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Performance Analysis of Passive and Active Solar Stills

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Abstract—*Water stress is being felt in many countries around the world. There are many techniques and methods to refine water from polluted/contaminated water resources. Majorities of available techniques are driven by energy obtained from combustion of fossils fuels. The reserve of such fuel is depleting rapidly and also impairs environment and ecology adversely on combustion. Solar distillation is method of producing potable water from unclean sources of water using thermal energy harnessed from sun. Solar distillation is very simple technology, economically viable, can be designed and fabricated using locally available materials, require less number of personals to operate and maintain it. There are many factors which have significant impacts on the performance of solar stills. In this communication performance analysis of passive and active solar stills are presented based on certain parameters.*

Keywords*: Potable water, solar stills, active and passive, performance analysis, ecology and environment.*

1. INTRODUCTION

Water paucity in any region may arise on account of mismatch in demands and supply needs of water consumer. This is not limited to a few countries but has become a global issue. Billions of people around the world are in shortage of clean and safe dirking water. In general this problem basically evolves due to shift in monsoon patterns resulting in flood situations in some regions and draught like situations in the other regions. Change in monsoon patterns are due to change in climatic conditions, larger population growth, indiscriminate use of safe drinking water, intensive agricultural and animal husbandry activities, rapid growth in industry, large scale of deforestation and poor management of water resources make the issue of water crisis more severe [1, 2-5]. As per WHO reports consumption of contaminated drinking water tolls 30,000 lives every day. The major causes of illness even in developing and developed nations estimate around 75-80% due to drinking of unclean water[6].In poor countries shortage of safe drinking water is a serious concern and majority of population do not have approach to clean water and bound to drink contaminated water. Unclean water can be purified for the purpose of drinking and cooking using several techniques and technologies. Majorities of the available technologies are powered by energy obtained from conventional sources of energy. These resources are scare and when subjected for combustion to convert them in usable energy produces irreparable damage to environment and ecology. Instead of using complex technology water can be purified to certain extent using simple filters. Filters are designed using one are more than one materials. It is not necessary that only sophisticated technology or high end technology based on automation techniques can be efficient, fruitful and result oriented [7]. On contrary to the rest of technologies solar still uses renewable sources of energy harnessed from solar energy. The technology is simple, easy to operate and maintain moderate cost and environmental friendly [8].The process of solar distillation can be well understood by hydrological cycle occurring in the nature. In this cycle, water evaporates by receiving energy from environment and decreases the temperature of ambience. In the next stage condensation goes on and energy is released to the surrounding resulting in rise in temperature [9]. The exchange of heat during hydrological cycle influences the climatic conditions. During the process of evaporation water is purified and it pours down on the earth surface in the form of rain, mist, snow etc. as pure water. Solar distillation is very simple method of producing drinking water from contaminated source, saline/brackish water using solar energy. Generally body of solar still is made of fibre reinforced plastic (FRP) with top cover made of transparent materials preferably glass. It is important to keep orientation of solar still in such a way so that maximum solar radiation is capitalised. Single slope solar still should have south facing whereas as double slope solar still should have east west orientation [10]. The inner surface is painted black to absorb maximum radiation. A small portion of solar radiation is reflected back from the top glass cover and also from the water surface. Maximum quantity of solar radiation penetrates into the still chamber and is absorbed by the basin liner and basin water kept for the purpose of purification. The amount of thermal energy absorbed mainly depends upon absorptivity and quantity of water mass kept within the still. This chamber is acting as heat trapping device and producing green house effect. The absorbed thermal energy is convected to the basin water mass and raises its temperature in the basin. This effect causes an increase in difference of temperature between evaporative surface i.e. .top surface of basin water and inner surface of glass cover. The process of evaporative heat transfer commences from basin water surface and reaches the inner surface of transparent cover also known as condensing cover. Water vapour condenses at the inner surface relinquishing its latent heat to the cover. The condensate so formed is free from impurities of almost all kinds which were available in the water as contaminants. The condensed droplets flow down into the channels kept at the lower end of glass cover under the influence of gravity [11, 12. 13-16].

Solar stills:

Solar distillation is simple approach of getting potable water. Evidence of solar still is found dated back to 1551 by Arab alchemist Della Porta (1589) [18], Lavoissier (1862), and Mauchot (1869) [18] were the scientists and naturalists who used solar distillation to provide fresh drinking water. It was Swedish engineer Charles who established first conventional type solar still in1872 in Las saline to cater the need of potable water for mining community. Solar stills are classified into two categories namely passive solar still and active solar still.

Passive solar still:

Passive type solar still is an air tight insulated basin having to cover made of transparent glass or plastic cover. When still is subjected to solar radiation, the incident sun rays get transmitted from top cover to the basin liner at the bottom, hence heating the water .Air available within the chamber is heated due to hot water and becomes unsaturated. Water gets evaporated and saturates the air around it. The flow of air inside solar still is due to the temperature gradient between water surface and the inner top cover. Passive solar still does not have any indirect heating arrangement .Passive solar stills are single slope as well as double slope. Tiwari et al. [19] investigated and reported that performance of single slope basin still is better than double slope basin still in winter season/ cold climate however, contrary results are sought in summer/hot climate. Passive solar stills are sub classified into conventional and efficient designs.

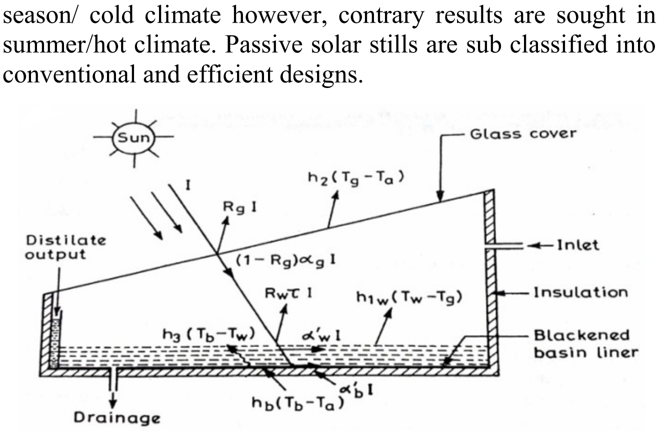

Fig. 1: Schematic diagram of Single basin single slope passive solar still.

Most of researchers have reported that the passive solar still is a slow process of water evaporation and daily total productivity is approximately 2.25 kg/m2/day during summer. The operating range of temperature for clear sunny day and for maximum solar radiation is in the range of 20°C-50°C.The fig. no.1 represents Schematic diagram of Single basin single slope passive solar still.

Active solar still:

In active solar still water kept in basin undergoes direct heating as well as well as heat added from external sources. Pre heated water is connected is fed in basin through connecting channels .Active solar stills may be integrated with solar heat concentrator, collector (single as shown in Fig. 2) number of collectors connected in series, flat plate collector, parabolic trough, solar still coupled with hybrid PV/T and heat exchanger. Industrial heat waste too can be retrieved and be utilized to preheat feed water before admitting it into the active solar stills. Evaporation rate is governed by the temperature achieved by the basin water. Kumar and Tiwari performed experiments on active solar stills and reported that the yield from active solar still was 3.5 times higher than passive solar still. Active solar distillation is sub classified as

High temperature distillation:

Hot water is supplied into basin which is pre heated by using solar collector/concentrator. The operating temperature may vary from 50°C-100°C and is generally known as high operating distillation.

Nocturnal production:

In this arrangement objective is to achieve distillation during off sunshine hours. During sunshine hours water of basin is heated and the major portion of heat energy received is stored in water mass. During off sunshine hours this stored energy is utilized for producing potable water. Rai et al. [21] reported that increase in temperature of fed water mass basin in the basin will be influenced by various factors such as mass flow rate, quality of heat absorbing materials and solar intensity falling on the still.

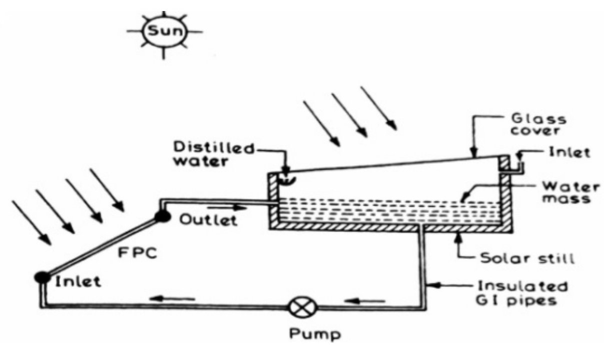

Fig. 2: Schematic view of active solar still with single collector.

2. SYSTEM DESCRIPTION

In Fig.1 passive single slope conventional solar still has been shown. Its body is made of fibre reinforced plastic (FRP) which serves as insulator to minimise heat loss from basin. Its top cover is made of transparent glass in rectangular shape through which solar radiation reaches in the rectangular shape basin having an effective area A_b=1 m^2 (as shown in Fig. 1). In order to receive optimum heat energy orientation of solar still is most important. The orientation of single slope is kept south facing for better performance. For optimum yield, the inclination of condensing cover is taken equal to 15^o for summer point of view. The basin liner and side walls are painted black to absorb maximum heat reaching to the basin. Contaminated water is kept in the basin chamber to produce potable water. The chamber is designed as air tight chamber to serve as heat trap and prevent vapour loss from the basin. Heat received raises temperature of water mass and creates temperature gradient between water surface and inner glass cover. Water vapour is transported to the inner glass cover and condensed there after releasing its latent heat to the cover and water droplets slips down to collecting jar.

Fig. 3 represents an active conventional solar still coupled with fully covered semitransparent photovoltaic thermal-flat plate collector (PVT-FPC). In this case, water is heated directly and also indirectly using the PVT-FPC. The main objective of integrating PVT-FPC with conventional passive solar still (referring to Fig.1) is to feed the hot water into basin and electric power generation which is used to run motor for circulation of basin water in closed loop through the collector. This arrangement will enhance the temperature gradient between water surface and inner condensing cover. Passive solar still operates at lower temperature range but active solar still operates at the higher temperature range. With gain in temperature, the rate of evaporation increases which results in increasing yield from solar still as compared to that of passive solar still.

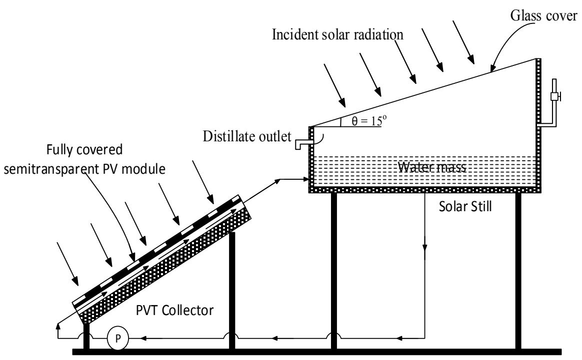

Fig. 3: Schematic representation of (PVT-FPC) integrated solar still under forced circulation.

3. THERMAL MODELING

For the purpose of simplification of the numerical simulation of the proposed model, the following assumptions are needed that are given as bellows:

1. The whole process in the proposed system is considered under the quasi-steady state conditions.
2. The heat capacities of the materials used in the design of the proposed model are neglected.
3. One-dimensional heat flow has been considered for the present simulation.
4. The ohmic losses between the solar cells of PVT-FPC collector are neglected.
5. There is no stratification of temperature between layers of fluid.
6. Vapour leakage proof system is considered.
7. The pressure losses in the pipe flow are neglected.

The energy balance for the active solar still (as shown in figure Fig. 3) considered in the present study has been shown as follows:

Energy balance for solar cells of PVT-FPC

$$\alpha_c \tau_g \beta_c I_t A_m = U_{t,ca}(T_c - T_a)A_m + U_{t,cp}(T_c - T_p)A_m + \eta_c \tau_g \beta_c I_t A_m \quad (1)$$

Energy balance for absorber plate of PVT-FPC

$$\alpha_c \tau_g^2 (1-\beta_c) I_t A_m + U_{t,cp}(T_c - T_p)A_m = F' h_{pf}(T_p - T_f)A_m + U_{t,pa}(T_p - T_a)A_m \quad (2)$$

Energy balance for the flowing fluid

$$\dot{m}_f C_f \frac{dT_f}{dx} dx = F' h_{pf}(T_p - T_f) b dx \quad (3)$$

Later on, solving above equations,T_p,T_c, and T_{fo} have been evaluated and further following parameters have been evaluated:

$$\dot{Q}_u = \dot{m}_f C_f (T_{fo} - T_w) \quad (4)$$

$$\eta_c = \eta_0 [1 - \beta_0 (\mathrm{T}_c - T_0)] \quad (5)$$

$$\eta_m = \tau_g \beta_c \eta_c \quad (6)$$

and,

$$E_{el} = \eta_m A_m I_b \quad (7)$$

Energy balance equation for condensing cover of still

$$\alpha_g' I(t) A_{co} + h_{1w}(T_w - T_{co})A_b = h_2(T_{co} - T_a)A_{co} \quad (8)$$

Energy balance equation for water of still:

$$\dot{Q}_u + \alpha_b' I(t) A_b + h_3(T_b - T_w)A_b = M_w C_w \frac{dT_w}{dT} + h_{1w}(T_w - T_g)A_b \quad (9)$$

where, $\dot{Q}_u$ is the useful heat gain (Eq. 4) feed to the solar till by PVT-FPC.

Further, using Eqs. (4), (8) and (9), one can write the resultant equation as given below:

$$\frac{dT_w}{dt} + aT_w = f(t)$$

$$\text{where, } a = \frac{1}{M_w C_w}(U + UA_{eff}) \quad (11)$$

and

$$f(t) = \frac{1}{M_w C_w}\left[\left((\alpha\tau)_{eff} + \alpha_{eff}'\right)I(t) + \left(U + UA_{eff}\right)T_a\right] \quad (12)$$

On solving the differential equation, the temperature of water in solar still is obtained as

$$T_w = \frac{\overline{f(t)}}{a}[1 - \exp(-a\Delta t)] + T_{W0}\exp(-a\Delta t) \quad (13)$$

where, T_{W0} is temperature of basin water at t = 0 and $\overline{f(t)}$ is average value of f(t) for time interval 0 to t.

The rate of heat losses in form of evaporation in the solar still and hourly yield of the proposed model can be evaluated as follows:

$$\dot{q}_{ew} = h_{ew}(T_w - T_{co})\text{W/m}^2 \quad (14)$$

$$m_{ew} = \frac{h_{ew}(T_w - T_{co})}{L} X\ 3600\ kg/m^2\text{h} \quad (15)$$

4. RESULTS AND DISCUSSION

Fig. 4 represents the hourly variation of solar radiation incident on the PVT-FPC collector (Ic) and solar still (Is). The available solar radiation have been evaluated by the Liu and Jordan method using the solar intensity data provided by the Indian Meteorological Department (IMD), Pune, India, for New Delhi climatic condition in the May month. It can be observed from the figure that the solar radiation available on the PVT-FPC collector is higher than on the solar still. The design parameters for the active and passive solar still have been given in the Table 1.

Table 1: Design parameters used in numerical computation

Parameters and Values	Parameters and Values
A_m = 2.1m2	PF_1 = 0.3782
A_b = 1m2	PF_2 = 0.9512
F' = 0.968	h_{pf} = 100W/m2
K_g = 0.816 W/mK	h_i = 5.7W/m2
L_g = 0.003m	h'_i = 5.8W/m2
K_i = 0.166W/mK	h_o = 9.5W/m2
L_i = 0.100m	h_w = 100 W/m2
K_p = 6W/mK	α_c = 0.9
L_p = 0.002 m	$\alpha_b{}'$ = 0.5861
L_i = 0.100 m	$\alpha_g{}'$ = 0.0095
U_{L1} = 3.47W/m2K	$\alpha_w{}'$ = 0.1787
U_{Lm} = 7.87W/m2K	α_p = 0.8
$U_{t,ca}$ = 9.17 W/m2K	β_0 = 0.0045
$U_{t,cp}$ = 5.58 W/m2 K	τ_g = 0.95
$U_{t,pa}$ = 4.8 W/m2 K	C_f = 4200J/kgK

Equation (8) has been used to evaluate the electrical power output for the active PVT-FPC integrated solar still. The Hourly variation of electrical power output of proposed active solar still has been shown in Fig. 5. From the figure, one can observed that the trends of variation of electrical power output is same as the solar radiation as per our expectation. It is also noted that proposed active solar still having electrical power output due to presence of PV module in the PVT-FPC collector. The generated electrical power can be used to run the pump of the proposed active system, thus it becomes self-sustained.

Equation (13) has been used to compute the temperature of water mass present in basin for passive and the proposed active PVT-FPC integrated solar still. The hourly variation of temperature of water mass for passive and active solar still have been illustrated in Fig. 6. From the figure, it is seen that the temperature of water mass for the proposed active solar still is higher than the passive one throughout the hours of the day (as shown in Fig. 6). One can observed from the figure that difference between the temperatures during the day hours is higher than the night hours due to absence of solar radiation at night.

Equation (15) has been used to compute the yield for passive and the proposed active PVT-FPC integrated solar still. The hourly variation of yield for passive and active solar still has been shown in Fig. 6. From the figure, it is found that the yield of the proposed active PVT-FPC integrated solar still is higher than the passive one throughout the hours of the day (as shown in Fig. 6). It can also observed from the figure that difference between the temperatures during the day hours is higher than the night hours due to presence of solar radiation during day hours. Further, the daily yield for passive and proposed active solar still are found as 3.16 and 7.86 kg/m^2 respectively under the given design and climatic parameters.

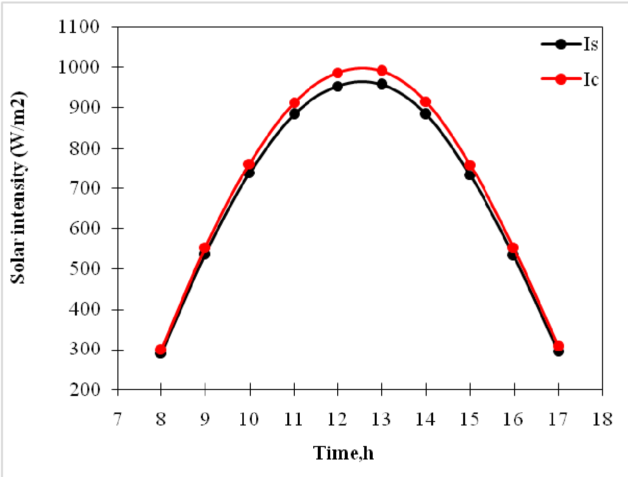

Fig. 4: Hourly variation of solar intensity on PVT-FPC collector and solar still in the May Month for New Delhi.

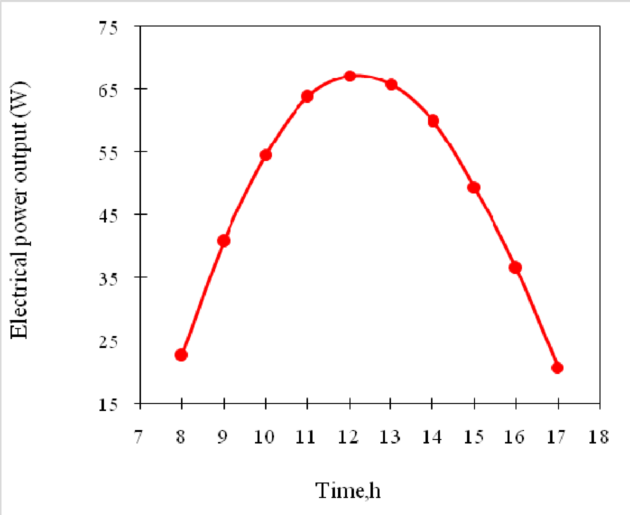

Fig. 5: Hourly variation of electrical power output by the PVT-FPC integrated solar still.

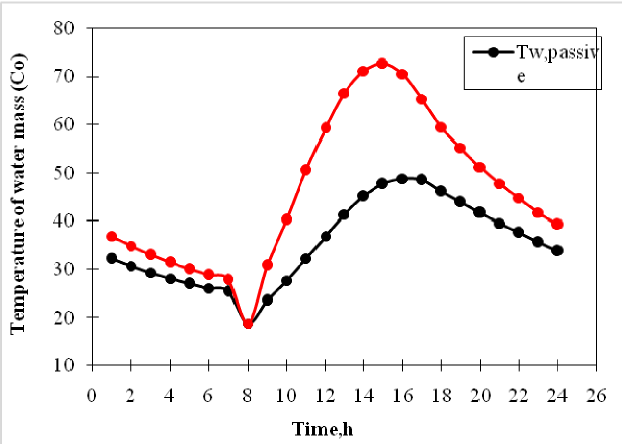

Fig. 6: Hourly variation of temperature of water mass present in basin for passive and active solar still.

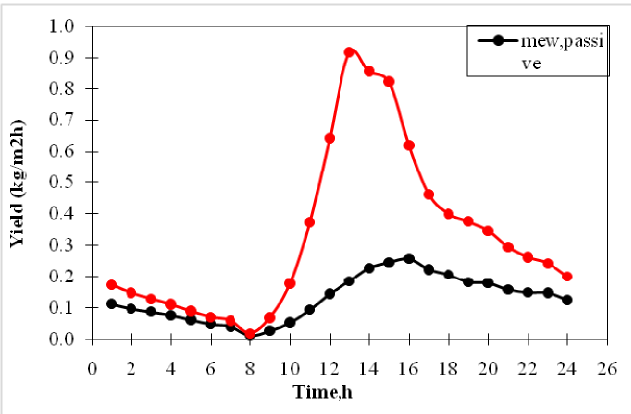

Fig. 7: Hourly variation of yield for passive and active solar still.

5. RESULTS AND DISCUSSION

On the basis of present studies, following conclusions have been made:

(i) The proposed active PVT-FPC solar still has electrical power output during day hours; hence this system will be self-operated during day hours.

(ii) The operating parameters i.e. temperature of water mass is recorded 30% higher in the proposed active solar still than the passive one.

(iii) The yield of the proposed active PVT-FPC active solar still has been found 150% higher than the passive one under the given design and climatic parameters.

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