating and cooling: Engineering practical design and economics ,p7.
- Kumar A. and Anand J.D., 1992, Modelling and performance of a tubular multiwick solar still, solar energy Vol 17, No,. 11, Pergamon press, pp 1067 – 1071.

- Kumar S and Tiwari G.N, 1996, Performance evaluation of a active solar distillation system Energy, 21, pp 805.
- .Lawrence S.A., Gupta.S.P. And Tiwari G.N.,1990, Effect of heat capacity on the performance of the solar still with water flow over glass cover, Energy Convers Mgmt, 30(3),277-285.
- Lesson. M.R and Boutebilla. J, 1987, A study for a solar collector, ISES solar wind Cong, W. Germany Paper No 2.14.2.pp 1406-1410.
- Lof G. OG, 1950, Solar distillation of sea water in the virgin Islands, office of saline water, U.S.Deparment of Interior, Report No. 5, P.B.161380.
- Lof O.G., 1961, Application of theoretical principals in improving the performance of basin type solar distillers, U.N. conference on new sources of energy, Rome ,35/S/77.
- Malik.M.A.S, Tiwari G.N, Kumar .A, and Sodha M.S.1982, Solar distillation, Pergamon press, Oxford.
- .Mathew K., Dallas.S., H.O G. Martin, 1982,Demonstration of a solar power self contained village water supply system, Murdoch university, Western Australia, 6150, 170 (RADG Group).
- Mazumdhar B.1999, Atext book of energy technology, A.P.H publishing house, PP.108.
- Mousa M.M, Abdelfatlah F.M and Sakr.I.A, 1978, Double exposure solar still, Proc of the International symposium- Workshop on solar energy (edited by T.N vezioglu), Pergamon press, oxford, pp 1546 – 1560.
- Moustafa S.M.A., Jarrar.D.I., El-mansy. H.I.1985, performance of self regulating solar multistage flash desalination system, Solar energy, Vol.35, No.4, Pergamon press,333-340.
- Moustafa. S and Brusewith G, 1979, Solar energy 22, 141 – 48.
- Morcos. V.H.1994, Some experimental and theoretical studies of a single basin solar still, Renewable energy, Vol.4, no.4, Pergamon press, 401-407.

- Morse R.N. and Read W.R.W., 1968, A national basis for engineering development of a solar still, Solar energy,2,15-17.
- Natarajan K, 1985, Single wick solar still: design, fabrication and experimental study (PhD thesis)
- Mc Cracken H, 1990, Distillate production of a simple direct solar still, Sunworld Vol – 14, No-3, pp 83 – 87.
- Nijegorodov. N. Jain P.K.,and Carlsson,1994, Thermal- electrical high efficiency solar stills,Renewable energy, Vol.4,No.1, Pergamon press1233-127.
- Pandey G.C., 1984, Effect of dried and forced air bubbling on the partial pressure of water vapour and the performance of the solar still, Solar energy, Vol.33, No.5, Pergamon press, 13-18.
- Pandey P.K, 2003,Promoting and financing renewable energy in India, IREDA ltd, New Delhi, India.
- Palaniappan.C, Kolar. A.K., Haridasan, T.M, 2001, Renewable energy technologies, Applications to industries and agriculture, Narosa publishing house.
- Palaniappan, March 30, 2004, " High TDS levels in Coimbatore ground water survey " The Hindhu", published in coimbatore.
- Pawar S.H and Ekal A.A, 2003, Advances in Renewable energy Technologies, Narosa publishing house, New Delhi, India, pp 47 – 48
- Rai S.N., Dutt D.K. and Tiwari G.N.,1990 Some experimental studies of a single basin solar still, Energy Convers Mgmt, 30(2),149-153.
- Rajamma K, 1980, Fabrication and study of solar still, PhD thesis.
- Reali M,1984, A refrigerator – heat – pump desalination scheme for fresh water and salt recovery, Energy, 538 – 588.
- Riffat S.B 1995, Solar absorption system for water desalination, Renewable Energy, Vol 6, No 2, pp.101 – 106.

- Saghaf. M. 1994, Development of a solar desalination plant, Renewable energy, Vol.5, part I ,Pergamon press ,pp. 529-31.
- Sharif M.A and kiss. L.I, 1987 , Performance study of stills, ISES solar world cong, W. Germany, Paper No 2. 14.1 pp. (1401 – 1405)
- Sharpley B.F. and Boelter L.M.K, 1973, Evaporation of water into quiescent air, Indus Eng, Chem 30 (1938).
- Sodha – M., Kumar A, Tiwari. G, and Tyagi R,1981, Solar energy 26,127
- Soliman.S.H.,1986, Optimization of the basin type solar still, Inst. Engng India idp 3 Vol.66.,68-69.
- Talbert S.,Elibling J, and Lof. S, 1970, Manual on solar distillation of saline water, U.S. Department of the Interior OSW R & D Report no.546.
- Tanaka. K., Yamashita, A and Watanabe. K, 1982, Experimental and analytical study of a tilled wick type solar still, In solar world forum, Vol. 2 ,Pergamon press, Oxford.
- Tiwari G.N and Madhuri, 1981, Effect of water depth on the daily yield of the still, desalination 61, 67-75.
- Tiwari G. Sharma S and Sodha M, 1984, Performance of a double condensing multiple wick solar still, Energy covers. Mgmt 25, 155 – 159.
- Tiwari G.N and Selim G.A.M. 1984, sol wind Technology 1,229.
- Tiwari G.N, Madhuri and Garg H.P, 1985, Effect of water flow over the glass cover of a single basin solar still with an intermittent flow of waste hot water in the basin,Energy convers. Mgmt 25(3), 315-322.
- Tiwari G.N.1985, Advanced solar distillation systems, Kamala Kuteer, India.
- Tiwari G.N Gupta S.P, Kumar, A, 1988, Int .J. Sol. Energy 6, 139.
- Tiwari and Yadav, 1987. Demonstration plants of FRP- wick solar still and experimental study, Solar and wind technology 6, 653.
- Tiwari G.N, Yadav Y.P, and Eames P.C & Norton B, 1994, Solar distillation systems: The state of the art in the design development and

performance analysis, Renewable energy, Vol-5, part I, Pergamon press, pp 509-516.

- Tiwari, G.N., and Suneja .S 1998, Performance evaluation of an inverted absorber solar distillation system, Energy conversion and Management39, pp 173.
- Tiwari G.N and Kumar, A, 1998 desalination 69, pp 309.
- Tiwari G. N. 2002, Solar energy, fundamentals design, modeling and application , Narosa publishing house, pp 278 – 308.
- www.hvac.mechanic.com/ heating/solar_hot_water_heaters.htm # Top.
- www. sunstar solution. com/floonics.htm
- www.sun.ac.za / polymer / solar.htm
- www. epsea.org/stills.html
- www.itdg.org/html/technicalenquiries/docs/solar .distillation.pdf
- www .solaqua .com/index. htm
- www. aqua del sol / solar. html.
- www. green home. com/ products/ appliances/ water_filters/106608/
- www.Landfall navigation.com/memss.htm
- www. seastead. org/ commented/ paper/infra.html.
- www.rpi.edu/dept/chem-eng/Biotech-Environ/Environmental/desal/solar.htm
- http://www.rpi.edu/dept/chem-eng/Biotech-Environ/Environmental/desal/solar.html
- Yadav.Y.P. Ph D thesis , 1986, IIT, Delhi
- Yen H.M and Chen L.C, 1986, The effects of climatic design and operational parameters on the wick type solar distillers, Energy covers. Mgmt 26,175-180.
- Zaki G. M. Radhwan A.M, and Balbeid, A.O, 1993, Analysis of assisted coupled solar stills, Solar energy, Vol 51, No.4, Pergamon press pp 277-88.