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STATUS OF USE OF SOLAR THERMAL ENERGY FOR SOLAR DESALINATION

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Abstract: The conventional desalination processes require significant amount of energy to convert brackish water into potable water for human consumption and industry. Solar still is an innovative device that utilizes solar energy to produce distilled water from brackish water. Numerous experimental research works have been reported in literature to analyze the performance of various types of solar stills under local climatic conditions. The aim of this study is that it provides energy researcher's insight into solar still design for clean water production and thus, it promotes commercialization of this product in rural development.

Keywords: Solar still, multi-effect, multistage, desalination, evacuated tube collector,

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INTRODUCTION

Water is one of the most important constituent for sustenance of mankind. It is useful for many purposes like agriculture, irrigation and domestic purposes like cooking. Fresh water is the most important issues of health hazard in today's world. With these reasons, desalination is found to be most challenging task and only viable solution to drive fresh or potable water from available brine and saline water resources all over the world. A single basin solar still is a simple device used for distillation purposes. The productivity of a simple solar still is very low. As the performance of solar still depends on the various climatic, operational and design parameters. The solar still receives thermal energy from the sun in the form of radiation and subsequently heats water mass in basin. Due to heating, the water gets evaporated to form water vapor. The air vapor mixture at the water surface has higher temperature and lower density than the air-vapor mixture near the top cover. This induces convection currents between water surface and top cover surface. The saturated air vapor mixture rises towards the upper side due to temperature and density difference and condenses partially when it is in contact with top cover surface, and then the distillate is collected. The solar still broadly classified as passive solar still and active solar still. The passive solar still utilizes the radiative energy and it is the only source to evaporate the water mass kept in basin. But in active solar still, additional thermal energy is fed into the basin water by means of some external devices, like flat plate collector, evacuated tube collector, parabolic concentrators, photovoltaic thermal system, etc (Kumar *et al*, 2015).

Several modifications were made in solar still to improve its productivity. In accordance with this active solar stills are now being preferred which include integration of external sources. Hence this paper includes an overview of active solar still having different modifications and configuration in order to achieve maximum distillate yield. Also the paper includes the thermal performance of system after implementing the changes in the system and impact of it on the performance of the system.

Experimental Investigation on Active Solar Still

Active methods significantly improve the temperature of water in basin by integrating the still with external heat sources. The system integrated with flat plate collector in which flat plate collector has been used to absorb solar energy, convert it into heat and then transfer that heat into stream of liquid. Then the water has been fed to basin of solar still in which temperature of water has been increased. Due to that the evaporation rate of water increases and ultimately the productivity also increases. Still coupled with flat plate collector has 22.26% more efficiency in comparison to still without coupling (Badran *et al*, 2005). A variety of technologies exist to capture solar radiation and one of them is the evacuated tube technology which is made of parallel evacuated glass pipes. Each evacuated pipe consists of two tubes, one is inner and other is outer tube. The inner tube is coated with selective coating while outer tube is transparent. Light rays pass through the transparent outer tube and are absorbed by inner tube. Both inner and outer tube has minimal reflection properties. Both inner and outer tube has minimal reflection properties. The inner tube gets heated while sunlight passes through outer tube and to keep heat inside inner tube, a vaccum is created which allows the heat to transfer. In order to create the vaccum, two tubes are fused together on top and existing air is pumped out. Thus heats stays inside inner pipes and collects solar radiation efficiently. Therefore, an evacuated tube collector is the most efficient solar thermal collector.

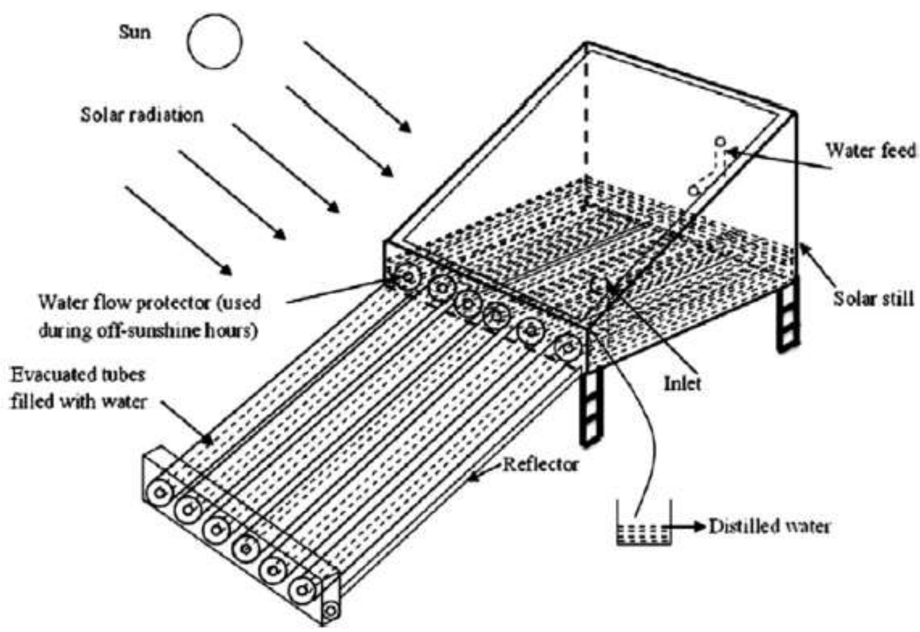

Fig. Solar still coupled with evacuated tube collector

(Mangal et al, 2010) mentioned that the peak energy output is provided by an FPC only at mid day when the sun is perpendicular to surface of collector whereas ETC tubes are able to track sun passively throughout the day because of cylindrical shape of tube. Different collector configuration can help to obtain large range of temperature i.e. 20-80^{0}C is operating temperature range of FPC (Sharma and Daiz, 2011) and 50- 200^{0}C for ETC (Kalogirou, 2013).

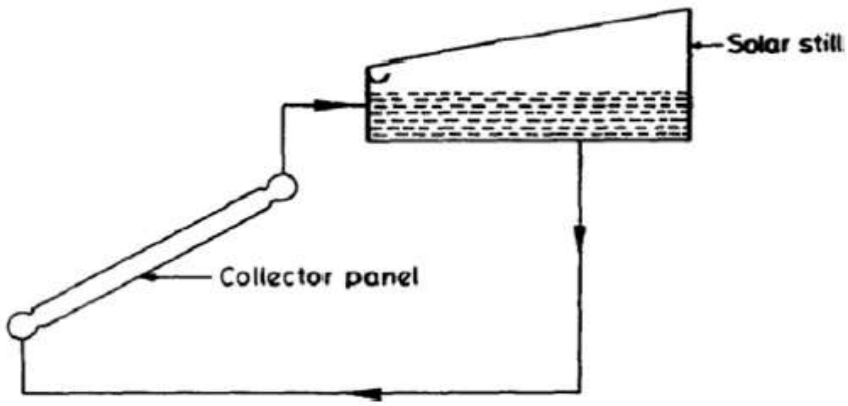

Fig. Flat plate collector assisted solar still

Solar concentrator devices have been used for solar distillation of water because it increases the intensity by concentrating the energy available over a large surface onto a smaller surface i.e. absorber. Due to the concentration on smaller area the heat loss is reduced. It has high delivery temperatures. (Zeinab and Ashraf, 2007) studied single slope solar still coupled to parabolic trough and found that the fresh water productivity was increased by 18 % in comparison with passive still.

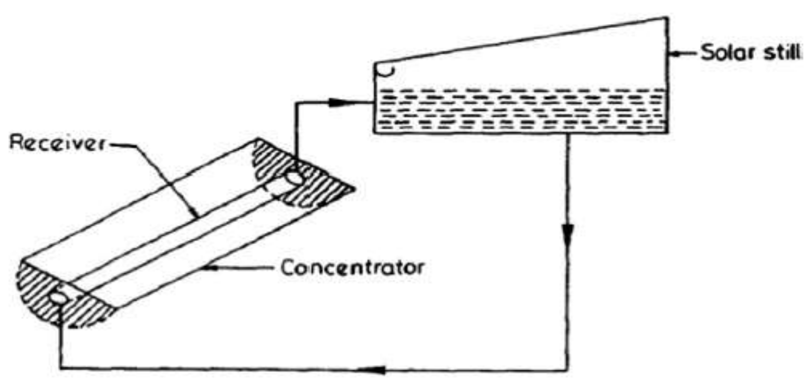

Fig. Concentrator assisted solar still

Photovoltaic thermal modules (PV/T) are the photovoltaic modules coupled to heat extraction devices. The system is mainly adopted to save the life of PV cells which are generally being over heated by solar irradiations due to their less conversion capacity of solar radiation to electricity. Thus, these hybrid systems in addition to converting solar energy to electricity also delivers useful form of thermal energy which can be coupled to desalination system. (Kumar and Tiwari, 2008) performed experiments on hybrid PV/T active solar still and reported that the productivity was 3.5 times more than passive solar still.

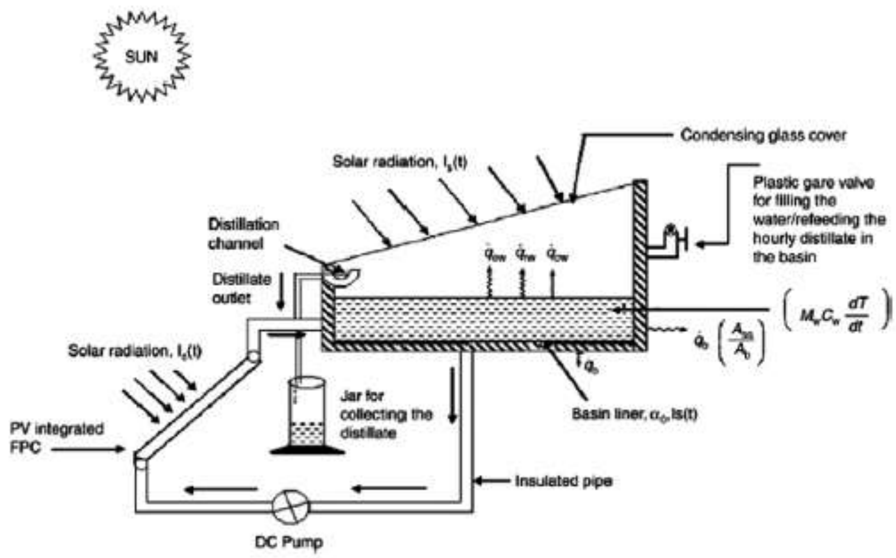

Fig. Hybrid PV/T integrated solar still

Developments in technology

Multi-basin solar still

A regenerative desalination unit which consists of two basins with provision for cooling water to flow in and out of second effect. It consists of two basins where the latent heat of condensation released to first glass cover was utilized to additional fresh water from a second effect. The second effect may be arranged in such a way that can have either a flowing water film or stationary one of larger thickness. It was found that the productivity of regenerative still is about 20% higher than that of conventional still (Zurigat *et al* 2004). Making the stills perfectly insulated increases their productivity. There is positive effect of insulation on regenerative solar still. The wind speed has positive effect on productivity of still, it can increase the productivity by 50 % if wind speed increases from 0 to 10 m/s. Also the thickness of water on top of the first glass cover and mass flow rate of water going into the second effect have marginal effect on productivity of regenerative still.

In the triple basin solar still, two glass sheets were fixed in between basin liner and glass cover of single basin still. These glass sheets served as the base of extra shallow depths of saline water, and the whole assembly behaved as three simple basin solar still placed one above other. The water in middle and upper basin makes use of latent heat of condensation released at inner surface of glass covers of lower and middle basin, respectively. The total productivity of the system is the sum of productivities of individual basins.

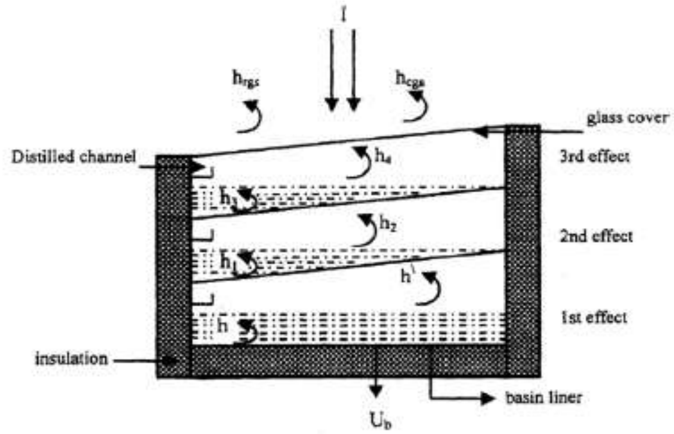

Fig. Triple basin solar still

Multi-effect Solar Still

The distillation unit consists of second effect still connected to a single slope still of a movable shutter type reflector back and located at its shaded side. The reflector will maximize the reflected solar energy at different site locations and different seasons and allow purging the vapor. The second effect still act as additional heat and mass sink that sucks evaporated water vapor from first effect still. The purged vapor condenses and it's sensible and latent heat is utilized to heat the basin water of second effect for additional evaporation.

Multistage solar still

It consists of two aluminium metallic trays kept one upon another. The upper tray is filled with water. A hot plate type electric heater was used for indirect water heating in lower tray. The condensate is collected through a trough fixed at central position of upper tray. The solar still consists of three stages placed on top of each other. There is perfect sealing between different stages such that the water vapor which evaporated during the boiling can pass only through orifice that connects two stages. Vapor generated in first stage condenses on the inclined bottom of second stage and inside the orifice passing through it, giving its heat to water in next stage. The rest of vapor expands through the orifice to join the vapor generated in second stage. The expansion accelerates the rate of evaporation. The same thing happens again between second and third stages and the condenser. (Jubran, *et al* 2000) found that daily productivity can be upto 9 kg/m^2 and distillation efficiency is 87 %.

Tubular solar still

It consists of transparent tubular cover and a blackened rectangular trough inside the cover. The solar radiant heat after transmitting the cover is mostly absorbed by saline water in the trough and rest is absorbed by cover and trough. Thus the saline water is heated up and evaporated. The water vapor density of humid air increases associated with evaporation from water surface and then the water vapor is condensed on inner surface of cover, releasing its latent heat due to evaporation. Finally, the condensed water naturally trickles down toward the bottom of cover due to gravity and is stored in collector**.** With heat extraction technique , compound parabolic concentrator – concentric tubular solar still with single slope solar still is 6460 ml/day (Arunkumar *et al*, 2015).

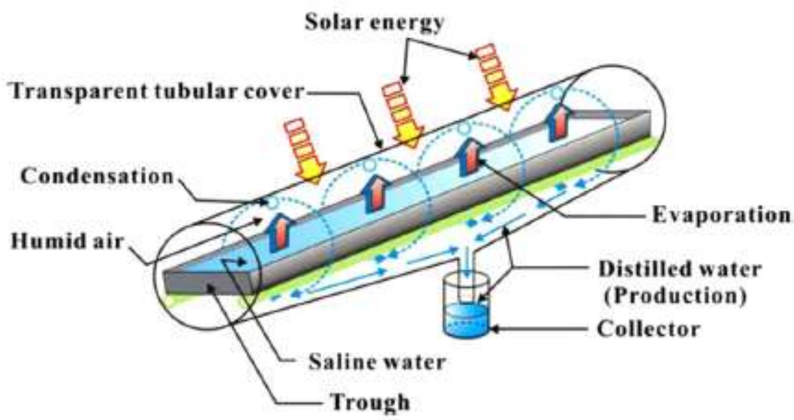

Fig. Mechanism of pure water production from tubular solar still

Inverted absorber solar still

The water temperature in the distillation system was increased by inverting the absorber to reduce the bottom heat loss. The solar radiation after transmission through glass cover was reflected back to inverted absorber of solar still. The absorbed solar radiation was partially transferred to water mass above inverted absorber by convection while rest of radiation was lost to atmosphere through glass cover. The evaporated water was condensed on inner surface of condensing cover releasing its latent heat. It was observed that there is significant increase in water temperature of inverted absorber solar still due to reduced bottom heat loss and higher absorptivity of the absorber plate (Tiwari and Suneja, 1998).

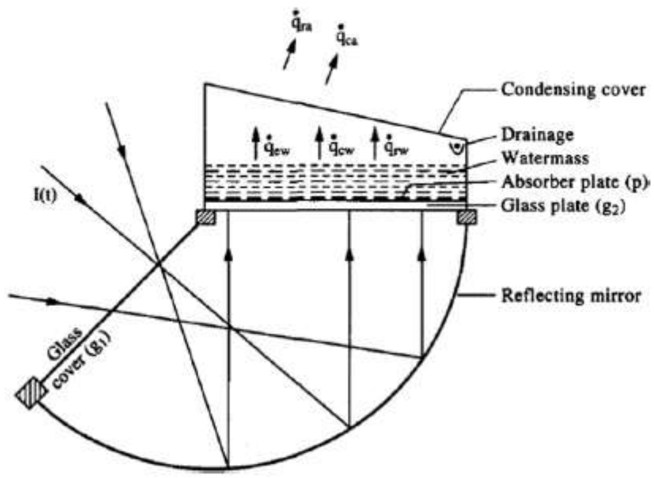

Fig. Inverted absorber solar still

Solar still designs by adopting some measures

Deep basins

It has been observed that the daylight productivity decreases with increase in water depth and reverse is the case for overnight productivity due to increase heat capacity of basin water with increasing depth (Aboul-Enein *et al*,1998).

Double glass cover

The formation of water droplets in inner surface of glass is responsible for reflection and absorbing some of the incident radiation. Two glass covers decreased the heat losses by convection to ambient resulting in higher basin water temperature. The heat capacity of evaporator was minimized due to small evaporator volume; consequently the system responded to solar radiation in shorter time. Mousa Abu-Arabi *et al,* investigated the thermal performance of a single basin solar still with double glass cover cooling. The brine water is made to flow between the double glass arrangements to lower glass temperature and thus increase the water and glass temperature difference.

Floating perforated black plate

Safwat Nafey *et al* developed solar still with a floating perforated black plate. A black plate painted aluminum sheet of thickness 0.5 mm was made floating on brine surface by stacking five floating balls under side surface of plate. The floating black plate allows only a thin layer of saline water to be formed above plate surface. This layer was heated rapidly by absorbed energy and hence rate of evaporation was increased. Also the floating black plate decreased the heat loss to the walls and bottom due to lowering the water temperature below the plate.

Suspended absorber

El-Sebaii *et al* presented a solar still with baffle suspended absorber. A movable suspended absorber plate was placed inside the basin water of solar still. The suspended absorber divided the basin water into two portions the upper and lower water columns and/or vice versa took place by conduction through the plate and by convection through vents.

Fins, sponges and wicks

It was observed from experimental study that, the porous fin- glass cover temperature difference is positive, even in the morning hours when basin water temperature is lower than the cover temperature. This corresponds to fact that fin type still starts producing in morning hours, because vertically extended fins starts receiving the solar radiation and due to their low thermal inertia, evaporation starts rapidly. During low intensity and off-sunshine period the distillate production is supplemented from relatively warm basin water.

Vacuum

The effect of applying vacuum inside solar still on its productivity was studied by Al-Hussaini and Smith. The vacuum inside solar still makes the convective heat transfer coefficient as zero. It was found that the enhancement of water productivity per day was more than 100% when using vacuum inside solar still. It was inferred that the existence of non-condensable gas such as air adjacent to condensate surface behaves as thermal barrier to heat transfer. The enhancement was 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 was applied.

Storage Medium

El-Sebaii *et al* presented a solar still integrated with a thin layer of sensible storage medium beneath the basin liner of still for the purpose of fresh water production during night time. Sand was used as storage medium because it is cheap and easily available. Part of the thermal energy from solar radiation was transferred by convection to water flowing over the basin liner and other will be transferred by conduction to sand beneath it. After sunset the sand act as a heat source for basin water consequently the solar still continued to produce fresh water during night.

In case of PCM as heat storage medium, when basin liner temperature becomes higher than that of PCM, heat is first stored as a sensible heat till the PCM reaches melting point. Then the PCM starts to melt and heat will be stored in melted PCM as sensible heat. When solar radiation decreases the still components starts to cool down, the liquid PCM transfer heat to basin liner and from the latter to basin water until the PCM completely solidified. In other words, PCM will act as a heat source for the basin water during low intensity solar radiation as well as during night. The still continues to produce fresh water after sunset even with thin layers of basin water.

Thermal energy evaluation

To improve the performance o solar still, many active methods were invented by researchers over the years. Many research works have been reported on active solar still with flat plate collector, evacuated tube collector, heat pipe and hybrid photovoltaic thermal system. In active solar still the quantity of additional thermal energy supplied to basin water is included during its thermal analysis.

Heat transfer process in solar still is considered as the transient heat transfer process due to variation in the temperature or heat flux with respect to time. The heat transfer process in a solar still can be broadly classified into internal and external heat transfer processes based on energy flow in and out of the enclosed space. The internal heat transfer is responsible for transportation of pure water in vapor from leaving behind impurities in the basin itself, whereas the external heat transfer through condensing cover is responsible for condensation of pure vapor as distillate.

The heat exchange between water surface and glass cover inner surface of solar still is known as internal heat transfer. The convection heat transfer takes place between basin water and glass cover inner surface across humid air due to temperature difference between them. The radiation heat transfer occurs through a mechanism that involves the emission of internal energy of object. The radiative heat transfer occurs at inside of solar still between water mass and glass cover inner surface. Evaporation occurs at the liquid vapor interface when the vapor pressure is less than the saturation pressure of liquid at a given temperature. The evaporation heat transfer occurs in solar still between water and water vapor interface (Elango *et al* ,2015).

The external heat transfer consists of conduction, convection and radiation processes which are independent of each other. It is considered as the loss of heat energy from solar still to the atmosphere. The heat lose in solar still from glass cover outer surface to atmosphere is called top loss heat transfer process and from water mass to atmosphere through insulation is called as bottom and side loss heat transfer process. Higher the former the higher will be yield from the solar still and lower the latter better will be yield.

Thermal evaluation of single basin single slope solar still is derived from energy balance equation of its components namely, basin, water mass and glass cover. From this evaluation we can develop energy balance equations for different technology that has been adopted to evaluate the performance of system. The energy balance equation at various portion of solar still are described as follows

For glass cover outer surface

Rate of energy received from glass cover inner surface by conduction = rate of energy lost to Ambient by convection and radiation

For glass cover inner surface

Rate of energy absorbed from solar radiation + rate of energy received from water mass by convection, evaporation and radiation = rate of energy lost to glass outer surface by conduction

Basin liner

Rate of energy absorbed from solar radiation = rate of energy lost to water mass by convection + Rate of energy lost to ambient by conduction and convection

Water mass

Rate of energy absorbed from solar radiation + rate of energy received from basin liner by convection + rate of energy received from external devices = rate of energy stored + rate of energy lost to glass inner surface by convection

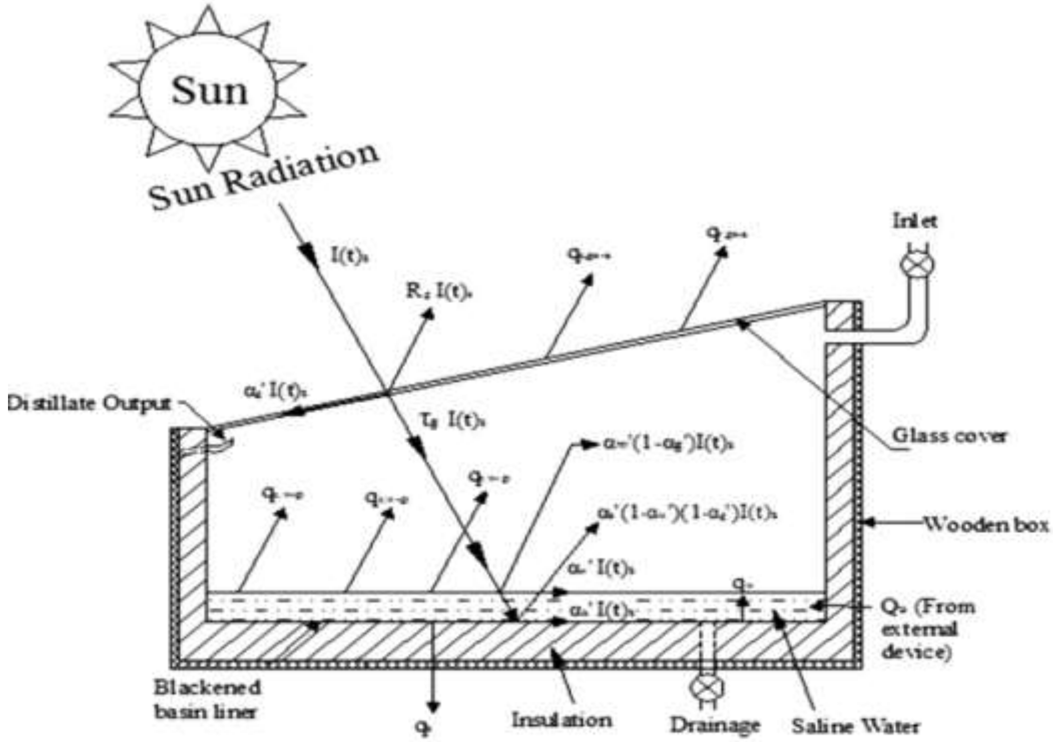

Fig. Heat transfer mechanism of solar still

CONCLUSIONS:

The works described above clearly show that the performance of still depends on mass of water in the basin, water temperature and exposure area. In active methods separate energy collector is used to supply the preheated water to the still. Solar still is an exceptional device for the production of potable water particularly for rural communities. The article reviewed the different solar still designs for commercialization. The selection of particular design is based on many parameters like economics, material availability, yield requirement, local climatic conditions, water quality and operational issues. It is useful to predict the behavior of particular type of solar still to understand its suitability and techno economic viability.

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