Design parameters of Solar Still including application of phase change materials: A Review

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***Abstract*: The demand in water for drinking, agriculture and industry largely exceeds the amount that fresh sources can meet, especially in the Rajasthan desert regions where rainfall is the lowest, with years of total drought. To overcome this serious water scarcity, solar desalination could be an effective solution. Solar distillation is one of the simplest techniques used in water desalination. This investigation presents an theoretical study on a slope solar still and different phase change materials used to enhance the distillation. This choice is justified firstly by the abundance and low price of solar energy, and by the simplicity of installation and easy maintenance of these devices.**

***Keywords*: solar desalination, theoretical, water desalination, phase change materials, enhances installation.**

1. Introduction

The potable water demand is increasing due to the increasing in population growth rate, while the available water cannot be used for drinking like brackish water and water containing harmful bacteria, which are the main water sources in the world. This brackish water could be utilized for drinking and for use in some industries after removal of salts and harmful bacteria. There are numerous methods used for water purification like filtration, disinfection, sedimentation and distillation.

Solar distillation is one of the most important water purification processes. In fig 1 Block diagram of double slope solar still showed one of the important methods of solar distillation. Water is essential to life next to oxygen, fresh water is most important substant for sustaining human life .access to water is considered to be a basic human right However, the increased use and misuse of this resource by the growing population and increasing industrial activities may lead to a situation whereby countries need to reconsider their options with respect to the management of its water resources [1].

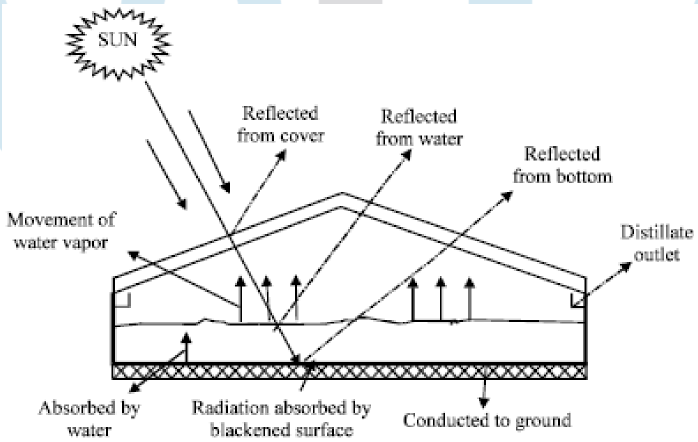

Figure.1 Block diagram of double slope solar still

Water shortage as of now influences each landmass. Water shortage is among the primary issues to be looked by numerous social orders on the planet. Water shortage is both a characteristic and a human-made marvel. There is sufficient freshwater on the planet for seven billion individuals yet it is dispersed unevenly and a lot of it is squandered, dirtied and unsustainably overseen. To defeat this issue, the most ideal arrangements are reviving aquifers/groundwater, water re-utilize and viable water treatment advances, framework repair and upkeep of water channels, appropriate water administration by the utilization of controls and approaches, water preservation and desalination. Water refining has perceived to be a decent way to deal with get convenient fresh water [2].

These days, sunlight based refining is generally utilized because of its points of interest, for example, supportability, ecological benevolence, simple task and ease. The main issue in sunlight based still is its low efficiency. To improve the execution sun powered still, coordinate the still with explanatory trough gatherer. The execution of the sun based stills can be evaluated by two procedures; specialized and financial investigations. Specialized examination is cantered just on execution of sun powered still. Monetary examination incorporates payback time, limit recuperation factor, yearly settled cost and so forth [3].

2. Reason of using solar still

Refining process is considered as one of the easiest and generally received systems for changing over seawater into crisp water. One of the principle points of interest of the refining procedure is that it requires warming just up to 130.6 to 135°C, which can be provided from sunlight based vitality or other shabby fills. The desalination procedures, for example, multistage streak vanishing, invert osmosis; electro dialysis, particle trade, stage change and dissolvable extraction are vitality escalated, costly and uneconomical for little amounts of crisp water. Then again, the utilization of regular vitality sources (hydrocarbon energizes) to drive these advancements negatively affects the earth. Nonetheless, sunlight based stills are especially reasonable for creating nations and particularly for remote provincial zones since they have awesome monetary favourable position over other refining forms with low working and support costs. In expansion to this, their day by day activity and routine support is straightforward, and over all the sun based vitality is rich, everlasting, cost free, contamination free furthermore, accessible on location. Due to the straightforwardness of the contraption plan, prerequisite of new water, and free warm vitality, work in the field of sun based refining has been in advance for in excess of one hundred years. The principle disadvantage of the sun powered desalination frameworks is that it requires extensive establishment regions and high introductory venture. Be that as it may, this is a fitting answer for remote regions and little groups in bone-dry and semi-dry districts with absence of consumable water. Sun powered refining process has been produced in various nations everywhere throughout the world like Australia, Greece, Spain, West Indies and India. There are different classes of sunlight based stills in particular bowl sun powered stills, sun based gatherer in any case, various gathering spread still, wick compose sun based still, vertical sun oriented still and so forth of which in excess of 90 percent of every single working still are of the bowl type. The insights about grouping and elements of different sun based refining frameworks are clarified in the following part. Albeit sun based refining at give can't contend oil let go desalination in expansive focal plants, it can possibly turn into a feasible innovation in not so distant future, when oil supplies stop [4].

3. Solar water distillation

Solar powered distillation of water can be defined as measures to separate and extract clean water by vaporization. This can be particularly useful to turn seawater, brackish or even contaminated water into clean water safe for drinking. The history of solar powered water distillation started with Aristotle, already back in the 4th century BC, described a technique of solar powered water distillation. However, it was not before late 19thcentury, that the first large scale solar water distillation plant was built. This plant, located in Chile, supplied as much as 20 000 liters of safe water to nearby inhabitants [5].

4. Principles of solar distillation system

There are different type of components of energy balance and thermal energy loss in a conventional double slope distillation unit. It is simple and hermetically sealed basin usually made up of galvanized iron and is made insulated from all sides by using insulation materials. The internal surface of the basin also known as basin liner is painted black so as to competently absorb the solar radiations incident on it. There is also a special prearrangement made for the collection of the quintessence output on the sides of the still or on the lower ends of the still. The briny or the saline water is delivered in the basin for the purification process.

4.1. Working principles of solar still

Solar radiation after transmission through the transparent cover is absorbed by water in the basin, thereby raising water temperature compared to that of the cover. In fig 2 Working mechanism of double slope solar still shown. The water now losses water by evaporation, convection, and radiation to the cover and by conduction through the base and edges of the still. The evaporated water from the basin increases the moisture content in the enclosure which finally condenses on the underside of the cover, slips down into the condensate channels and through them out of this still for use [6].

5. Classification of solar still system

Different kinds of solar stills have been made known in literature, including basin and wick stills. In a basin type solar still, briny water is fed into a basin where it is heated by incoming solar radiation. Then, vapour from the hot saline water is condensed for the production of distilled water. A conventional solar still has one basin with no heat recovery from the transparent cover which results in a low efficiency. Nonetheless, various basins may be piled to improve heat. In this case, the lowest basin liner is blackened while the other basin liners are made of a transparent sheet (such as glass) to allow incoming solar radiation reach the bottom part of the still. In a wick type solar still, a blackened wick is soaked with saline water and heated by incoming solar radiation. Again, vapour from the hot wet wick is condensed for the production of distilled water. Basin type solar stills are common and they have been exploited in supplying clean water in areas that cannot be easily accessed.

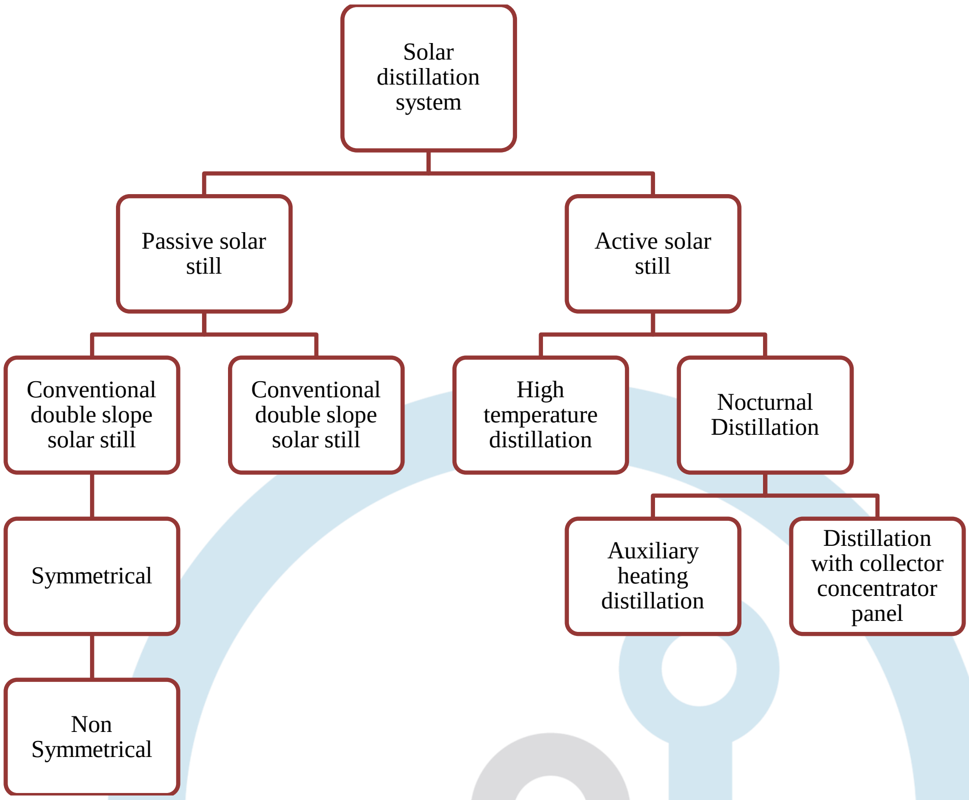

Figure.2 Classification of solar desalination system.

There may be large number of stills, but in nutshell they may be classified into two types:

(1) Active Solar stills
(2) Passive Solar stills

5.1 Active solar still

In these systems, an extra thermal energy is supplied to the basin through an external mode to increase the evaporation rate and in turn improve its productivity. Though being more costly than passive system these structures are more efficient comparatively. Such type of system requires high operating and maintenance cost and also high initial investment cost. The basic advantage of using active system is that such system can provide distillate during non-sunbeam hours by the usage of energy storage mediums, and other such advantages can also be achieved by enhancing the design of the still or by using some external sources like fins can be used so as to increase the exposure area, by using some sensible heat storage medium, etc. Some of the examples of active still are as follows:-

- Solar still using Flat Plate Collector
- Solar still using parallel plate collector
- Vertical solar still using Flat Plate Collector
- Still unified with Parabolic Collector
- Solar still unified with solar pond
- Solar still unified with hybrid PV/T system
- Hybrid solar still
- Pre- heated water solar still

5.2 Passive solar still

Passive solar stills are the initial stills that are modified agreeing to the working principle. Here the distillation takes place purely by direct sunlight to boost the performance some changes were made in the basin design of double slope solar still. Modification can be done to enhance evaporation, condensation, increasing heat gain and reducing heat loss from the still. These are inexpensive to mount and require no maintenance, can be installed easily. These structures are the most economical device to obtain useful water for domestic or minimal purposes and so can be used for rural or remote areas. The basic disadvantage that is faced in such type of system is of lower yield of the quint essence output. Roughly some improved conventional stills are given as follows:-

- Double slope solar still

- Modified double slope solar still
- Double slope still
- Multi-Wick solar still
- Stepped solar still
- Tubular solar still
- Vertical still
- Inclined solar water decontamination system
- Conical solar still
- Solar Earth water still [7]

6. Double Slope Solar Still

The absorption of radiation in solar still was studied by Cooper (1969) considering the number of variables the day of the year, latitude, cover slope, orientation, percentage of diffuse radiation and insolation intermittency. It is found that intermittency has an insignificant effect and the greater than the daily proportion of diffuse radiation, the lower the absorptance in the double slope solar still. Onyegegbu (1986) studied the nocturnal distillation in basin type double slope

Solar stills in the effect of water depths 0.178 m and 0.076 m. It indicates that on average, nocturnal distillation accounted for about 78% of the total daily output of the 0.178 m deep still while accounting for about 50% of the daily output of the 0.076 m deep still. The dimensionless analysis of the factors which affect the night time distillation was carried out and the dimensionless variables, namely dimensionless distillate, overall system efficiency, internal system efficiency and radiative heat loss factor were studied. Boukae and Harmim (2001) studied the effect of desert climatic conditions on the performance of a simple basin solar still and a similar one coupled to a flat plate solar collector. The performance of the simple still is compared with the coupled one. They were tested for all day productivity under clear sky conditions, with different depth levels of brackish water for winter and summer period and for a three months round test from January to March 2000. Data were taken during all type of sky conditions. A three months round study showed that the productivity of the simple basin and similar coupled to a flat plate solar collector strongly depends on the solar radiation and ambientTemperature. The daily still productivity in summer period varies from 4.01 to 4.34 l/m2/day for simple basin solar still and from 8.02 to 8.07 l/m2/day for the coupled one(8).

7. Types of phase change material

PCM Classification

For the non-trivial set of minds PCM is classified as follows:-

7.1 Organic PCMs

Organic resources are further subcategorized as paraffin and non-paraffin compounds. These materials have the ability of melting and freezing repeatedly without phase separation and

Deterioration of latent heat of fusion.

1. **Paraffin's:-** Paraffin's nomenclature name is hydrocarbons and are generally given as

C_nH_{2n+2}. These generally exist in the form of wax at normal temperature (i.e. room temperature). Paraffin wax is of the utmost known and used storage PCM for different applications. The paraffin falling between C5 and C15 are in liquid state and the rest are categorized as waxy solids. These are the mixture of straight chain. Some basic advantages and disadvantages of paraffin are as follows:-

Advantages

- They don't separate
- They are safe and easy to use
- They are chemically stable
- They are non-corrosive
- They are accessible in different temperature range.

Disadvantages

- They have low conductivity
- They are flammable
- Some paraffin which are pure in nature are expensive, the low grade paraffin are
- Cheaper

Figure.3 Paraffin Wax

2. **Non-paraffin: -** Such types of organic PCMs are known by their diverse properties. Each material have its own unique property as compared to paraffin as they have similar properties. Some examples of such type of PCM are formic acid, glycerine phenol etc. These materials are highly combustible and should not be exposed to high heat and fire. Some basic advantages and disadvantages of non-paraffin are as follows:-

Advantages
- Have high heat of fusion.

Disadvantages
- They have low conductivity
- flammable
- Instable at high temperatures.

7.2 Inorganic PCMs

In-organic materials are further subcategorized as salt hydrates and metallic. These materials do not cool easily and do not deteriorate easily.

1. **Salt hydrates:-** These are basically the combination of salt and water in the crystalline Form. There are different types of salt hydrates comprise of diverse melting point range probably within 15-117oC. Some important PCMs falling in this category are $Mg(NO_3)_2.6H_2O$, $Na_2SO_4.10H_2O$, $Na_2CO_3.10H_2O$ etc.

Some advantages and disadvantages of non- paraffin are as follows:-

Advantages
- Latent heat of fusion is comparatively higher than paraffin's
- Thermal conductivity is also moderately greater than paraffin's
- Highly available
- Cheaper in cost.

Disadvantages
- Phase separation
- Sub cooling
- They cause corrosion in the holding device if they are made of metal, and metal
- containers are common in use in such system

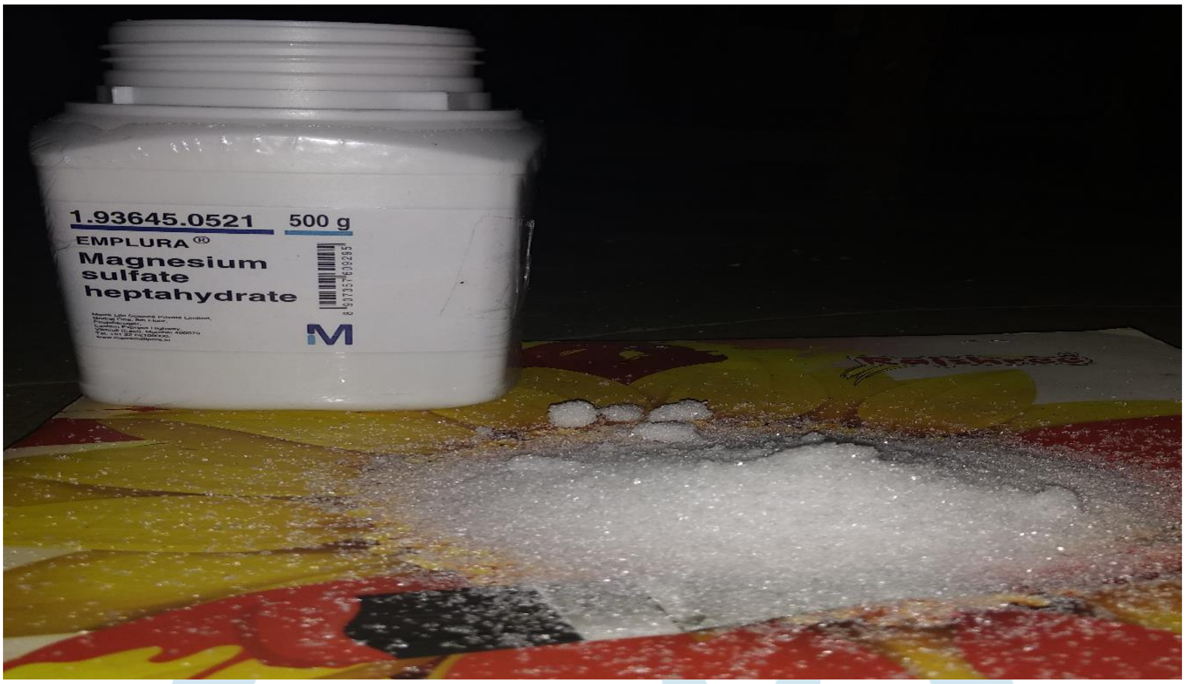

Figure.3 Magnesium Nitrate Hexahydrate

2. **Metallics: -** These types of PCM are not of much interest because of their heavy weights.
They are made into use where the weight is not a point of interest. Such types of PCM have relatively low vapour pressure. Gallium, Cerro bend eutectic etc. are some examples.

7.3 Eutectics: - Eutectic are the type of PCM which are made up by the combination of 2 or
More constituents**.** In such kind of PCMs each element melts and freezes conjointly forming a crystal. At the time of melting the components liquefies at the same time so that the segregation of components is not possible. These further can be sub-divided as inorganic-inorganic, organic- organic and inorganic-organic. Some examples of such types of PCM are $CaCl_2.6H_2O$+$CaBr_2.6H_2O$, Triethylolethane+ H_2O +urea, $CaCl_2$+$MgCl_2.6\ H_2O$ etc. [9]

8. Effect of Design Parameters of Solar Still

8.1 Effect of Water Depth

The depth of water in the basin affects the performance of a still considerably at low water depth, the thermal capacity will be lower and hence the increase in water temperature will be faster resulting in higher outputs. Water depth becomes important especially in the morning when low energy from the sun is available and it is required to heat the water quickly to producing fresh water. Hence the only solution is to operate the still at lower depth. An increase in the water depth from 1.27 cm to 30 cm reduces the output by 30%.

8.2 Effect of the Gap Distance

Reducing the gap distance between the evaporating surface and the condensing cover improves the still performance. The effect of the gap distance is much important than the effect of the cover slope. Reducing the gap distance will reduce the height of the walls of the still and hence will reduce the shadowing effect of these sides. Also less time is elapsed by the saturated air to reach the condensing surface and therefore continuous and quicker air movement in the still is established. Reducing the gap distance from 13.0 cm to 8 cm for the same cover slope increases the output by 11%. (Ghoneyem 1995)

8.3 Effect of Number of Covers

Number of transparent covers used in a solar still does not increase the output, because it Increases the temperature of the inner cover (condensing surface). But it also keeps the still air tight. Due to double glass cover reduction of 25-35% of the output was noticed. Also uses a Double glass cover increases the initial cost of the still. (Ghoneyem 1995)

9. Effect of Meteorological Parameters on Solar Still

9.1 Effect of Wind Velocity

Wind velocity has little effect on productivity, but even low wind speeds increases the
Production rates as compared to zero wind conditions. The fact is high wind velocity will increase the heat loss by convection from the cover to the ambient. This causes a decrease in the
Condensing surface temperature and accordingly increases the yield of a still. The numerical calculations showed that when the wind velocity changes from 1 to 9 m/s, the productivity decreases by 13%. (Nafey et al. 2000).

9.2 Effect of Ambient Air Temperature

The effect of ambient temperature variations on solar still productivity is examined by the Several researchers. The numerical results showed that a slight increase of 3% in the solar still productivity is obtained by increasing the ambient temperature by 5%. (Nafey et al. 2000).

9.3 Effect of Solar Intensity

The effect of solar intensity has been studied by many researchers and it is observed that the average daily output increase with increase of total intensity falling on still in a day.

9.4 Other Effects

Concentration of the water is increased, the yield of the still decreases, also with time if the salt sticking to the absorbing plate is not removed completely, this will reduce the efficiency of the absorbing plate. Also salty water damages the materials of the still. Some other effects may be mentioned like the degree of salinity of water. In some experiments to increase the absorptivity of water in the basin and hence the output of the still, the water is colored with some dyes or charcoal pieces are added. Charcoal pieces have the properties of wettability, large absorption coefficient for solar radiation and that they scatter rather than reflect the solar radiation. It was concluded that their effect is most noticed in the mornings and on cloudy days when the value of the solar radiation is low. However, the presence of the charcoal pieces reduces the start-up time of evaporation. [10]

10. Heat transferred modes in solar water distillation system

The heat transfer in solar still is mainly classified into two ways, internal and external heat transfer.

10.1 Internal heat transfer

In solar still basically internal heat is transferred by evaporation, convection and radiation. The convective and evaporative heat transfers takes place simultaneously and are independent of radiative heat transfer.

a) Radiative heat transfer: The view factor is considered as unity because of glass cover inclination is small in the solar still. The rate of radiative heat transfer between water to glass is given by

$q_{r,\,w\text{-}g} = h_{r,\,w\text{-}g}\,(T_w - T_{gi})$

Where,

$h_{r,\,w\text{-}g}$ = Radiative heat transfer coefficient between water to glass,

$h_{r,\,w\text{-}g} = \varepsilon_{eff}\,\sigma\,[\{(T_w + 273)^2 + (T_{gi} + 273)^2\}/\,T_w + T_{gi} + 546]$

ε_{eff} = Effective emission between water to glass cover, is presented as

$\varepsilon_{eff} = 1/\,[(1/\varepsilon_g + 1/\varepsilon_w) - 1]$

b) Convective heat transfer: Natural convection takes place across the humid air inside the basin due to the temperature difference between the water surfaces to inner surface of the glass cover. The rate of convective heat transfer between water to glass is given by [11]

$q_{c,\,w\text{-}g} = h_{c,\,w\text{-}g}\,(T_w - T_{gi})$

Where,

$h_{c,\,w\text{-}g}$ = Convective heat transfer coefficient depends on the temperature difference between evaporating and condensing surface, physical properties of fluid, flow characteristic and condensing cover geometry.

The various models were developed to find the convective heat transfer coefficient.

One of the oldest methods is developed by Dunkle's [12] and his expressions have certain limitations, which are listed below.

I. Valid only for normal operating temperature (≈50 ˚C) in a solar still and equivalent temperature difference of ΔT = 17 ˚C.
II. This is independent of cavity volume, i.e., the average spacing between the condensing and evaporating surfaces.
III. This is valid only for upward heat flow in horizontal enclosed air space, i.e., for parallel evaporative and condensing surfaces.

The convective heat transfer coefficient is expressed as [12]

$h_{c,w\text{-}g} = 0.884(\Delta T')^{1/3}$

Where,

$\Delta T' = (T_w - T_{gi}) + [(P_w - P_{gi}) + (T_w + 273) / (268.9 \times 10^{-3} -)]$

$P_w = \exp\,[25.317 - \{5144 / (273 + T_w)\}]$

$P_{gi} = \exp\,[25.317 - \{5144 / (273 + T_{gi})\}]$

Chen et al [25] developed the model of free convection of the solar still for wide range of Rayleigh number ($3.5 \times 10^3 < Ra < 10^6$) and as follows,

$h_{c,w\text{-}g}\ 0.2\,Ra^{0.26}\,k_v / x_v$

Where,

$Ra' = (x_v^3\,\rho_v\,g\,\beta / \mu_v\,\alpha_v)\,\Delta T''$

$\Delta T'' = [(T_w - T_{gi}) + [(P_w - P_{gi}) / [\{ M_a P_t / (M_a - M_{wv})\} - M_{wv})\}- P_w]\,(T_w + 273.15)]$

The convective heat transfer between basins to water is given by [13]

$q_w = h_w\,(T_b - T_w)$

The convective heat transfer coefficient between basins to water is given as,

$h_w = K_w / X_w\, C\,(Gr \times Pr)^n$

Where, C = 0.54 and N =1 / 4

c) Evaporative heat transfer: The performance of solar still depends on the evaporative and convective heat transfer coefficients. Various scientist developed mathematical relations to evaluate the evaporative and convective heat transfer coefficients. The general equation for the rate of evaporative heat transfer between water to glass is given by [12]

$q_{c, w\text{-}g} = h_{e, w\text{-}g} (T_w - T_{gi})$

$h_{e, w\text{-}g}$ = Evaporative heat transfer coefficient.

$h_{c, w\text{-}g} = 16.273 \times 10^{-3} \times h_{e, w\text{-}g} [P_w - P_{gi} / T_w - T_{gi}]$ (developed by Dunkle's [24])

Malik et al [14] developed a correlation based on Lewis relation for low operating temperature range and it is expressed as,

$h_{e, w\text{-}g} = 0.013\, h_{c, w\text{-}g}$

The total heat transfer coefficient of water to glass is defined as,

$h_{t, w\text{-}g} = h_{c, w\text{-}g} + h_{e, w\text{-}g} + h_{r, w\text{-}g}$

The rate of total heat transfer of water to glass is defined as,

$q_{t, w\text{-}g} = q_{c, w\text{-}g} + q_{e, w\text{-}g} + q_{r, w\text{-}g}$

$q_{t, w\text{-}g} = h_{t, w\text{-}g} (T_w - T_{gi})$

10.2 External heat transfer

The external heat transfer in solar still is mainly governed by conduction, convection and radiation processes, which are independent each other.

a) Top loss heat transfer coefficient: The heat is lost from outer surface of the glass to atmosphere through convection and radiation modes. The glass and atmospheric temperature are directly related to the performance of the solar still. So, top loss is to be considered for the performance analysis. The temperature of the glass cover is assumed to be uniform because of small thickness. The total top loss heat transfer coefficient is defined as

$h_{t,g\text{-}a} = h_{r,g\text{-}a} + h_{c,g\text{-}a}$

$q_{t,g\text{-}a} = q_{r,g\text{-}a} + q_{c,g\text{-}a}$

$q_{t,g\text{-}a} = h_{t,g\text{-}a} (T_{go} - T_a)$

The radiative heat transfer between glass to atmosphere is given by [28]

$q_{r,g\text{-}a} = h_{r,g\text{-}a} (T_{go} - T_a)$

The radiative heat transfer coefficient between glass to atmosphere is given as

$h_{r,g\text{-}a} = \varepsilon_g \sigma [(T_{go} + 273)^4 - (T_{sky} + 273)^4 / T_{go} - T_a]$

Where, $T_{sky} = T_a - 6$

$q_{c,g\text{-}a} = h_{c,g\text{-}a} (T_{go} - T_a)$

The convective heat transfer coefficient between glasses to atmosphere is given as

$h_{c,g\text{-}a} = 2.8 + (3.0 \times v0$

The total internal heat loss coefficient ($h_{t, w\text{-}g}$) and conductive heat transfer coefficient of the glass (K_g / L_g) is expressed as

$U_{wo} = [(1/ h_{t, w\text{-}g}) + (K_g / L_g)]$

As

$U_{wo} = h_{t, w\text{-}g} (K_g / L_g) / h_{t, w\text{-}g} + (K_g / L_g)$

The overall top loss coefficient (U_t) from the water surface to the ambient through glass cover,

$U_t = h_{t, w\text{-}g}\, h_{t, g\text{-}a} / (h_{t, g\text{-}a} + U_{wo})$

b) Side and bottom loss heat transfer coefficient: The heat is transferred from water in the basin to the atmosphere through insulation and subsequently by convection and radiation from the side and bottom surface of the basin. The rate of conduction heat transfer between basin liner to atmosphere is given by [17]

$q_b = h_b(T_b - T_a)$

The heat transfer coefficient between basin liner to atmosphere is given by [17],

$h_b = [Li / Ki + 1 / h_{t, b\text{-}a}]^{-1}$

Where,

$h_{t,b\text{-}a} = h_{c,b\text{-}a} + h_{r,b\text{-}a}$

There is no velocity in bottom of the solar still. By substituting v = 0, to obtain the heat transfer coefficient. The bottom loss heat transfer coefficient from the water mass to the ambient through the bottom is expressed as,

$U_b = [1 / h_w + 1 / h_b]^{-1}$

The conduction heat is loss through the vertical walls and through the insulation of the still and it is expressed as,

$U_s = (A_{ss} / A_s)\, U_b$

The total side loss heat transfer coefficient (U_s) will be m=neglected because of side still area (A_{ss}) is very small compared with still basin area (A_s). The overall heat transfer coefficient from water to ambient through top, bottom and sides of the still is expressed as [16].

$U_{Ls} = U_t + U_b$

11. Thermal performance analysis of solar still

Thermal efficiency of solar still

$$\eta = \left[\frac{mL}{I_s A_s t}\right] \times 100\ \%$$

Where,

m : Mass of evaporator water (liters)

L : Latent heat of evaporation (2260 KJ / kg)

I_s : Global solar radiation on solar still (W / m^2)

A_s : Surface area of solar still (m)

t : Time (s)

12. Conclusion

Solar stills offer to provide solar-powered desalination based on essentially simple principles whereby solar energy drives directly the evaporation of water. However, the goal of implementing solar stills at commercial scale remains elusive mainly because of their limited output For successful implementation, researchers continue to investigate a wide range of innovations in solar stills, based on operating parameters geometry, system, configuration and materials.

Heat conduction and heat convection are two forms of heat transfer methods occurring inside the PCMs during the phase change process. However, most heat transfer enhancement techniques can lead to an increase of heat conduction and suppression of heat convection. Further research on the heat conduction and heat convection of PCMs is needed for the optimization of heat transfer enhancement technique and PCM container.

References

[1] Zobaidah Al Zghoul, "Solar Desalination with solar still having phase change material and connected to solar collector" ,MEDRC Series of R & D Reports MEDRC Project: 14-JS-033 January, 2016.

[2] Tabrizi FF, Sharak AZ, "Experimental study of an integrated basin solar still with a sandy heat reservoir" Desalination, 253,195–9, 2010.

[3] Murugavel KK, Sivakumar S, Ahamed JR, Chockalingam KKSK, Srithar K "Single basin double slope solar still with minimum basin depth and energy storing materials" Applied Energy, 87,514–23, 2010.

[4] Tanaka, H., and Nakatake, "Theoretical analysis of a basin type solar still with internal and external reflectors", Desalination, 197(1), PP-205-216, 2006.

[5] Ismail B. I., "Design and performance of a transportable hemispherical solar still", Renew. Energy, 34(1), pp-145-150, 2009.

[6] Abu-Hijleh Bassam A/K & Rababa'h Hamzeh, M, 'Experimental study of a solar still with sponge cubes in basin', Energy Conversion Management, vol. 44, no. 9, pp. 1411-1418, 2003.

[7] Porteiro, J., Míguez, J.L., Crespo, B., de Lara, J., Pousada, J.M., "On the Behavior of Different PCMs in a Hot Water Storage Tank against Thermal Demands" Materials, 9, 213, 2016.

[8] Moreno-Alvarez L., Herrera J. N., and Meneses C., "Measurement Science and Technology "21(12), 127001, 2010.

[9] Richa Dubey, "Theoratical and experimental analysis of solar distillation using energy storage medium" IJRMET Vol. 7, Issue 2, ISSN: 2249-5772, ISSN: 2249-5670, 2018.

[10] Paul M. Allred Phase change materials for solar thermal energy storage, Copyright by Paul M. Allred, 2014.

[11] P. Sundaram, R. senthil, "Productivity enhencement of solar deselination system using paraffin wax" Int. J. Chem. Sci.: 14(4), 2339-2348 ISSN 0972-768, 2016.

[12] Bharat Kumar Patil, Sanjay Dambal, "Design and Experimental Performance Analysis of Solar Still Using Phase Changing Materials and Sensible Heat Elements,", IJRMET Vol. 6, Issue 2, ISSN : 2249-5762,2016.

[13] Mauli k dubey, Akshay T dhalpe,"Study of performance of solar still with stearic acid as PCM", Journal for Research ,Volume 03, Issue 03 , ISSN: 2395-7549,2017.

[14] A.E. Kabeel1, Y. A. F. El-Samadony, Wael M. El-Maghlany, "Theoratical performance comparision of solar still using different PCM", Twentieth International Water Technology Conference, IWTC20 Hurghada, 18-20 May 2017.

[15] Dr. M. Ravi Kumar, M. Sridhar, S. Madhan Kumar, C. Vignesh Vasanth,, "Experimental Investigation of Solar water Desalination with Phase Change Material and TiO_2" ,Imperial Journal of Interdisciplinary Research (IJIR) Vol-3, Issue-3, ISSN: 2454-1362,2017.

[16] Avesahemad S.N. Husainy , Omkar S. Karangale, Vinayak Y Shinde, "Experimental Study of Double Slope Solar Distillation with and without Effect of Latent Thermal Energy Storage "Asian Review of Mechanical Engineering ISSN: 2249 - 6289 Vol. 6 No. 2, 2017.

[17] Piyush Pala, Pankaj Yadava, Rahul Deva, Dhananjay Singh, "Performance analysis of modified basin type double slope multi–wick solar" ,still Desalination 422, pp-68–82,2017.