Int. J. Chem. Sci.: 13(3), 2015, 1109-1122
ISSN 0972-768X
www.sadgurupublications.com

– A REVIEW

PERFORMANCE ANALYSIS OF WICK TYPE SOLAR STILLS

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ABSTRACT

In this paper an attempt has been made to study and analyse various designs of wick type solar stills used in domestic, commercial and industrial applications. Under various Indian climatic conditions, the floating wick type solar stills can produce higher output of 6.25 Litres per square metre of absorber plate area during the month of June. It is also observed that the productivity of the wick type solar stills can be improved to around 53% by integrating the solar stills with fins by enhancing the heat transfer coefficients. The daily yield of the distilled water can be increased by around 14% to 34% by using various inclination angles and reflectors in the solar stills. The average annual values of convective heat transfer coefficient for the passive and hybrid active solar stills were observed as 0.78 and 2.41 W/m^2K.

Key words: Soalr energy, Solar distillation, Inclined solar still, Wick type solar still.

INTRODUCTION

The water and the energy are the two most essential resources for sustaining of life. Both of them are to be conserved and preserved for the sustainable development of the world. Around 97% of the water in the world is in the ocean, approximately 2% of the water in the world is at present stored as ice in polar region, and 1% is fresh water available for the need of the plants, animals and human life.

The left over 1% water is available in rivers, lakes and underground reservoirs. This ground water has also been polluted due to industrial, agricultural and population growth over many years. All ecosystems and every field of human activities depend on clean water and it is one of the most precious resources in present world.

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Solar distillation is used to produce drinking water or to produce pure water for domestic, industrial and commercial purposes. It is recommended that the drinking water generally have 100 to 1000 mg/L of salt to maintain electrolyte levels and for taste. Some saline water may need to be added to the distilled water for acceptable drinking water.

Distillation operates by the escape of moving molecules from the water surface into the gases above it. Sensible heat is caused by the movement of molecules, zig zagging about constantly, except that they are not all moving at the same speed. Further, addition of energy makes them to move further faster and a situation is reached when the fastest-moving ones escape the surface to become vapor. It takes a lot of energy for water to vaporize. While a certain amount of energy is needed to raise the temperature of a kilogram of water from 0^oC to 100^oC, it takes five and one-half times that much to change it from water at 100^oC to water vapor at 100^oC. Practically all this energy, however, is given back when the water vapor condenses.

The salts and minerals do not evaporate along with the water. Ordinary table salt, for example, does not turn into vapor until it gets to a temperature over 1400^oC, so it remains in the brine when the water evaporates. This is also the way we get fresh water in the clouds from the oceans. All the fresh water on earth has been solar distilled. It is not necessary for the water to actually boil to bring about distillation. Steaming it away gently does the same job as boiling, except that in the solar still, it will usually turn out even more pure, because during boiling the breaking bubbles may contaminate the product water with tiny droplets of liquid water swept along with the vapour[1].

Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base. This interior surface uses a blackened material to improve absorption of the sunrays. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapour evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. Feed water should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process. If the still produced 3 Litres of water, 9 Litres of make-up water should be added, of which 6 Litres leaves the still as excess to flush the basin[2].

EXPERIMENTAL

Literature review

Aybar[3] has proposed mathematical modeling of inclined solar still with wick. This kind of solar still generates distilled water and hot water simultaneously. In the parametric studies, several parameters were investigated such as the feed water mass flow rate and solar intensity. The system can generate 3.5-5.4 Kg/d distilled water (for a 1 m^2 absorber plate area). The temperature of the generated hot water is about 40^{o}C, which is good enough for domestic usage. The simulation results are in good agreement with the experimental results.

Aybar et al.[4] experimentally analyzed inclined solar still. The system was tested with three variants: bare plate, black-cloth wick, and black-fleece wick. Brackish feed water from reservoir tank is 4060 ppm.with the bare plate hardness of fresh water is 42 ppm. With the black-cloth and black-fleece, the hardness of the fresh water was 79 ppm and 140 ppm, respectively. By using black fleece and black cloth wick the inlet water mass flow rate is minimized. So black fleece and black cloth producing more fresh water than bare plate. With black fleece solar still produce 2800 mL per day.

Tiwari et al.[5] have carried out the analysis and application of solar desalination in the current scenario of world and concluded that the basic heat and mass transfer relations are responsible for the development and testing procedures for various design of solar stills.

Kumar and Tiwari[6] have estimated the internal heat transfer coefficients of a deep basin hybrid Photovoltaic/Thermal (PV/T) active solar still based on outdoor experimentation for the composite climate of New Delhi. The internal heat transfer coefficients are evaluated by using various thermal models and concluded that the average annual values of convective heat transfer coefficient for the passive solar still and hybrid Photovoltaic/Thermal (PV/T) active solar still were observed as 0.78 and 2.41 W/m^2K, respectively at a water depth of 0.05 m.

El-Sebaii[7] has investigated the effect of wind velocity on the output parameters of active and multi-effect passive solar stills and concluded that the yield increases with increase in wind speed since the rate of evaporation increases with increasing wind velocity.

El-Sebaii[8] has analyzed the influence of wind speed on the performance for multiple masses of water in basins and concluded that the thermal performance improves with increase in wind speeds.

Tripathi and Tiwari[9] have attempted to investigate the effects of different water depth basin solar stills on the heat and mass transfer coefficients for the passive and active modes and concluded that the distillate output significantly decreases in tandem with increasing water depth in the basin of the solar still. It has also been concluded that the case yield of active solar distillation system is better than that of the passive solar still.

Tiwari and Tiwari[10] have experimentally investigated three solar stills with different inclinations of condensing cover and concluded that keeping the water level minimum at an angle of 15^o maximizes the annual distillate yield for a particular latitude and longitude. It was also observed that the angle of inclination of the condensing cover as 45^o degrees works effectively during winters.

Singh and Tiwari[11] have conducted a numerical analysis for latitudes of 13-28^oN considering the effect of solar radiation, wind speeds, water depths and cover tilt angle on productivity and observed that the optimum glass tilt angle for maximum annual output must be the equal to the latitude of the location.

Different designs of wick-type solar stills

The following are the various designs of wick type solar stills:

- Basin wick type
- Wick-basin type
- Floating-wick type
- Multi-wick type
- Floating cum tilted-wick type
- Tilted wick-type with flat plate reflectors
- V-Type solar still with-wick as absorbing material
- Concave wick-type
- Single basin wick type with fin
- Clothes moving wick-type

The solar radiation falling on the glass cover is transmitted to the wick surface. A part of the energy is utilized for heating the water flowing through the wick due to capillary action. A large amount of heat gets trapped inside the still, and transfer of energy takes place from the wick surface to the glass cover and to the ambient air.

The heat transfers in the distillation system are governed by external and internal modes. The external heat transfer mode occurs due to convection and radiation, which are in dependent of each other and occurs outside the still. The heat transfer within the solar distillation unit is referred to as the internal heat transfer mode, which occurs due to radiation, convection and evaporation. In internal heat transfer mode, the mass transfer accompanied with radiation and convective heat transfer. Water flowing through the wick surface gets heated and evaporated into vapour. The saturated water vapour condenses in the lower surface of the glass cover after releasing the latent heat of vaporization. The condensed water droplets trickle down due to gravity and get collected in the drainage channel.

The basin wick-type solar stills

Jute wick material in simple basin solar still is proposed by Yeh and Chen[12] and Sengar et al.[13] The basin wick-type solar stills, with jute and charcoal as wick materials are very simple in construction. The system consists of a simple basin enclosed in a thermally insulated wooden box and covered by a glass.

Charcoal wick material is introduced in the tilted basin and analyzed by Mahdi et al.[14] The analyses have been carried with the following assumptions:

- The wick type solar still is made vapour tight.
- The absorptivity of glass cover and water are negligible.
- The stills are perfectly insulated.
- The wick material used is blackened for more absorption.
- The heat capacity of the glass cover and insulating material of the solar still are negligible.

The jute wick material in the basin sucks water and due to capillary action, the upper surface of the wick material is always wet during peak sunny hours. The water gets evaporated and the water vapour condensed in the condensing surface which is pure distilled water. The thermal capacity of the still is less as the jute wick is made to float in the basin water. The charcoal wick material introduced in the tilted basin acts as the evaporating surface during the working hours of the still and water flows throughout the wick material due to good capillary action which serves as thin film of water surface for evaporation. The schematic diagram of the design is shown in Fig. 1, which is provided with an option of changing the angle of inclination of the still for maximum interception of solar radiation.

The results of the study have proven that the wick-type solar still is more effective than the conventional basin type solar still due to limited thermal capacity.

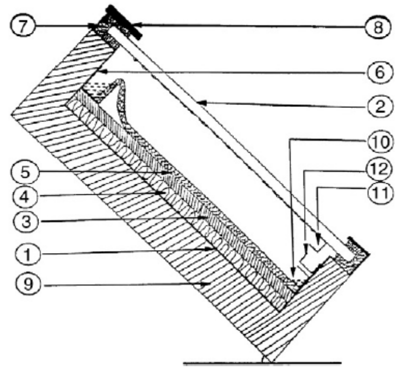

Fig. 1: Cross sectional view of the basin wick type solar still[12]

(1) Galvanised steel tray, (2) glass cover, (3) support board, (4) polystyrene, (5) charcoal cloth, (6) aluminum channel, (7) rubber gasket, (8) steel strip, (9) styrofoam, (10) brine gutter, (11) distillate gutter, and (12) distillate outlet channel.

Wick-basin type solar still

A wick-basin type solar still designed by Minasian and Al-Karaghouli et al.[15] has great potential due to its higher productivity compared to the other type stills. The construction of the still is quite simple. The basin and the wick type are integrated to form a wick-basin type solar still. The still consists of metallic basin made of galvanized iron sheets and a glass cover. The bottom and sides are well insulated. The black painted wick used to absorb the solar energy is enclosed by a wooden frame.

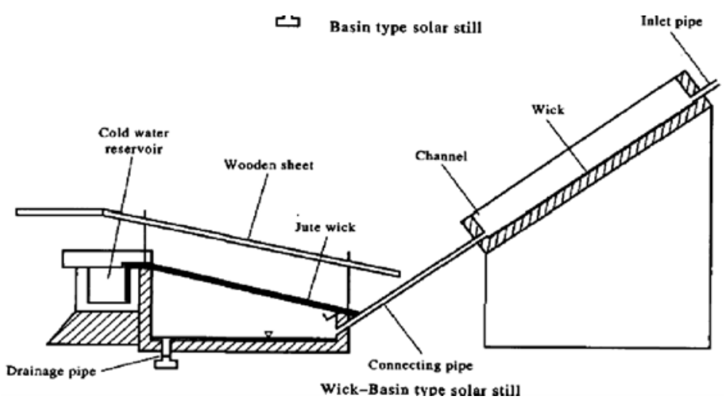

Fig. 2: Wick basin type solar still[15]

The preheated water from the tilted-wick type solar still is fed into the conventional basin type solar still through a connecting pipe. Both the units work together as a single unit for the production of distillate. The schematic diagram of the wick-basin type is shown in Fig. 2.

Floating wick type solar still

Al-Karaghouli and Minasia[16] have proposed a floating wick type solar still with blackened jute wick and aluminium black plate as floating materials inside the still. Floating-wick type solar still can produce more fresh water than basin type and tilted wick type solar still. Floating-wick type solar still produces maximum 10,025 mL m^{-2} day^{-1} in peak summer.

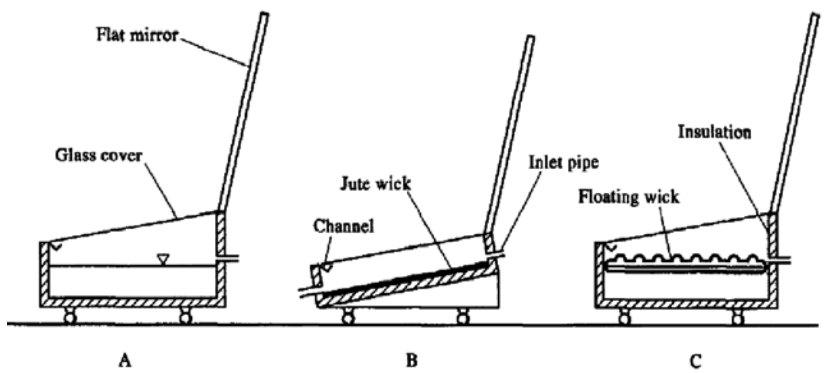

Fig. 3: Experimental still-floating wick-type[16]

Nafey et al.[17] experimentally analyzed solar still productivity using floating perforated black plate. Using the floating aluminum perforated black plate in the solar still increases the solar still productivity by 15% for a water depth of 3 cm and 40% for a water depth of 6 cm.

Multi-wick type solar stills

Ohshiro et al.[18] have proposed a multi-wick type solar still, which has great potential due to its high productivity, simplicity and less maintenance. The still consists of an evaporating wick, condensing wick and a poly tetra fluoro ethylene (PTFE) net sandwiched between them as shown in Fig. 4. Water vapour diffuses through the spaces in the net from the evaporating wick to the condensing wick. The sandwiched 2 mm thick PTFE net reduces the gap between evaporating and condensing surfaces considerably, yet prevents contamination of the condensate with saline water due to its very low wettability. By using wick-net-wick unit distillate contains less than 10 ppm

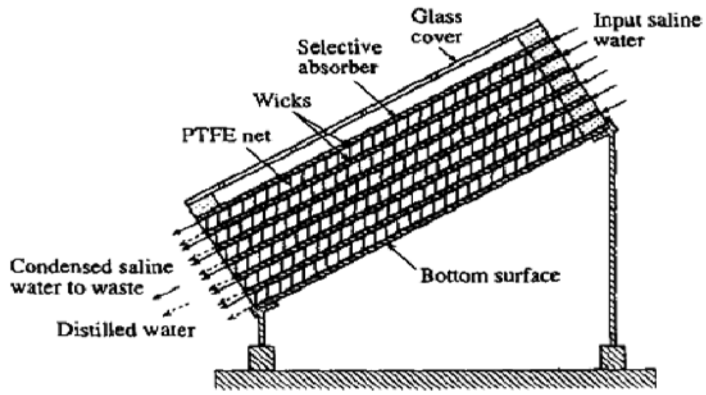

Fig. 4: Multi-wick still with wick/PTFE net/wick layer units[18]

Floating cum tilted wick type stills

Janarthanan et al.[19] have proposed a different design of floating cum tilted wick type solar still which is simple in construction as shown in Fig. 5. In this study, the blackened jute wick is spread along with a 15^{o} tilted portion. The remaining part of the wick has been prepared in a corrugated shape and floated in the water reservoir inside the still with a thermo coal sheet of thickness 2½ cm. The water level in the reservoir is always maintained to stay below the reservoir by 0.25 cm to make sure that the water does not overflow in the tilted portion.

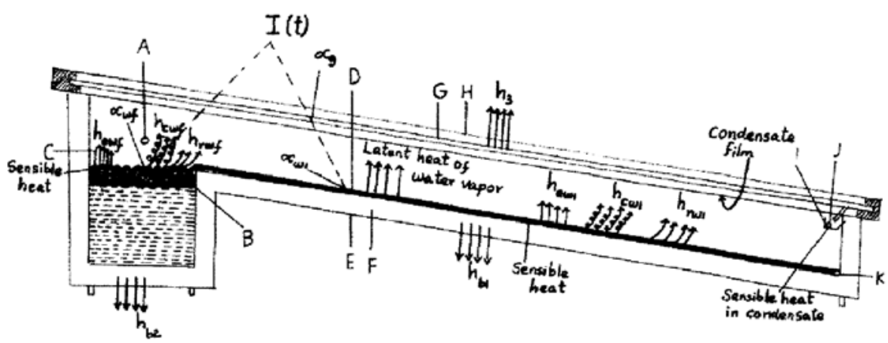

Fig. 5: Sectional view and energy flow diagram for a closed cycle system of a floating tilted wick solar still[19]

(A) Constant water level inlet; (B) Thermocole sheet 2½ cm thick; (C) Floating wick surface; (D) Tilted wick surface; (E) Outer plywood; (F) Glass wool insulation; (G) Glass cover 4 mm thick; (H) Wooden frame; (I) Distilled water outlet; (J) Distilled water collection channel (K) Excess saline water outlet.

The solar radiation through the glass cover is absorbed by the tilted wick and floating wick surfaces. A part of the energy is utilized to heat the water flowing through the wicks due to capillary action. There is a transfer of energy from the tilted wick and floating wick surfaces to the glass cover and to the ambient air by evaporation, convection and radiation. The system achieves average water temperature 29.07^{o}C and instantaneous efficiency 18% at 12.30 pm.

Tilted wick-type solar still with flat plate reflector

Hiroshi and Yashuhito[20] have proposed a tilted wick type solar still with flat plate reflector which is simple in construction. The still consists of a glass cover, tilted-galvanized iron tray, wick material and a flat plate reflector to improve the amount of distillate output for different seasons across year. This type of still has yielded greater distillate output compared to that of a tilted wick type solar still with inclined external flat plate reflector[21], with one step azimuth tracking of a tilted wick solar still[22], tilted wick type still with bottom reflector[23] and tilted wick still for the determination of optimum inclination and influence of the reflector[24].

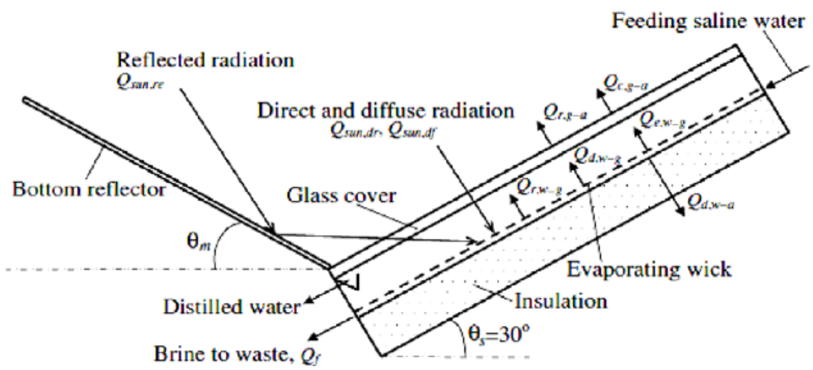

Fig. 6: Wick type still with top and bottom reflector[24]

V-Type solar still with charcoal absorber

Selvakumar et al.[25] have proposed a V-type solar still with charcoal as absorbing material. The construction of the still is simple and it consists of galvanized iron tray, glass cover, charcoal absorber, boosting mirror and water collection segment as shown in the Fig. 7. In this study, the heat transfer taking place inside the still, outside the still and the performance of the still have been calculated with the help of Nusselt number (Nu) and Grashof number (Gr). Still with charcoal, still with mirror and still with charcoal and mirror produces 3.22, 2.7, and 3.515 Litres of distilled water, respectively.

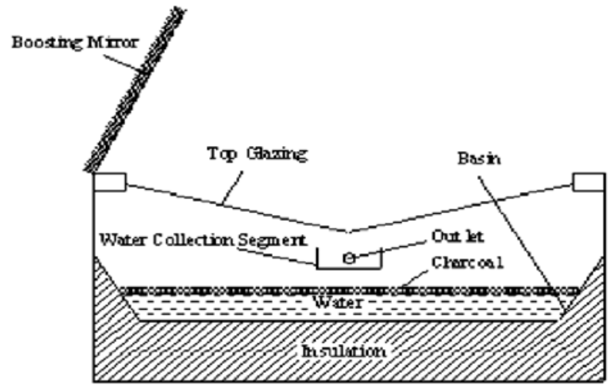

Fig. 7: V - type solar with charcoal absorber[25]

Concave wick type solar still

Kabeel[26] has investigated the performance of a solar still with a concave wick evaporation surface as shown in Fig. 8. The working of the still is like that of the normal wick type solar still and the advancement used in this type of still is, the concave wick arrangement and the four side condensing covers. Use of glass covers at four sides of the still reduces the shading effect compared with that of conventional solar still. This study has revealed that the instantaneous efficiency is 45%, and average daily efficiency is 30% more than the conventional type stills.

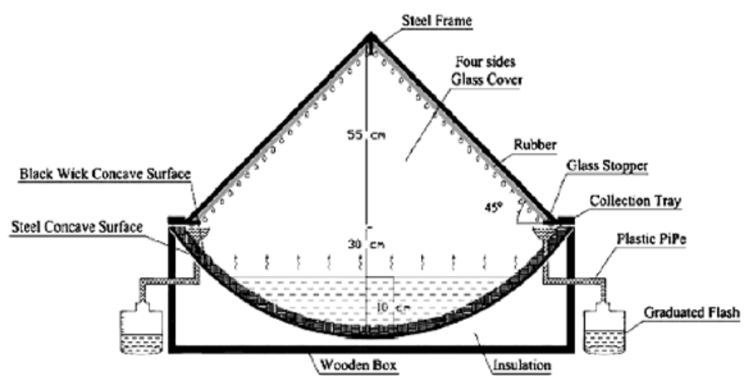

Fig. 8: Concave wick type solar still[26]

Fin type solar stills

Velmurugan et al.[27] have experimentally studied a single basin solar still with fin for enhancing the productivity with three different types of modified stills and with three different absorbing materials namely wick, sponge pieces and fins of equal sizes. The three types of the stills contain glass cover, galvanized sheet iron tray, absorbing materials, wooden box covering the still, and a tilted tray for tilted wick type solar still. The evaporative area is 1 m^2 when the still is without fin and the basin area was 1.0045 m^2 when fins were used. The schematic representation of the still using wick materials as absorber is shown in Fig. 9. The sponge type solar stills require more exposure area as compared to that of the wick type solar stills. But the sponge type provides more evaporation rate and as a result the productivity of the still increases about 15.3% when sponges were used. In case of wick type the productivity of the still has increased by around 29.6%. It has been concluded that the productivity of the solar still increases by around 45.5% when the fins are used at the bottom of the still, absorber plate can absorb more solar radiation due to increase in exposure area, and preheating time for saline water has been decreased.

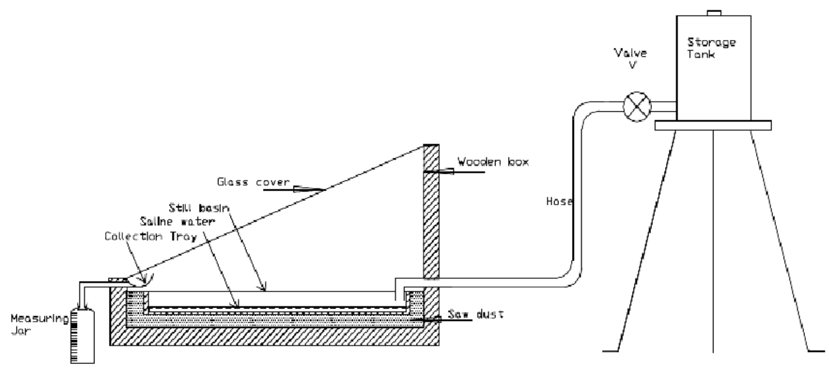

Fig. 9: Schematic diagram of wick type solar still[27]

Double slope wick type solar still

Murugavel et al.[28] have experimentally investigated the thermal performance and concluded that the productivity of the still depends mainly on the parameters like solar radiation, wind velocity, atmospheric temperature, basin water depth, glass cover material, thickness, its inclination and the heat capacity of the still.

A double slope single basin passive type still with basin area of 1.75 m^2 is fabricated and tested under laboratory conditions for a thin layer of 3.4 Kg of water in the basin. The still is very easy to construct and consists of a basin made of mild steel, inner basin, outer basin, two glass covers enclosing the still and tight insulation with rice husk as shown in Fig. 10. The performance of the still is justified with absorbing materials like light cotton cloth, light jute cloth, sponge, and quartzite rock and washed natural rock. The production rate is slightly higher for the still with the light cotton cloth, light jute cloth and sponge as basin materials than the still with quartzite rock and washed natural rock as basin materials during heating period. The maximum production rate value is higher for the still with light cotton cloth as basin material. During cooling, the production rate for the still with quartzite rock as basin material is higher. Cotton cloth reaches maximum production rate of 1000 g/h than other absorbing materials.

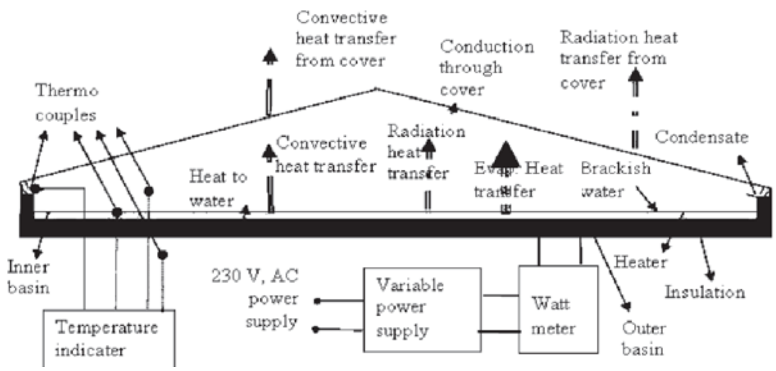

Fig. 10: Single basin double slope simulation still[28]

CONCLUSION

Based on the studies of various designs of wick type solar stills the jute and charcoal as wick material can produce 2.3 to 3.4 Litres of distilled water in the winter and summer seasons, respectively per square metre of absorber plate area. Further, under various Indian climatic conditions, the floating wick type solar still can produce higher output of 6.25 Litres per square metre of absorber plate area during the month of June. The productivity of the solar stills can be increased to 53% by integrating the solar stills with fins in the conventional type than the normal conventional type solar still. The daily yield of distillate can be increased by around 14% to 34% by using various inclination angles and reflector in the solar stills. The average annual values of convective heat transfer coefficient for the passive and hybrid active solar still were observed as 0.78 and 2.41 W/m^2 K.

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Revised : 20.03.2015 *Accepted : 22.03.2015*