EXPERIMENTAL STUDY ON CONVENTIONAL AND STEPPED SOLAR STILL'

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Abstract — In a analytical methodology a trails have been analysed on the Temperature, Distillation and efficiency for a solar still with conventional and stepped solar still. In the experimental investigation, The setup comprises of a wooden box with an area of 1.1 × 1.1 m2 and height 0.61 m in one end and 0.4 m at the other end. The gap of 0.2 m between the sides of the tray and wooden box is filled with saw dust. This will prevent the side loss of heat through conduction. Conventional basin of area 1 m2, is placed at the bottom of the still. Another absorber plate of stepped type is fixed on the conventional basin as shown. Stepped solar still has subsequent trays and inclined flat plate collectors. The result of conventional solar still and stepped solar still was concluded by comparing temperature, distillation and efficiency. And stepped solar still are gives the better result.

Keywords— Conventional solar still, Stepped solar still,Water distillation

I. INTRODUCTION

Solar Still- A solar still distils water, using the heat of the Sun to evaporate, cool then collect the water. There are many types of solar still, including large scale concentrated solar stills, and condensation traps (better known as moisture traps amongst survivalists). In a solar still, impure water is contained outside the collector, where it is evaporated by sunlight shining through clear plastic or glass. The pure water vapour condenses on the cool inside surface and drips down, where it is collected and removed.

Distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing into water again as it cools and can then be collected. This process leaves behind impurities, such as salts and heavy metals, and eliminates microbiological organisms. The end result is pure distilled water.

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

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

II. BASIC OF SOLAR STILL

The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapor rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is water cleaner than the purest rainwater. The SolAqua still is a passive solar distiller that only needs sunshine to operate. There are no moving parts to wear out.

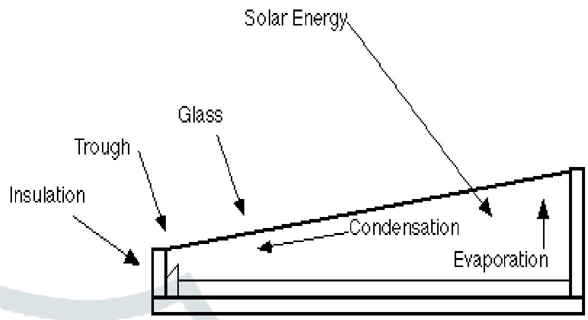

Figure 2.1 Basic of Solar still

The distilled water from a Sol Aqua still does not acquire the "flat" taste of commercially distilled water since the water is not boiled (which lowers pH). Solar stills use natural evaporation and condensation, which is the rainwater process. This allows for natural pH buffering that produces excellent taste as compared to steam distillation. Solar stills can easily provide enough water for family drinking and cooking needs.

Solar distillers can be used to effectively remove many impurities ranging from salts to microorganisms and are even used to make drinking water from seawater. Sol Aqua stills have been well received by many users, both rural and urban, from around the globe. Sol Aqua solar distillers can be successfully used anywhere the sun shines.

The Sol Aqua solar stills are simple and have no moving parts. They are made of quality materials designed to stand-up to the harsh conditions produced by water and sunlight. Operation is simple: water should be added (either manually or automatically) once a day through the still's supply fill port. Excess water will drain out of the overflow port and this will keep salts from building up in the basin. Purified drinking water is collected from the output collection port

III. BENEFITS OF DISTILLATION

Finally we decided to go by distillation method owing to the following benefits:-

- It produces water of high quality.
- Maintenance is almost negligible.
- Any type of water can be purified into potable water by means of this process
- The system will not involve any moving parts and will not require electricity to Operate.
- Wastage of water will be minimum

IV. SOLAR WATER DISTILLATION

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×1011 MW. Which is many thousands times larger than the present all commercial energy consumption rate on the earth. Thus in principle, solar energy could supply all the present and future energy needs of the world on a continuous basis. This makes it one of the most promising of all the unconventional energy sources. In addition to its size, solar energy has two other factors in its favour. Firstly, unlike fossil fuels and nuclear power, it is an environmentally clean source of energy. Secondly, it is free and available in adequate quantity. Solar water distillation is a solar technology with a very long history and installations were built over 2000 years ago, although to produce salt rather than drinking water. Solar distillation systems can be small or large. They are designed either to serve the needs of a single family, producing from ½ to 3 gallons of drinking water a day on the average, or to produce much greater amounts for an entire neighbourhood or village. In some parts of the world the scarcity of fresh water is partially overcome by covering shallow salt water basins with glass in greenhouse-like structures. These solar energy distilling plants are relatively inexpensive, low-technology systems, especially useful where the need for small plants exists. Solar distillation of potable water from saline (salty) water has been practiced for many years in tropical and sub-tropical regions where fresh water is scare. However, where fresh water is plentiful and energy rates are moderate, the most cost-effective method has been to pump and purify. Solar distillation is a relatively simple treatment of brackish (i.e. contain dissolved salts) water supplies. In this process, water is evaporated; using the energy of the sun then the vapour condenses as pure water.

ADVANTAGES OF SOLAR STILL -

- It is a low cost device and can be constructed with common materials.
- Design of solar still is very simple and it can be easily constructed by people living at remote villages.
- Its operation is pollution free and it requires very low maintenance.
- There is no requirement of skilled labour for construction or operation of the solar still.

V. LITERATURE REVIEW

Y.A.F. El-Samadony et.al. [1] investigated new theoretical analysis of the radiation heat transfer rate inside a stepped solar still is presented. Radiation shape factor between hot salinewater and glass cover for a stepped solar still is computed. The effect of taking the radiation shape factor into consideration is qualitatively and quantitatively determined. The effect of glass cover inclination angle (from 10° to 70°) and solar insolation (from200 to 1200 W/m2) onstepped solar still productivity; taking into account the radiation shape factor is investigated. It is found that the influence of the radiation shape factor on the thermal performance predictions is significant. Moreover, the productivity of the solar still is found to be sensitive to the radiation shape particularly at low solar insolation and/or high glass cover inclination angle (i.e. latitude angle of the site) and vice versa. At lowsolar insolation of 200 W/m2 and glass cover inclination angle of 70°, the percentage increase in the still productivity, when considering the radiation shape factor, is up to 18.8%. Finally, fair agreement between the present theoreticalwork and the previous experimental result has been accomplished..

Khalifa et al. [2] in their research work developed various performance correlations for basin type solar still. The effect of climatic, operational and design parameters on the performance of solar still were examined on the basis of various experimental and numerical studies. A comprehensive review of various research works has been presented. The most important parameters investigated were solar radiation, cover tilt angle, brine depth and use of dyes with the brine. The effect of each parameter was quantified and correlations were formed.

Murugavel et al. [3] reviewed the progress in the works done on single basin passive solar still to enhance its productivity. The effect of various parameters such as still orientation, glass cover inclination, cover plate material, basin material and condensing area on the still productivity were taken into consideration and critically reviewed. Important findings are summarized below:-

- Orientation of the glass cover depends upon the latitude of the place. For lower latitude places double slope solar stills are preferred over single slope solar still.
- Productivity of the solar still depends on the depth of water in the basin.
- For higher sun radiation intensity places, deep basin still is preferable, on the other hand for lower sun radiation intensity places shallow basin still is preferable.
- Black dye is suitable in deep basin solar stills in order to increase the absorption and surface heating effect.
- Rubber is very good basin material to enhance absorption, storage and evaporation effects.

Shankar and Kumar [4] presented a review article on the solar distillation process. In that extensive review of solar distillation history of solar distillation, working of solar still, advantages and disadvantages of solar still and parametric study on the solar still was presented. Moreover, various types of designs of solar still were also reviewed. Many recommendations and conclusions were drawn for solar stills based on the literature review. It was concluded that the single slope solar still is more effective than a double slope solar still in high altitude areas. Several parameters which affect the distillation rate of solar still were also investigated. Solar still was recommended as the best suited alternative to provide the clean drinkable water for remote villages

Ayoub et. al [5] introduced a new and sustainable development modification in conventional solar still. A slowly rotating drum was introduced within the still cavity which allows the formation of thin water films and enhances the evaporation rate. Influence of various parameters such as the drum speed, brine depth, solar intensity, and cover cooling etc. on the still productivity was also investigated in this work. It was concluded that slow drum speed improve the daily yield of solar still.

Badran [6] studied the performance of a single slope solar still using different parameters in order to improve its productivity. Solar still productivity was increased by 51% when asphalt basin liner and sprinkler were introduced as the enhancement parameters to the conventional still. Moreover the effect of water depth on the daily yield was studied. It was found that the daily yield decreases with increase in the water depth in the basin. It was also concluded that the ambient conditions such as wind velocity and ambient temperature have a direct effect on the productivity of solar still.

Kumar et al. [7] integrated a single slope solar still with an evacuated tube collector (ETC) and operated in forced mode. In order to evaluate the performance of integrated system, a thermal model was also developed under the climatic conditions of New Delhi, INDIA. The water temperature as well as the distillate yield was increased by the integration of the ECT. The daily yield obtained was 3.47 kg/m2 for 0.01 m basin water depth at 0.006 kg/s mass flow rate. The maximum daily energy and exergy efficiencies at optimum flow rates were found to be as 33.8% and 2.6% respectively. This work also included economic analysis of the integrated system and the cost of Rs. 2.01/kg of distilled water was estimated with a payback period of 3.7 years.

Kumar et al. [8] conducted an experimental study on various designs of solar stills. They fabricated seven different designs of solar stills that are spherical solar still, pyramid solar still, hemispherical solar still, double basin glass solar still, concentrator coupled single slope solar still, tubular solar still and tubular solar still coupled with pyramid solar still. The performance of each design was tested under same climatic conditions. From the experimental results, tubular solar still coupled pyramid solar still showed the maximum amount of productivity due to the concentrator effect.

Sahoo et al. [9] conducted an experimental study on a solar still in order to study its performance. Performance of solar still was first studied on the basis of removal of fluoride contamination from water. Solar still was found to be effective in removing fluoride contaminants as the reduction of 92–96 % was found as compared to the untreated samples. Solar still efficiency was calculated by varying the initial water depth in the basin. There was a marginal increase in still efficiency when the quantity of brackish water was increased in the basin. The efficiency of solar still was found to be increased by 4.69% and 6.05% when the basin was stepped with a blackened base liner and with a blackened base liner with bottom and side thermocol insulation respectively.

Rajaseenivasan et. al. [10] conducted experimental study to compare the performance of the double and single basin type solar stills. In their research work two solar stills, single basin double slope and double basin double slope were fabricated and tested. The performance of both of the solar stills was analysed and compared a various depths of water in the basin, different wick materials, porous materials and different energy storing materials. The water production in double basin type solar still was found to be 85% more than that of single basin solar still for the same type of basin and similar operating conditions.

VI. ANALYTICAL CALCULATION

The energy balance equation for the absorber plate can be written
as follows:

Energy received by the basin plate is equal to the summation of the energy gained by the basin plate, energy lost by convective heat transfer between basin and water, $Q_c, b-w$, , and side losses, Q_{loss}. In symbol, this can be written as,

$$A_b \alpha_b = m_b c_{pb}\left[\frac{dT_b}{dt}\right] + Q_c, b - w + Q_{loss}$$

Where absorbtivity of water,αb, The mass of water, (mw) and mass of basin, (mb). The energy received by the saline water in the still (from sun and base) is equal to the summation of energy lost by convective heat transfer between water and glass, Q_c, $w-g$, radiative heat transfer between water and glass, Q_r, w−g, evaporative heat transfer between water and glass, e, w−g, and energy gained by the saline water.

$$\alpha_w A_w + Q_{c,b-w} = Q_{c,w-g} + Q_{r,w-g} + Q_{e,w-g} + m_w c_{p,w}\left(\frac{dT_w}{dt}\right)$$

The absorbtivity of the water αw is 0.05. Energy gained by the glass cover (from sun and convective, radiative and evaporative heat transfer from water to glass) is equal to the summation of energy lost by radiative, $Q_{r,g-sky}$ and convective heat transfer between glass and sky, $Q_{c,g-sky}$, and energy gained by glass.

$$\alpha_g A_g + Q_{c,w-g} + Q_{e,w-g} = Q_{r,g-sky} + Q_{c,g-sky} + m_g c_{p,g}\left(\frac{dT_g}{dt}\right)$$

The still hourly average efficiency was identified

$$\eta_{h,i} = \frac{M_w L_{w,av}}{3600 A_b H} \times 100$$

The equations governing the heat transfer rates are:-

Conduction

$$Q = kA\frac{dT}{dx}$$

Convection

$$Q = hA \text{ (Tsurface- Tambient)}$$

Both the losses are greatly dependant on the area and temperature difference between the medium i.e., water and ambient. Hence if we can reduce temperature of the whole system we can reduce the heat loss and hence improve the efficiency. But reducing operating temperature will come at the cost of lower rated of evaporation and consequently lower rated of condensation leading to slower distillation. So now the problem boils down to increasing the rated of evaporation at lower temperature.

$$\frac{Mass\ loss\ rate}{unit\ area} = \left((Vapour\ Pressure - Ambient\ Partial\ Pressure)\right)^2$$

(Molecular Weight)/(2×$\pi \times R \times T$)

The Vapor Pressure of a liquid at a given temperature is a characteristic property of that liquid. Vapor pressure of a liquid is intimately connected to boiling point. Vapor Pressures are influenced by Temperature logarithmically and this relationship is defined with the Clausius Clapyron Equation:

$$\log\frac{p_2}{p_1} = \Delta H\ Vaporization\ \frac{\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}{2.303(R)}$$

where: R = universal gas law constant = 8.31 J/mol-K = 8.31 X 10-3 Kj / mol-K P1 and P2 = vapor pressure at T1 and T2 T1 and T2 = Kelvin Temperature at the initial state and final state At 373K the pressure is 1 atm. We all know that boiling takes place when the ambient temperature equals that of the vapor pressure of the liquid. This means that we can increase the rate of evaporation by reducing the pressure of the vessel. This will ensure higher rates of evaporation even at low temperatures.

The heat transfer by radiation q_r from water surface to glass cover can be calculated from the equation

$$q_r = F\sigma\left(T_w^4 - T_g^4\right)$$

Where F= Shape factor

σ = Stefan Boltzmann constant

VII. EXPERIMENTAL SET-UP

The experimental setup is shown in fig 3.1. The setup comprises of a wooden box with an area of 1.1 × 1.1 m2 and height 0.61 m in one end and 0.4 m at the other end. The gap of 0.2 m between the sides of the tray and wooden box is filled with saw dust. This will prevent the side loss of heat through conduction. Conventional basin of area 1 m2, is placed at the bottom of the still. Another absorber plate of stepped type is fixed on the conventional basin as shown. Stepped solar still has subsequent trays and inclined flat plate collectors. The trays consist of four compartments having total area of 240 cm2. The trays are made of iron sheet with 2 mm thickness because of low cost and easy fabrication. Three inclined flat plate collectors of size 60 × 70 cm2 each are sandwiched among the three trays. Wicks are placed on the inclined flat plate collectors to improve the evaporation rate by capillary action. A glass of 3 mm thickness and 1.1 × 1.1 m2 area is fitted on the top to receive solar radiation. The glass cover is fitted with an angle of 11° and facing toward the south. The water condensed on the glass surface is directed to be collected in the collection trough by a piece of glass gutter attached to the bottom of the glass. The storage tank with a capacity of 30 L supplies feed water through a pipe. A gate valve V1 is provided at the inlet of the tank. A plastic drain tank is used to collect the impure brackish water from the basin. Value V2 is connected between basin and the drain tank.

Fig. 7.1 Experimental setup of solar still.

VIII. RESULT AND DISCUSSION

The solar still used for water purification process. Experimentally, results are presented in order to show the effects of temperature distribution with respect to time in the solar still. We found that the both solar still (conventional solar still and stepped soar still) temperature, distillation and efficiency w.r.t. variation in time. We found the all temperature, distillation and efficiency in hourly 10.00 AM to 4.00 PM.

8.1 Experiment Result Of Conventional And Stepped Solar Still Temperature W.R.T. Variation In Time

Table 8.1 Experimental Results of variation in temperature for the conventional and stepped solar still with variation in time

Time	Conventional solar still	Stepped solar still
10:00 AM	26	28
11:00 AM	28	31
12:00 PM	33	36
1:00 PM	37	40
2:00 PM	42	46
3:00 PM	40	44
4:00 PM	39	41

shows the experimental Results of variation in temperature for the conventional solar still with variation in time. We found the all temperature in hourly 10.00 AM to 4.00 PM.

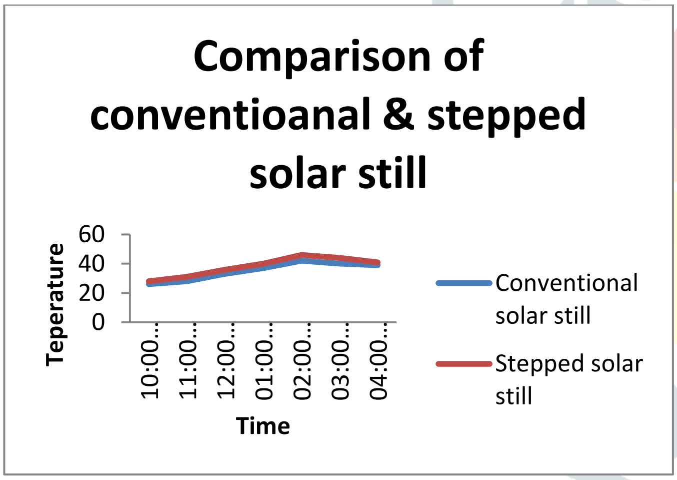

Figure 8.1 Experimental Results of variation in temperature for the Conventional solar still and stepped solar still with variation in time

8.2 Experiment Result Of Conventioanal And Stepped Solar Still Distillation W.R.T. Variation In Time

Table 8.2 Experimental Results of variation in distillation for the solar still with variation in time

Time	Conventional solar still	Stepped solar still
10:00 AM	60	170
11:00 AM	140	520
12:00 PM	200	900
1:00 PM	400	1100
2:00 PM	350	1000
3:00 PM	210	750
4:00 PM	50	400

shows the experimental Results of variation in distillation for the solar still and stepped solar still with variation in time. We found that Stepped still are increases the distillation.

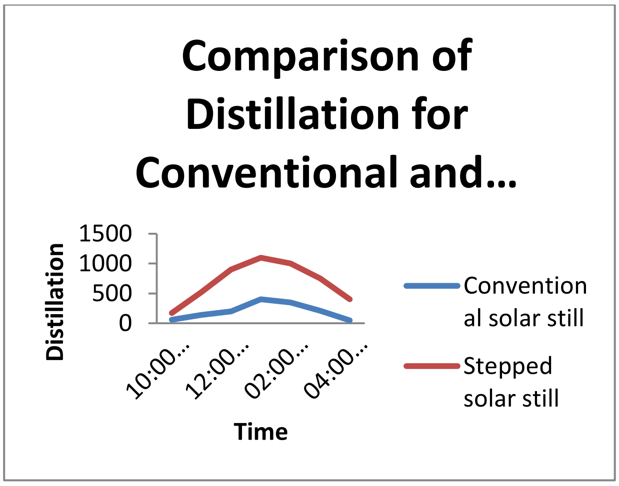

Figure 8.2 Graph of Friction factor versus Reynolds Number of smooth plate

8.3 Experiment Result Of Conventioanal And Stepped Solar Still Overall Efficiency W.R.T. Variation In Time

Table 8.3 Experimental Results of variation in overall efficiency for the solar still with variation in time

Time	Conventional solar still	Stepped solar still
10:00 AM	10	18
11:00 AM	19	29
12:00 PM	41	50
1:00 PM	69	75
2:00 PM	77	85
3:00 PM	73	82
4:00 PM	60	68

shows the experimental Results of variation in efficiency for the solar still and stepped solar still with variation in time. We found that Stepped still are increases the efficiency.

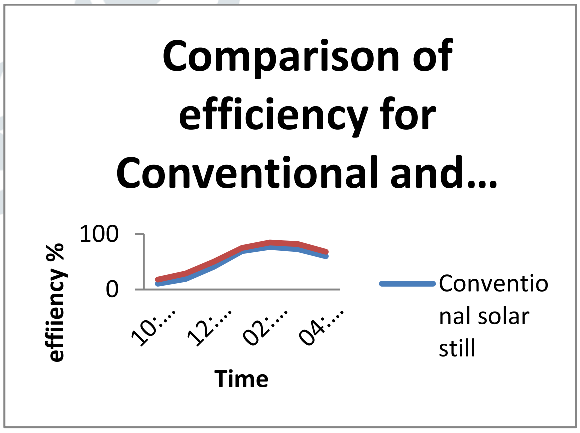

Figure 8.3 Graph of Nusselt Number versus Reynolds Number of continuous discrete ribs

COMPARISON OF CONVENTIONAL SOLAR STILL AND STEPPED SOLAR STILL EXPERIMENTAL WORK-

1. For average value of temperature obtained stepped solar still varies by about 6.8% to the Conventional solar still for experiment results.

2. Distillation is a method where water is removed from the contaminations rather than to remove contaminants from the water. Solar energy is a promising source to achieve this. This is due to various advantages involved in solar distillation.. For average value of distillation obtained stepped solar still varies by about 9.2% to the Conventional solar still for experiment results

IX. CONCLUSION

1. The conventional solar still and stepped solar still experimental results are shows the temperature of increase in stepped solar still as compare to the conventional solar still.
2. The conventional solar still and stepped solar still experimental results are shows the distillation rate is higher in stepped solar still as compare to the conventional solar still.
3. Stepped solar still efficiency is better as compare to the conventional solar still

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