EFFECT OF EARTH HEAT ON THE PERFORMANCE OF SOLAR STILLWITH ENERGY STORAGE MEDIUM

ISO 9001:2008
Certified

A PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report

FFECT OF EARTH HEAT ON THE PERFORMANCE

F SOLAR STILL WITH ENERGY STORAGE MEDIUM

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ABSTRACT

Water scarcity increases from day to day due to increase in population density.This scarcity can be reduced by using sea water for human consumption and irrigation purposes .The availability of sea water helps to meet the demand effectively with little processing. Though there are several methods available in conversion of the sea water to pure water the most inexpensive method involves in using solar desalination.

Practically for huge productions conventional solar still is used where the loss of heat is due to radiation and convection to the surroundings this heat is stored using thermal energy reservoir, later this heat is used to get the yield when the solar intensity is low. Earth,gravel is used as energy storage medium as they are inexpensive when compared to other storage medium. The black gravel is used for absorbing the excess heat energy from solar radiation during the noon hours

Added advantage of using the thermal energy reservoir is that the heat in the space between the water and glass surface is reduced to greater extent as the heat is transmitted to the storage medium and hence the temperature difference between the water and glass surfaces increases which leads to effective condensation of the evaporated water .

The depth of the gravel layer in the basin will influence the performance of the still and some of the parameters like basin temperature, water temperature, glass temperature and still productivity. This study deals to show the effectiveness of the modification, its performance is compared with the conventional still by using heat under the same climatic condition

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First We wish to express our gratitude to the Almighty God, the lifter of our head and the giver of all wisdom, for our life and for the grace of going through this project successfully. He truly deserve all the glory and the honor, for he did not let our foot slip.

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Desalination

Desalination refers to any of several processes that remove some amount of salt and other minerals from saline water. Salt water is desalinated in order to produce fresh water that is suitable for human consumption or irrigation. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on developing cost-effective ways of providing fresh water for human use.

1.2 Methods for desalination

There are many methods used. The most commonly used methods for desalination are

- Reverse Osmosis,
- Solar Desalination,
- Geothermal Desalination,
- Thermionic Process.

1.3 Solar desalination

Solar desalination is a technique to desalinate water using solar energy. This trend is currently reversed again, because all of the fossil resources required for 20th century desalination are becoming scarce. Using thermal energy reservoirs the yield in the solar desalination plant is increased to considerable extent.

1.4 Objectives Of The Project

The main objective of this project is to utilize the earth heat and energy storage material to improve the yield. The main objectives of this present study are summarized as follows:

1. To build a conventional still and conduct the experiments to find the optimum quantity of saline water that will produce the maximum yield.
2. To conduct the experiments in the solar still using earth heat without any energy storage medium and study the effect of different depths of saline water on the hourly yield.
3. To study the performance of the solar still using earth heat with energy storage medium granite gravel and compare with that of conventional still.
4. To study the performance of the solar still using earth heat without energy storage medium and with energy storage medium like granite gravel and to compare with that of Conventional Still.

1.5 Limitations Of The Project

- large solar radiation collecting area is required.
- The demand is very less.
- Weather dependent yield.
- Efficiency is low & cost is high.
- Salt formation capacity is high so heat loss increases as the still ages.

1.6 Scope of the project

Solar desalination is used to supply water to the population where water scarcity is high but salt water is readily available. the scope of the project is to develop cost efficient and effective solar still using thermal energy reservoirs. This project involves in using common materials like gravel as energy storage medium. This project focuses on comparison of yield rate of conventional still and modified thermal energy reservoir stills.

CHAPTER 2

STUDIES ON SOLAR STILL

Some of the literatures that were studied for the development of solar still for desalination process are as follows

Badran et al., (2005), conducted experiments by connecting a flat plate solar collector with single stage basin type solar still and studied the effect of augmentation on the solar still. He found that daily still yield increased from 3.04 kg /m^2 to 4.4 kg /m^2 and efficiency increasing to 52 %. The results showed that the still performance could improve significantly but the system cost would also increases. In some cases, the daily yield of the simple still coupled with flat plate collector increased from about 3 kg / m^2 day to about 6.5 kg / m^2 day.

Madhuri et al., (1985), investigated this idea by conducting experiments in a single effect solar still. They found that a still with intermittent flows of hot water to the basin, still yield increases with increasing temperature of the waste water.

Tiwari et al., (2003), presented a literature survey about the advantages and benefits of the single slope still. Evaporation at a low temperature, utilizing vacuum conditions, leads to a good improvement in the system efficiency as the evaporation rate increases with the reduction of pressure. Many researchers reported that still hourly yield is higher than that of similar solar desalination systems operating under atmospheric pressure. In all configurations described previously, the latent heat of condensation was simply dissipated to the environment. However, the latent heat of condensation could be used to preheat the feed water, which would lead to an improvement in the still efficiency. Latent heat of condensation could also be utilized for evaporating part of the saline water in a multi-effect solar still. In such still, heat is usually supplied to the first effect from a solar collector. Then the vapour produced in that effect ascends upward by natural convection, and condenses when it is exposed to the bottom of the second effect by giving up its latent heat to that stage.

Malik et al., (1973), suggested that hot saline water could be fed to the basin at night to improve the nocturnal (distilled water produced at night) production of pure water and found that distilled water produced at the night depends on the initial saline water temperature and depth of saline water.

Minasian et al., (1995), constructed and tested a vertical conical floating still using blackened cotton cloth for rises the saline water from the basin and helps to vapourise the pure water. They achieved 2 to 4 kg of still yield per m^2 area per day.

Khalifa et al., (1999), modified the conventional still by preheating the saline water and utilizing external and internal condensers. They have reported that still yield had increased from 3.2 kg/m^2 day to 4.0 kg/m^2 day.

Akash et al., (2000), conducted experiments with different types of absorbing materials like black rubber mat, black dye and black ink resulted in increasing of still yield from 2.25 kg/m^2 day to 3.5 kg/m^2 day.

Nafey et al., (2001), conducted experiments in a modified solar still using black rubber sheet and black gravels as storage media. They had conducted experiments to study the effect of sizes of gravel and quantity of the saline water and reported that the still yield was approximately 3.5 kg $/m^2$ day.

Abdallah et al., (2008), modified the still design from a flat basin into step-wise basin gave a higher production rate with an average increase of 180%. Also, coupling the modified still design with a sun tracking system gave further improvement, reaching up to a 380% increased in the production rate of distilled water.

Arjunan et al., (2009), used blue metal stones as an energy storage medium for increasing the productivity of still. Also, conducted experiments to store excess of heat energy in the solar stills during day time for the continuation of the process at evening and night time used blue metal stone as energy storage medium.

Radwann et al., (2009), designed the highest average distillate production still from Inclined 20° One Direction Configuration with matt black fiber glass as an absorbing material. The highest productivity was obtained at August when compare to May, June and July. In this work, experimental results of still yield as well as the average still efficiency were increased by increasing the average solar radiation.

CHAPTER 3

CONSTRUCTION OF THE SOLAR STILL

3.1 Basic Components

The experimental setup for the solar stills(conventional type, still using earth heat only & still using earth heat and energy storage medium) requires the following four basic components. They are,

1. Basin,
2. Transparent glass cover,
3. Support structure and
4. Collection trough (water channel).

3.1.1 Basin

The basin required for the setup should be of single side slided trough form so that the optimum amount of solar radiation enters into the basin to evaporate the water. The construction of the basin is made sure that it is not too shallow since the water dries out easily. On a hot day, the solar heat can evaporate about 0.5 cm of water.

The main functions of the basin are as follows.

1. It must absorb solar energy.
2. It must be insulated against heat loss from the bottom and edges.

The materials used for the still should have the following characteristics:

1. The material should be of high thermal conductivity.
2. Materials should have a long life under exposed conditions
3. They should be sturdy enough to resist wind damage and slight earth movements.
4. They should be nontoxic and not emit vapors or instill an unpleasant taste to the water

5. They should be able to resist corrosion from saline water and distilled water.

The inner surface of the basin considered as basin liner is blackened to absorb the solar radiation effectively.

3.1.2 Transparent Glass Cover

The transparent cover is mounted at the top of the still on the slided face of the basin and must be able to transmit a lot of solar radiation with minimum absorption and reflection. The angle at which the transparent cover is set influences the amount of solar radiation entering a solar still. The glass cover material should also be strong enough to resist high winds, rain, hail and small earth movements and prevent the intrusion of insects and animals. The still should be insulated to minimize the unproductive conductive losses through the sides and base. The transparent cover is sealed over the basin using silicon rubber.

3.1.3 Support Structure

The basin is supported using insulated material since this area is highly susceptible to heat loss. In this work, the insulating material of thermocol of 40 mm thickness having thermal conductivity of 0.028-0.031 W/m^2 °C is used.

3.1.4 Collecting Trough

The collecting trough is the storage medium to collect the drained water from the basin. The desalinated water deposited over the glass cover is drained through the holes & collected in the trough. The measuring jar is used as the collecting trough to collect the water and to measure the amount of water collected.

3.2 Instruments used

Various instruments were used to measure the different variables:

1. Solarimeter (to measure the solar radiation)

2. Measuring jar (to collect & measure the distillate water)

3. Thermocouple (to measure temperature at various points in the still by thermocouples

4. Digital Temperature Indicator (12 node digital indicator is used to measure the temperature at different parts of the still components).

A solarimeter is a device used to measure the intensity of solar radiation. Solarimeter measures energy developed from solar radiation based on the absorption of heat by a black body. The solarimeter is a direct-reading instrument. It is several times less expensive than the pyrheliographs. This direct reading instrument is designed for both solar and sky radiation.

Fig 3.1 shows the photographic view of the solarimeter. Thermocouples measure the temperature by generating a small voltage signal proportional to the temperature difference between the junctions of two dissimilar metals. Thermocouples (Ni Cr- Ni type) have been used to measure the temperatures of different components of the still and the ambient air temperature. Fig 3.2 shows the Ni Cr- Ni thermocouple arrangement.

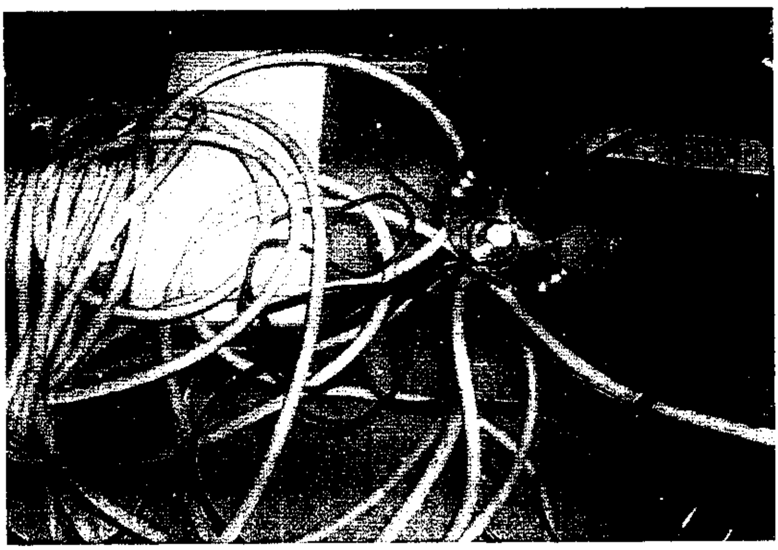

Fig. 3.1 Digital type Solarimeter

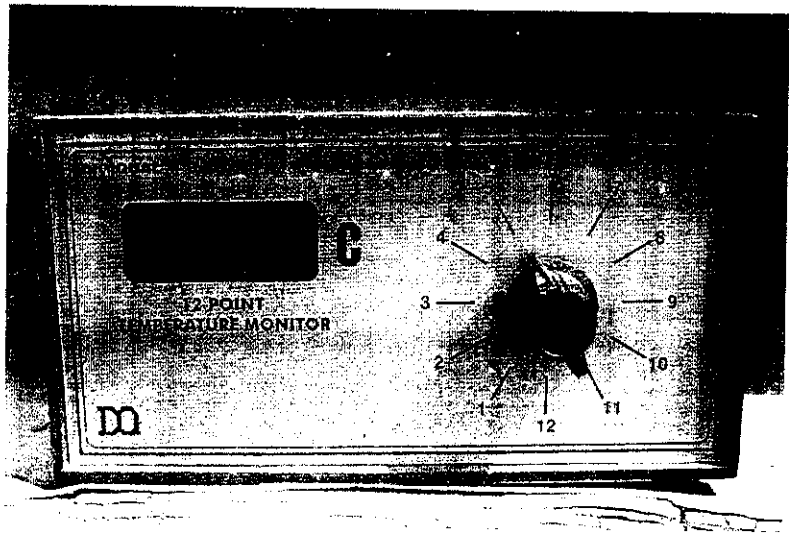

Fig. 3.2 Ni Cr-Ni Thermocouple

3.3 Experimental Set-Up For Conventional Still

The experimental setup for the conventional solar still is shown in the fig 3.3. The dimensions and specifications of the still are given in Table 3.1. The cad modeling of the still is done using PRO-E and is shown in the fig 3.4.

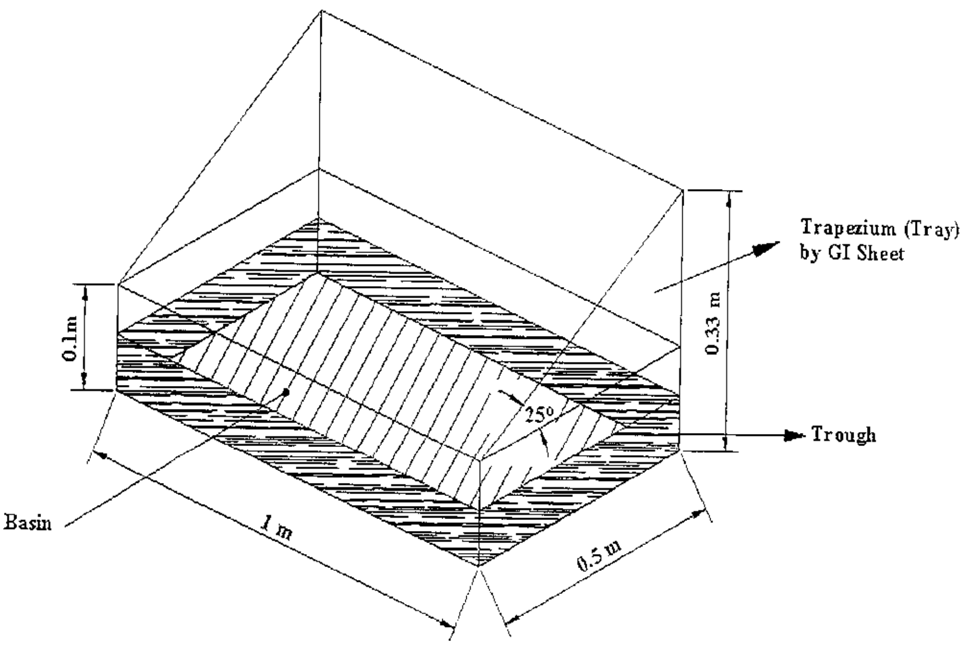

Fig. 3.3 Dimensions of the conventional still basin

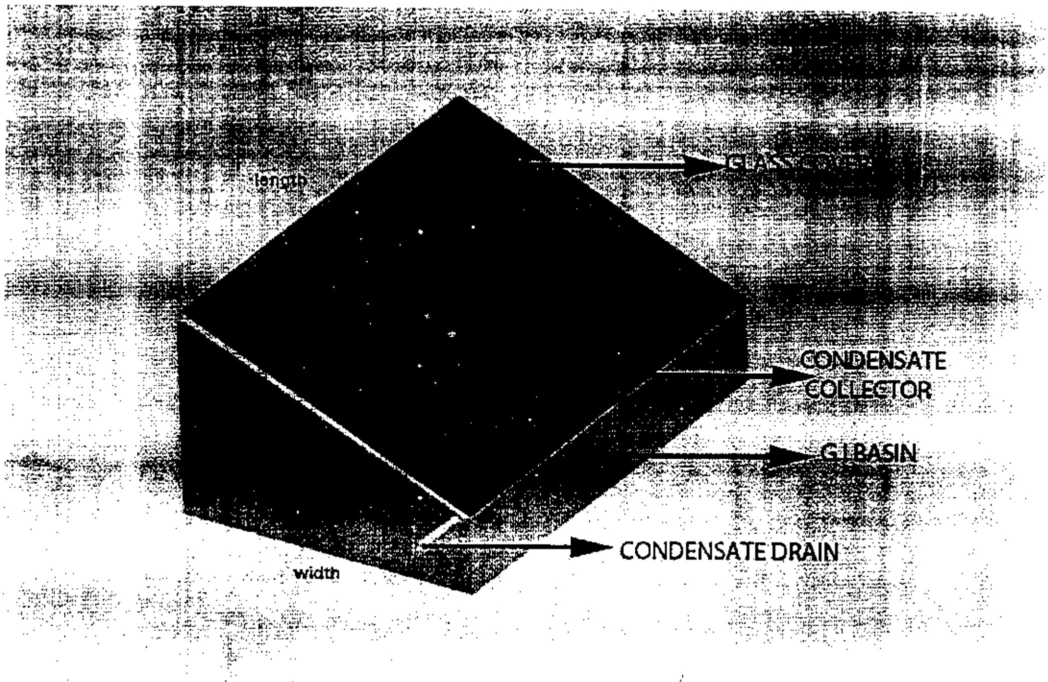

Fig 3.4 Table 3.1 Specifications of the conventional still

S. No.	Specifications of the Solar Still	Measurements
1	Length	1 m
2	Width	0.5 m
3	Glass cover inclination	25°
4	Depth of basin in front side	0.1 m
5	Depth of basin in back side	0.33 m
6	Thickness of Glass cover	3 mm

It consists of a rectangular basin trough of 60 mm depth and area of 1 m × 0.5 m, fabricated from G.I sheet of 2 mm thickness and it is kept in a trapezoidal trough made of G.I sheet as a cover material. Along the lengthwise (1m) the trough had rectangular shapes having height of 0.1 m in the front side and height of 0.33 m in the back side of the still. The whole arrangement is kept in a trapezoidal wooden tray and space of about 40 mm is given in all the sides and bottom so that the still would be insulated to prevent the loss of heat.

Photographic view of the conventional still with thermocouples and digital temperature indicator attached with the solar still are shown in the Fig 3.5. The inner surface of the basin considered as basin liner facing the sun is painted black. The basin is coated with black pigmented silicone to form a strong absorbing surface. The space between the inner tray (basin) and wooden cover was tightly packed with insulation materials like thermocol for thickness of 40 mm.

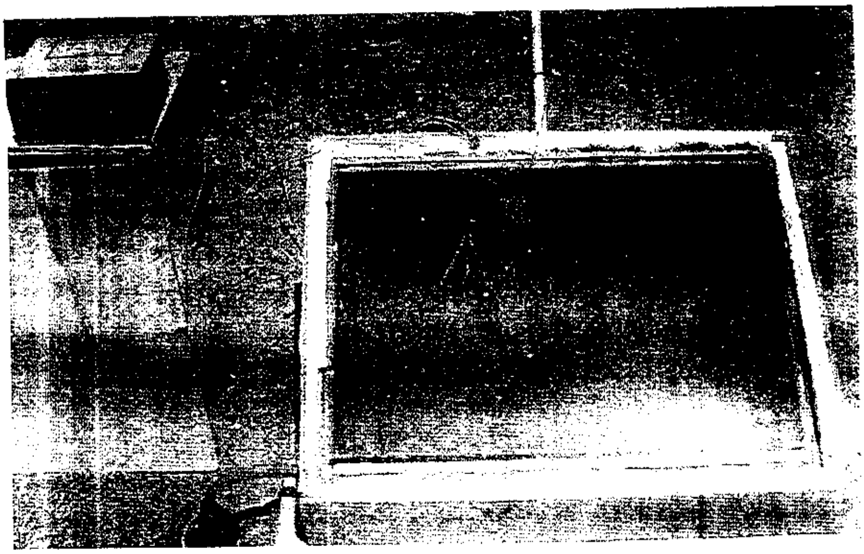

Fig. 3.5 Photographic view of the conventional still

The transparent cover used is the glass sheet of thickness 30 mm (.003m) and kept on the wooden frame at inclined position of 25° angle with respect to horizontal. An aluminum channel is attached to the lower end of the glass cover plate to collect the condensed water (yield) which flows through the inclined glass cover plate. The condensate is collected in the channel and taken out using funnel arrangement and collected in a measured jar. Holes are made in the sides of the still frame for feeding the raw saline water, and a tap is provided to drain the saline water.

Calibrated Ni Cr-Ni thermocouples, connected to a multi channel temperature recorder are inserted through the holes provided in the sides of the still and fixed at different points to measure the temperatures of different parts of the still, like basin, water, vapor-air space, inner and outer surfaces of the glass and ambient temperature.

Sectional view of the conventional still to show the different components is given in the Fig 3.6. The still is placed along the East-west direction and inclined glass cover surface is facing south to intercept maximum solar radiation.

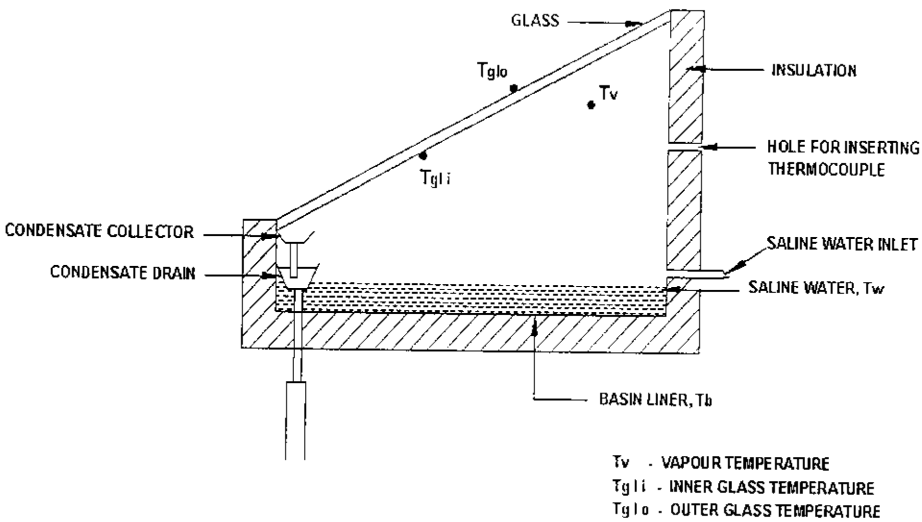

Fig. 3.6 Basin type single Slope solar still

Experiments were carried out in the conventional solar still for different quantity (depth) of saline water under the same climatic conditions to compare the rate of still yield and to find the optimum depth of saline water.

3.4 Modifications Of Solar Still Using Earth Heat

The conventional single slope still modified without energy storage medium and with energy storage medium like gravel is used here. The insulation layer (thermocole) used is removed. Earth has the ability to sustain the heat for finite depth. The heat loss from the basin is directly laid in the ground without insulation. According to this work, the modified solar still must give the highest still yield productivity.

3.4.1 Experimental Setup For Still Using Earth Heat Only

The conventional still is modified by using earth heat without any energy storage medium. In the modified solar still,the insulation is removed from the conventional still. Various experiments were conducted for different thickness (10, 20 and 30 mm) of layer of saline water. In addition, the thermocouple is attached with the earth to measure the earth temperature.

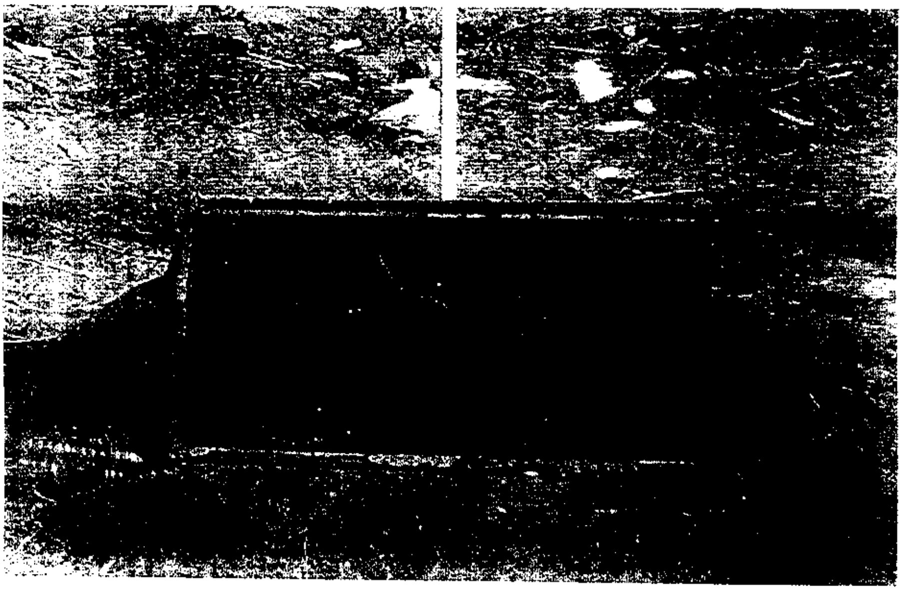

Fig. 3.7 Photographic view of the modified still using earth heat without gravel

3.4.2 Experimental Setup For Still Using Earth Heat And Energy Storage Medium.

In addition to the above setup, the gravels are used in the basin as the energy storage medium. Experiments were carried out to find the effect of thickness of (quantity) gravel layer for different depths of water level on the still yield. When thickness of the gravel layer increases, the bottom loss coefficient decreases which will reduce the heat loss from the still. Due to increase in thickness of gravel layer, heat capacity of the gravel-saline water combination increases which causes the reducing the gravel and water temperatures to reduce the radiation loss.

The experimental set-up was same as in the case of modified still except that gravel was placed in the basin along with saline water. In 1 m^2 of basin area, quantity of gravel required to form a 6 mm thick layer with 6 mm size of gravel is 10 kg. In addition to the thermocouples provided in the conventional still, two thermocouples were attached with the gravel to measure the gravel temperature and earth heat temperature

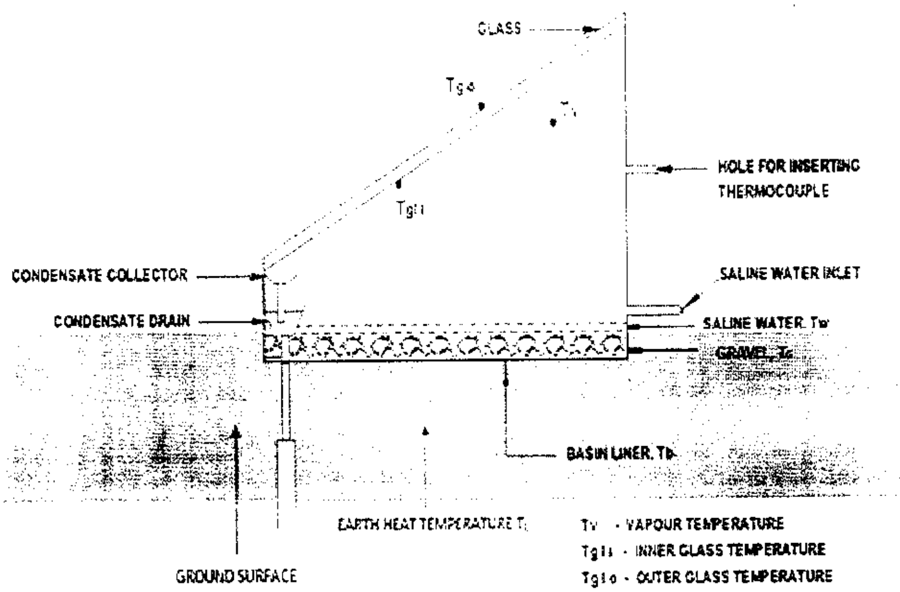

Fig. 3.8 Sectional view of the modified still using earth heat with gravel

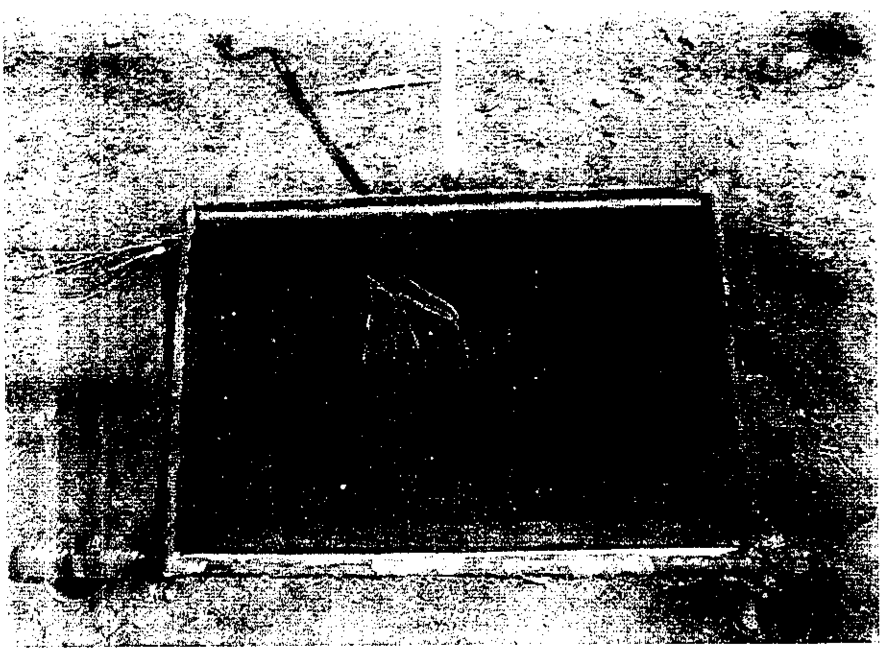

Fig. 3.9 Photographic view of the modified still using earth heat with gravel

CHAPTER 4

PROCEDURE FOR MATHEMATICAL MODELLING

4.1PROCEDURE FOR MATHEMATICAL MODELLING FOR CONVENTIONAL SOLAR STILL

The procedure for designing the mathematical model is given in the fig 4.1 .the thermal circuit diagram is drawn for the conventional still.

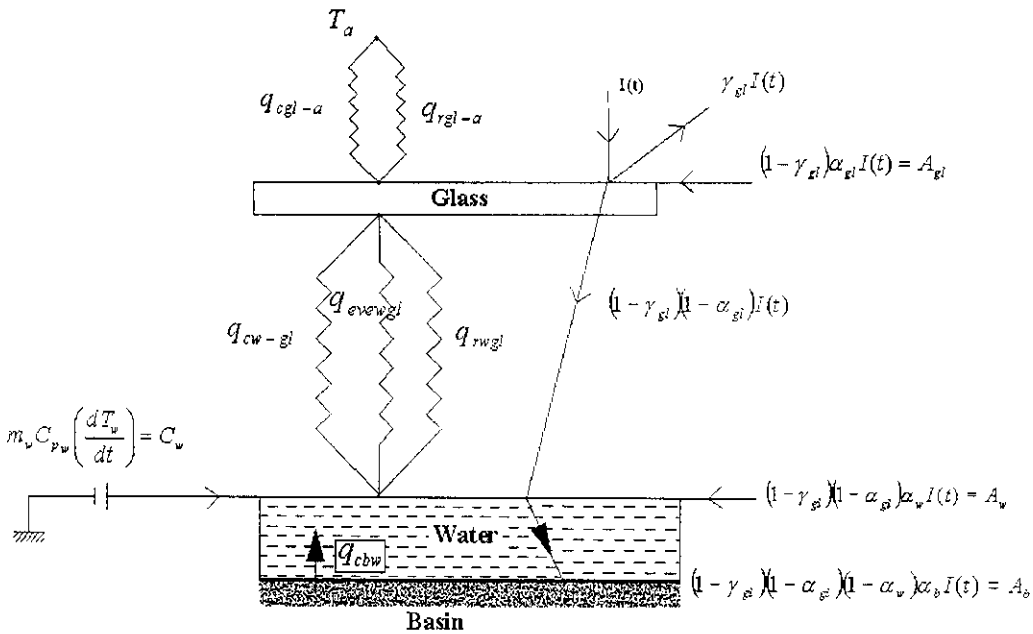

Fig. 4.1 Thermal Circuit Diagram for the conventional still

Solar energy is being utilized in the following ways Thermal radiation from the saline water to the glass cover. Sensible heat transferred from brine surface to cover via circulating air in the enclosure. Conduction losses to the ground or other surroundings. Sensible heat in the distillate water

The heat input to the solar still is from the sun's radiation which is denoted in intensity I(t). the heat is transferred from basin liner to the water (q_{cbw}). The heat transfer from the surface of the water to the glass cover takes place by convection(q_{cw-gl}), radiation(q_{rw-gl}), & evaporation($q_{evaw-gl}$),. The heat transfer from the glass cover to the ambient air takes place by convection(q_{cgl-a}), and radiation(q_{rgl-a}),. The heat is stored in water due to it's specific capacity(c_w). Applying the law of conservation of energy for each component in the system, the following methodology is obtained.

Let the intensity of radiation striking on the glass surface be I(t). some amount of intensity is reflected by the glass cover which is denoted by γ_{gl}. some intensity is absorbed by the glass cover denoted by α_{gl}. The remaining is transmitted to the water surface (1- γ_{gl}) α_{gl}. Again some intensity is absorbed by the water surface which is denoted by α_w. The remaining intensity is transmitted to the basin which is completely absorbed since it is a black surface. The reflectivity of water is neglected.

For Glass Cover

Rate of energy absorbed by the glass cover out of solar radiation	+	Rate of energy received from water surface by radiation, convection and evaporation	=	Rate of energy lost to atmosphere from glass cover by convection and radiation

For Water Mass

Rate of energy absorbed by the water out of solar radiation strikes on water	+	Rate of heat energy absorbed by water from basin by convection	=	Rate of energy stored in water due to its specific heat	+	Rate of heat loss from water to glass cover by radiation, convection and evaporation

For Basin Liner

Rate of energy absorbed by the basin out of solar radiation strikes on it	=	Rate of heat from basin to water by convection	+	Rate of heat lost from basin to atmosphere through bottom and sides of the still by conduction and convection

As the basin and glass cover are assumed as not storing heat energy, their temperatures vary according to the solar intensity only not due to its thermal mass. For the saline water, its thermal mass depends on the depth of the saline water. So the temperature of the saline water is the parameter which influences the still hourly yield.

4.2 Procedure For Mathematical Modelling Solar Still Without Any Energy Storage Medium

The procedure in designing mathematical model for the solar still using earth heat, the following assumptions have been made while writing the energy balance equation. They are:

1. The system is in a quasi -steady state condition
2. There is no vapour leakage

In Figure 4.2, thermal circuit diagram and solar radiation absorbed by the different system components the glass cover; saline water and ground surface are given.

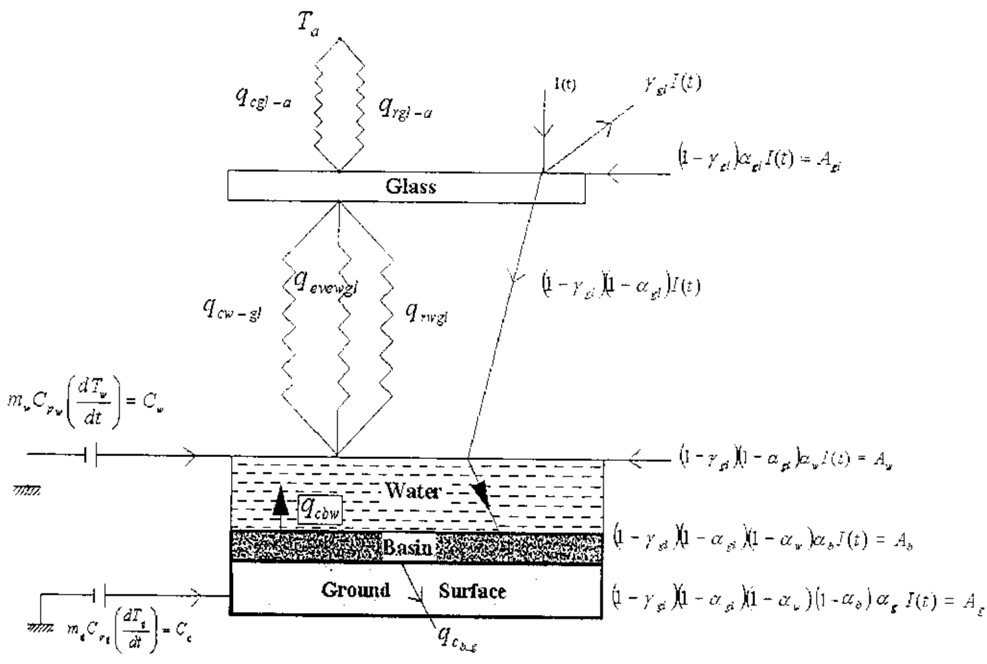

Fig. 4.2 Thermal circuit diagram and solar radiation absorption for different components of a still using earth without any energy storage medium

The heat input to the solar still is from the sun's radiation which is denoted in intensity I(t). the heat is transferred from basin liner to the water (q_{cbw}). The heat transfer from the surface of the water to the glass cover takes place by convection, radiation & evaporation. The heat transfer from the glass cover to the ambient air takes place by convection and radiation. The heat is stored in glass, water & ground surface due to their specific capacities. Applying the law of conservation of energy for each component in the system, the following methodology is obtained.

Let the intensity of radiation striking on the glass surface be I(t). some amount of intensity is reflected by the glass cover which is denoted by γ_{gl}. some intensity is absorbed by the glass cover denoted by α_{gl}. The remaining is transmitted to the water surface (1- γ_{gl}) α_{gl}. Again some intensity is absorbed by the water surface which is denoted by α_w.the remaining intensity is transmitted to the basin which is completely absorbed since it is a black surface. The reflectivity of water is neglected.

For Glass Cover

Rate of energy absorbed by the glass cover out of solar radiation striking on it	+	Rate of heat received from water by convection, evaporation and radiation	=	Rate of heat stored in the glass cover due to its heat capacity	+	Rate of heat lost from the glass cover to atmosphere by convection and radiation

For Saline Water

Rate of energy absorbed by the water surface out of solar radiation strikes on it	+	Rate of heat transferred from the basin to water by convection	=	Rate of heat stored in water due to its heat capacity	+	Rate of heat lost from water surface to glass cover by convection, evaporation and radiation

For Ground Surface

Rate of energy absorbed by ground	=	Rate of heat stored in ground due to its heat capacity	+	Rate of heat from basin to ground surface

4.3 PROCEDURE FOR MATHEMATICAL MODELLING FOR THE MODIFIED SOLAR STILL USING EARTH HEAT WITH ENERGY STORAGE MEDIUM (GRAVEL)

To develop a mathematical model for the modified still with the granite gravel, the following assumptions have been made while writing the energy balance equation. They are:

1. There is no temperature gradient along the thickness of glass cover and water column
2. The heat capacity of the basin liner is negligible.
3. As absorptance of water is very low it is assumed that solar rays strike directly on gravel.

For Gravel Layer

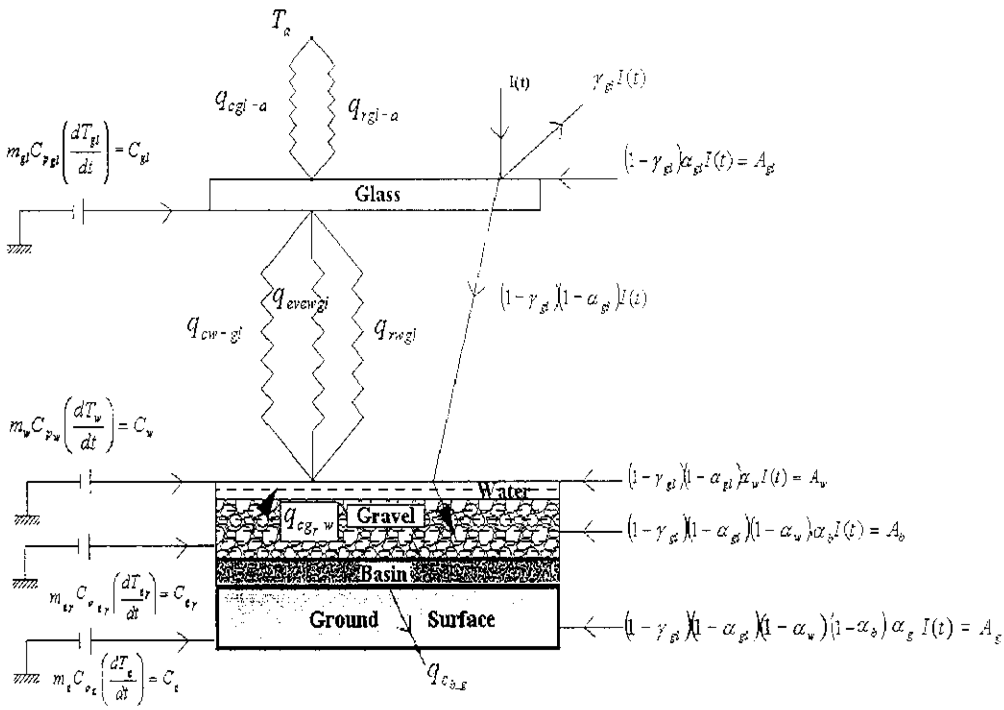

Fig. 4.3 Thermal circuit diagram and solar radiation absorption for different components of a still using earth with energy storage medium (gravel stones)

The heat input to the solar still is from the sun's radiation which is denoted in intensity I(t). the heat is transferred from basin liner to the water (q_{cbw}). The heat transfer from the surface of the water to the glass cover takes place by convection, radiation & evaporation. The heat transfer from the glass cover to the ambient air takes place by convection and radiation. The heat is stored in glass, water, gravel & ground surface due to their specific capacities. Applying the law of conservation of energy for each component in the system, the following methodology is obtained.

Let the intensity of radiation striking on the glass surface be I(t). some amount of intensity is reflected by the glass cover which is denoted by γ_{gl}. some intensity is absorbed by the glass cover denoted by α_{gl}. The remaining is transmitted to the water surface $(1-\gamma_{gl})\,\alpha_{gl}$. Again some intensity is absorbed by the water surface which is denoted by α_w. some amount of intensity is absorbed by gravel denoted by α_{bl}. the remaining intensity is transmitted to the basin which is completely absorbed since it is a black surface. The reflectivity of water is neglected.

For Gravel Layer

Rate of energy absorbed by gravel	=	Rate of heat stored in the gravel layer	+	Rate of heat from gravel layer to water	+	Rate of heat lost from gravel layer to ground

Calculation for theoretical yield

Rate of heat transferred due to convection is given by the formula

$$Q = hA(T_w - T_{gl})$$

Amount of heat stored in a system per degree kelvin is given by,

$$Q = m\,h_{fg}$$

Equating the above equations

$$hA(T_w - T_{gl}) = m\,h_{fg}$$

for unit area, the theoretical yield becomes

$$m = \frac{h_{eva\ w\text{-}gl}\left(T_w - T_{gl}\right)\times 3600}{h_{fg}}\ \frac{kg}{m^2hr}$$

h_{fg} – Latent heat of evaporation of water = 2366×10^3 J/kg for the average saline water temperature of 57° C.

CHAPTER 5

EXPERIMENTAL OBSERVATIONS

5.1 Experimental Observations For Conventional Still

The experimental observations for the conventional still are taken for every hour from 10 a.m. till evening 7p.m for the water depth of 20mm. The various parameters such as solar radiation intensity, inner glass temperature, water temperature are noted every hour till 7 p.m.

After 7.00 p.m, condensation of pure water at the bottom surface of the glass cover and still hourly yield will get reduced very much. Nocturnal production of pure water takes place till saline water temperature equals to glass plate temperature. The readings are observed and noted in the given tabular column 5.1. Similarly the experiments are carried out for different depths of water level such as 30mm, 40mm and the readings are tabulated in their respective tables.

The different temperatures are taken using thermocouples, the yield is measured by collecting the water in the measuring jar and the intensity of solar radiation is measured using solarimeter. The maximum yield is obtained at the depth of 30mm due to specific capacity of water. It is more when compared to that of 40mm the since the amount of heat stored in the water is high enough to rise the temperature of the basin so that the heat is lost through the basin.

Table 5.1 Experimental observations for the conventional still with 20 kg (20 mm depth) of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Inner Glass Temp T_{gli} °C	Outer Glass Temp T_{glo} °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	32.5	30.2	35.6	35.2	455	0.00
11.00	42.1	38.9	44.8	41.6	529	0.15
12.00	49.6	47.5	48.6	44.3	531	0.22
13.00	53.4	52.3	51.2	46.2	500	0.38
14.00	55.5	57.9	53.7	48.6	489	0.65
15.00	56.1	57.0	52.7	45.4	383	0.77
16.00	54.8	56.5	50.4	43.4	304	1.05
17.00	52.5	52.4	48.6	41.2	109	1.21
18.00	50.0	50.1	40.8	35.8	0	1.30
19.00	38.8	40.4	34.1	30.5	0	1.85

Table 5.2 Experimental observations for the conventional still with 30 kg (30 mm depth) of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Inner Glass Temp T_{gli} °C	Outer Glass Temp T_{glo} °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	37.5	35.6	42.5	42.1	455	0.00
11.00	42.1	38.0	44.1	41.4	529	0.18
12.00	47.3	45.1	48.8	44.8	531	0.46
13.00	53.6	51.5	51.5	46.8	500	0.66
14.00	55.4	57.3	54.5	49.7	489	0.87
15.00	58.2	55.7	52.0	48.2	383	1.10
16.00	54.5	52.7	46.6	39.8	304	1.25
17.00	53.9	48.4	42.2	36.3	109	1.37
18.00	44.1	44.5	37.8	32.7	0	1.65
19.00	39.0	41.2	34.7	30.6	0	2.10

Table 5.3 Experimental observations for the conventional still with 40 kg (40 mm depth) of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Inner Glass Temp T_{gli} °C	Outer Glass Temp T_{glo} °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	35.5	33.2	40.5	40.1	455	0.00
11.00	42.2	38.5	44.5	41.8	529	0.16
12.00	48.5	46.8	48.8	44.5	531	0.36
13.00	53.8	52.5	51.3	46.4	500	0.55
14.00	56.0	58.2	54.2	48.0	489	0.78
15.00	57.2	57.4	52.5	45.2	383	1.05
16.00	54.0	56.6	48.9	43.2	304	1.20
17.00	53.2	52.9	44.6	41.0	109	1.35
18.00	48.4	50.6	38.9	35.6	0	1.65
19.00	40.1	46.7	34.0	30.4	0	1.98

5.2 Experimental Observations Of Modifed Still Using Earth Heat Without Using Any Energy Storage Medium

Experiments were conducted for different thickness (10, 20 and 30 mm) of layer of saline water having equivalent mass of 10, 20 and 30 kg respectively under the same climatic conditions. The basin was kept in the earth surface to receive the heat during night time and hence control the saline water temperature to reduce the radiation heat loss from the water surface. In this study, effect of thickness of saline water and the effect of earth heat also was studied.

Temperature of the saline water depends on both quantity of saline water and effect of earth heat. But already from the experiments conducted on the conventional still, it was found that still yield is optimum for keeping 30 kg of saline water in the still basin. Therefore in this study, experiments were conducted on the modified solar still without gravel, for different thickness of saline water to study the still yield with the effect of earth heat as variable.

The main objective of this experiment is to find the effect of earth heat on the solar still . Theoretically calculated results were compared with the experimental results. Observations noted during the experiments in the modified still with different thickness (10, 20 and 30 mm) of saline water are given in the Tables 5.4, 5.5 and 5.6 respectively. When comparing to the conventional still it gives more still yield productivity during day and evening hours.. This is very similarly like conventional solar still, due to the utilization of earth heat during day and night time increased the productivity of still and also the lost basin heat during the day time given back to the basin during evening hours, it utilized the heat loss from the basin respectively.

Table 5.4 Experimental observations in the modified still using earth heat with 20 kg (20 mm depth) of saline water and without using any energy storage medium

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Inner Glass Temp T_{gli} °C	Earth Heat Temp T_e °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	37.1	41.1	48.3	40.7	455	0.00
11.00	55.6	57.8	56.9	42.5	529	0.24
12.00	57.7	59.1	58.2	43.6	531	0.48
13.00	62.3	63.2	61.5	46.1	500	0.78
14.00	63.1	64.4	61.9	48.3	489	1.05
15.00	59.0	61.0	57.4	48.6	383	1.26
16.00	48.2	48.8	44.3	44.9	304	1.44
17.00	41.9	44.6	37.7	41.3	109	1.59
18.00	34.6	33.6	28.1	41.2	0	1.80
19.00	32.1	31.9	26.5	40.6	0	2.01

Table 5.5 Experimental observations in the modified still using earth heat with 30 kg (30 mm depth) of saline water and without using any energy storage medium

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Inner Glass Temp T_{gli} °C	Earth Heat Temp T_e °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	31.9	30.9	39.7	26.7	455	0.00
11.00	38.2	37.4	49.5	27.6	529	0.23
12.00	42.0	41.8	52.4	27.8	531	0.41
13.00	49.6	49.3	55.6	31.1	500	0.65
14.00	52.4	53.8	54.8	34.2	489	0.91
15.00	53.8	54.2	52.8	38.0	383	1.13
16.00	51.3	51.6	45.5	40.8	304	1.34
17.00	46.1	46.3	40.4	41.8	109	1.53
18.00	41.3	41.5	35.3	41.3	0	1.71
19.00	38.1	38.0	33.2	40.3	0	2.43

Table 5.6 Experimental observations in the modified still using earth heat with 40 kg (40 mm depth) of saline water and without using any energy storage medium

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Inner Glass Temp T_{gli} °C	Earth Heat Temp T_e °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	40.8	41.6	47.3	33.4	455	0.00
11.00	49.6	51.2	49.0	36.8	529	0.27
12.00	51.2	53.2	54.5	41.2	531	0.50
13.00	54.3	54.6	55.7	44.6	500	0.75
14.00	58.9	59.2	59.3	50.9	489	1.02
15.00	57.5	58.4	57.1	51.7	383	1.32
16.00	52.9	53.3	48.5	49.2	304	1.56
17.00	48.2	45.9	40.3	42.6	109	1.79
18.00	36.5	36.8	32.9	42.2	0	2.01
19.00	34.1	33.9	29.5	41.6	0	2.19

5.3 Experimental Observations Of Modified Still Using Earth Heat With Energy Storage Medium (Gravel Stones)

Gravel is used as an energy storage medium to transfer heat to the water. Experiments were conducted for different thickness (12, 18, 20 and 25 mm) of layer of gravel having equivalent mass of 20, 30, 35 and 40 kg of gravel respectively. In this study, effect of thickness of gravel layer with same quantity of saline water is studied. The gravel was kept in the bottom of basin to store the solar radiation during day time. When thickness of the gravel layer increases, the bottom loss coefficient decreases which will reduce the heat loss from the still. Due to increase in thickness of gravel layer, heat capacity of the gravel-saline water combination increases which causes the reducing the gravel and water temperatures to reduce the radiation loss. Temperature of the saline water depends on both quantity of saline water and thickness of gravel layer. But already from the experiments conducted on the conventional still, it was found that still yield is optimum for keeping 30 kg of saline water in the still basin.

Therefore in this study, experiments were conducted on the modified solar still using earth heat with gravel as energy storage medium, for different thickness of gravel layer with same quantity of saline water to study the still yield with thickness of gravel layer as variable. The main objective of this experiment is to find the effect of modification on the performance of the still. Theoretically calculated results from mathematical model were compared with the experimental results. Observations noted during the experiments in the modified still with different thickness (12, 18, 20 and 25 mm) of gravel layer with 30 kg of saline water are given in the Tables 5.7, 5.8, 5.9 and 5.10 respectively.

In this chapter, construction of conventional still and the modifications with gravel and without gravel were discussed. Parameters like temperatures of basin, water, glass cover and temperatures of air vapour mixture in between saline water and glass cover were noted down. Some of the parameters like gravel temperature and earth heat temperature which are important for analyses and comparison with the performance of the conventional still also were noted.

Table 5.7 Experimental observations in the modified still with gravel of 12 mm thick layer and 30 kg of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Glass Cover Temp T_{gl} °C	Earth Heat Temp T_e °C	Gravel Temp T_{gr} °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	36.3	37.3	43.2	28.8	35.0	455	0.00
11.00	38.8	39.7	45.4	29.5	37.5	529	0.18
12.00	47.8	48.6	53.9	31.7	46.3	531	0.35
13.00	51.5	52.1	53.5	32.8	50.0	500	0.55
14.00	54.0	54.5	52.0	35.7	52.5	489	0.81
15.00	50.7	50.3	47.6	39.3	52.1	383	1.02
16.00	46.7	46.2	40.9	40.6	49.2	304	1.20
17.00	41.8	41.5	36.2	41.3	43.0	109	1.47
18.00	38.0	37.7	32.4	40.2	42.6	0	1.70
19.00	35.6	35.2	30.1	39.6	42.6	0	2.04

Table 5.8 Experimental observations in the modified still with gravel of 18 mm thick layer and 30 kg of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Glass Cover Temp T_{gl} °C	Earth Heat Temp T_e °C	Gravel Temp T_{gr} °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	35.6	35.8	41.3	26.5	33.9	455	0.00
11.00	38.9	40.1	47.7	30.9	36.5	529	0.18
12.00	46.7	47.5	51.2	32.2	45.1	531	0.39
13.00	50.2	50.6	52.5	36.0	49.7	500	0.77
14.00	56.0	57.4	56.8	38.4	55.1	489	1.10
15.00	55.4	56.2	54.4	40.5	57.9	383	1.35
16.00	51.7	51.8	45.9	43.3	53.9	304	1.55
17.00	45.2	44.6	36.0	42.4	47.8	109	1.70
18.00	40.2	40.0	34.3	41.8	44.0	0	1.80
19.00	37.3	37.3	31.6	41.2	43.9	0	2.16

Table 5.9 Experimental observations in the modified still with gravel of 20 mm thick layer and 30 kg of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Glass Cover Temp T_{gl} °C	Earth Heat Temp T_e °C	Gravel Temp T_{gr} °C	Solar Intensity W/m^2	Cumulative Still Yield kg/m^2
10.00	35.2	35.6	42.3	26.2	34.0	455	0.00
11.00	39.2	39.8	43.4	28.2	37.5	529	0.23
12.00	45.6	46.4	46.5	28.9	43.2	531	0.47
13.00	50.0	50.3	48.5	31.5	48.1	500	0.78
14.00	53.2	53.7	52.5	34.4	55.7	489	1.16
15.00	54.5	55.1	54.4	38.1	56.9	383	1.49
16.00	50.9	50.9	45.4	41.1	55.2	304	1.73
17.00	45.9	45.4	39.2	42.3	50.3	109	1.95
18.00	40.8	40.8	36.1	41.8	44.1	0	2.16
19.00	38.1	37.8	31.4	41.4	44.1	0	2.55

Table 5.10 Experimental observations in the modified still with gravel of 25 mm thick layer and 30 kg of saline water

Time h	Basin Temp T_b °C	Sea Water Temp T_w °C	Glass Cover Temp T_{gl} °C	Earth Heat Temp T_e °C	Gravel Temp T_{gr} °C	Solar Intensity W/m²	Cumulative Still Yield kg/m²
10.00	32.8	32.4	43.0	27.2	31.3	455	0.00
11.00	36.7	37.2	46.4	30.7	35.2	529	0.26
12.00	45.9	46.8	50.2	33.4	43.6	531	0.53
13.00	51.4	55.3	53.1	37.1	52.9	500	0.84
14.00	56.2	57.7	56.2	39.6	58.0	489	1.25
15.00	55.8	56.9	54.8	41.2	57.1	383	1.50
16.00	51.9	52.4	45.8	43.8	53.2	304	1.77
17.00	46.2	46.3	39.6	42.9	49.8	109	2.10
18.00	40.5	41.0	35.2	41.6	44.5	0	2.22
19.00	38.5	37.9	32.0	41.6	44.5	0	2.70

CHAPTER 6

RESULTS AND ANALYSIS

6.1 Comparison of yield at different depths of water against time for conventional still

The experiments were conducted on different depths of water level such as 20mm, 30mm & 40mm and the respective yields are plotted against corresponding time as shown below.

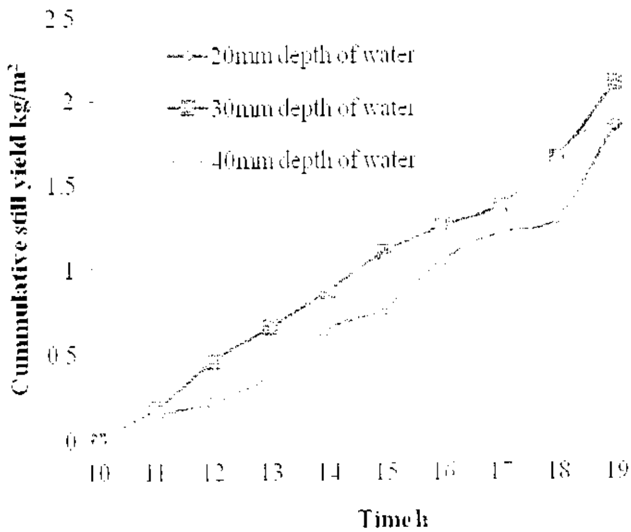

Fig6.1 yield at different depths of water against time for conventional still

From the graph, it is found that as the saline water depth increases the hourly yield also increases this is due to the fact that the water stores the heat but beyond certain depth of water more heat is stored by the water which is used in increasing the temperature of the basin thus reducing the water temperature which reduces the yield rate thus the optimum value for the given dimension to get the maximum yield is obtained from the depth of 30mm as shown in graph.

6.2 Comparison of yields at different depths of water of the solar still using earth heat without using any energy storage medium.

The experiments were conducted in the same solar still for different depth (10, 20,and 30 mm) of saline water and the respective yields are plotted against corresponding time as shown below.

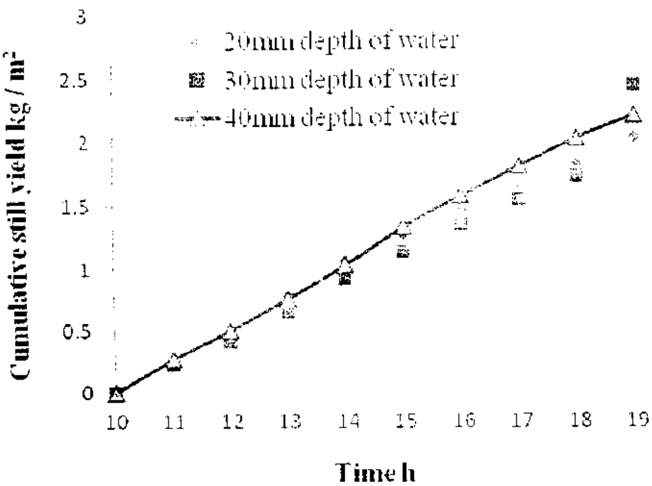

Fig 6.2 Cumulative still yield for different thickness of saline water in the Modified still using earth heat without any storage medium

From the graph, it is found that due to the heat storage capacity of the earth and the glass the temperature of the water is very less due to this fact the yield is very less during day time and as the solar intensity is high during the noon the does not peak rather the yield is normal but during late evening hours the intensity get's reduced the heat is released from the earth and hence the yield during late hours is high and due to the different storage capacity of water the yield varies accordingly and yield is high in the depth of 30mm.

6.3 Comparison of yields at different depths of water level for solar still using energy storage medium & earth heat.

The experiments were conducted on different depths of water levels(20mm, 30mm & 40 mm) and for different layers of energy storage medium.

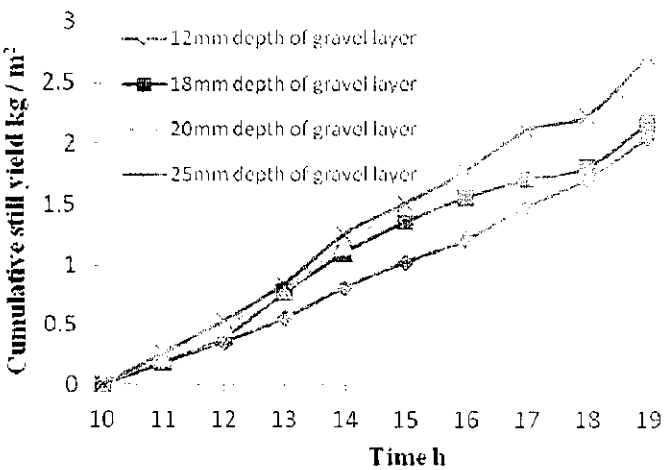

Fig 6.3 Cumulative still yield for different thickness of gravel layer with 30kg of saline water in the modified still

From the graph, it is noted that as the depth of the gravel layer increases the yield increases as expected this is due to the fact that during the peak in solar intensity the heat gets stored in the gravel layer due to it's specific heat capacity which is utilized during late hours in the evening as the gravel layer thickness increases the amount of energy stored also increases thus yield is high for the 25mm depth with 30mm depth of saline water.

6.4 Comparison of yield for conventional still, solar still that uses earth heat only & solar still that uses earth heat& energy storage medium.

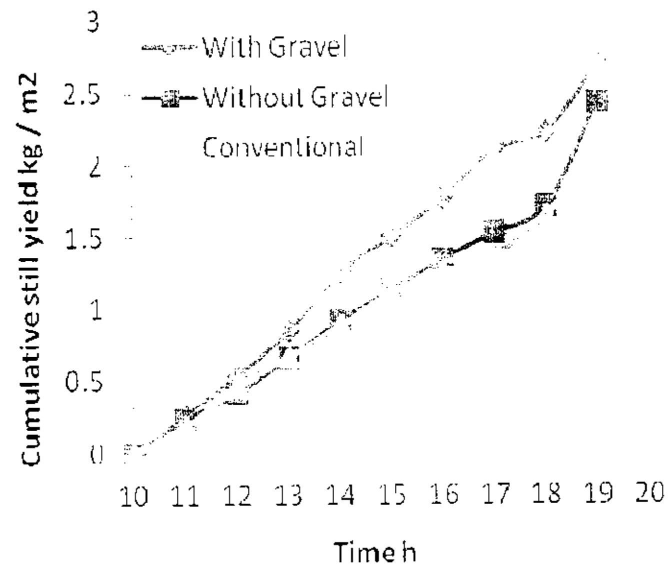

Fig 6.4 cumulative still yield of the modified still with gravel and without gravel and conventional still with 30 kg of saline water

Fig 6.4 compares the cumulative still yield of the modified still using earth heat with and without energy storage medium and with conventional still. Thus as expected the yield is high for the modified still which uses the earth heat when compared to conventional still and the yield is still higher for the still which uses gravel layer as the energy storage medium

Table 6.1 Comparison of experimental hourly yield of the conventional still with 30 mm depth (30 kg) of saline water and the modified still with different thick layer of gravel and with 30 kg of saline water

As the results from the graph denotes that 30mm depth of the saline water yields the higher value the results are tabulated as shown below the varying depth of gravel is considered and yield results for each values are tabulated.

Time h	Conventional still	12 mm thick layer of gravel	18 mm thick layer of gravel	20 mm thick layer of gravel	25 mm thick layer of gravel
11.00	0.23	0.18	0.18	0.23	0.26
12.00	0.18	0.17	0.21	0.24	0.27
13.00	0.24	0.2	0.38	0.31	0.31
14.00	0.36	0.26	0.33	0.28	0.41
15.00	0.22	0.21	0.25	0.33	0.25
16.00	0.21	0.18	0.2	0.24	0.27
17.00	0.19	0.27	0.15	0.22	0.43
18.00	0.18	0.23	0.1	0.21	0.12
19.00	0.72	0.34	0.36	0.39	0.48
Daily yield kg / m^2	**2.10**	**2.04**	**2.16**	**2.55**	**2.70**

The solar still which uses the earth heat & energy storage medium has a higher yield rate when compared to the conventional still. The results shows that the increasing gravel layer thickness increases yield and maximum yield occurs at 30mm depth of water with 25mm thick gravel layer.

CHAPTER 7

CONCLUSION

A water distillation system that uses low cost, easily available energy storage media like black granite gravel have been studied experimentally. In this work, an attempt has been made to develop a simple and low cost solar still which can be used and maintained by common people to fulfill the daily requirement of pure and potable water. Main objective of this work is to use the earth heat and see the effects on the yield an attempt has been made to study the effects of gravel layer on the yield . From the of data collected over the span of two months, the following conclusions are drawn:

1. The modified still which uses earth heat with gravel yields (2.7 kg/m^2 day), modified still without gravel yields 2.43kg/ m^2 day and in the conventional still yields 2.10 kg/m^2 day respectively.

2. The depth of saline water in the conventional still with 30 mm gives the maximum yield.

3. The low cost, cheap material like black granite gravel to increase the still hourly yield and efficiency of the still.

In further improvement, storing of solar radiation heat energy during day time and utilization of latent heat of condensation could be combined by using gravel powder instead of gravel pieces.

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