Solar Assisted Water Purification System Analysis

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Abstract - A theoretical analysis of solar assisted water purification is presented in this research. A system is designed in which Maximum heat energy is absorbed by collector, the heated primary fluid is transferred to heat exchanger consists of salt water. Vapourization of salt water takes place and pure water vapour is taken out by vaccum pump and further condensed to get drinkable water. The remaining salt is flushed out from heat exchanger. The components that system consisted are parabolic troughs, heat exchanger, vaccum pump, primary fluid and the pump which circulates the primary fluid. The designed collector is parabolic which helps to take more amount of solar energy and transmit to pipe consisting primary fluid. The primary fluid used is Duratherm 450 because it is economically and thermally stable, it gives high performance, it is environmentally friendly and cost effective. Parametric analysis carried out with help of computer model which simulated experimental results by solving equations and calculations, based on this graphical analysis was done which concluded our experiment.

Index Terms - Parabolic trough, Solar Desalination, Water Purification, Distillation.

I. INTRODUCTION

Solar water purification does not rely on any types of fossil fuels and reduction of energy can also be associated. The energy which we are using is free of cost and helps to decrease the carbon and lead content in water.

II. LITERATURE REVIEW

System consists of heat recovery unit and temperature modulating polypropylene hydrophobic fibres used for system design. Environmental friendly and cost effective desalination process is necessary. Membrane distribution is best [1]. Solar desalination is eco-friendly and cost effective, water carried out from it is used for all purposes. Various technologies are used for desalination and solar desalination is most economical. Solar stills are developed for production of fresh water on large scale [2]. Due to increase in demand of fresh water sea water desalination process are done they are expensive and large amount of energy waste and water waste is done. So to overcome the cost and reducing the energy lost solar assisted sea water desalination will be good option [3]. Natural means of gravity and atmospheric pressure is used by a system to create vacuum by which liquid can be evaporated at low temperature and lower energy than any other. Methods or techniques according to theoretical simulations the system will perform better than a simple flat basin solar still [4]. Designing and fabricating of single effect desalination unit is done which is connected to solar assisted heat pump. Desalination chamber is connected by vacuum pump and spray nozzle used to generate droplets of feed water in unit, before spraying by nozzle feed water is preheated. In the system desalination units incorporates falling film evaporation and flashes distillation concepts. After performing the experiment we can find the performance ratio and performance of COP [5].

Performance of solar still can be increased by integrating various types of collectors, collector is kept perpendicular by which it absorbs maximum solar energy. The performance of solar humidification and dehumidification plant can be increased with high relative humidity available and high temperature of hot air achieved with solar evacuated tubes [6]. Auto flash is a multi-staged flash system designed to be coupled with a heat source of varying temperature "Auto flash" process water is sucked through a de-aerator, preheated in condenser tubes by vapour releasing heat of condensation at sub-atmospheric pressures. Indirect solar desalination is a promising way of meeting water demand in remote areas and as a way to reduce the carbon footprint of commercial desalination. Membrane technologies such as RO (Reverse osmosis) and ED (Electro dialysis) are currently the most costcompetitive solar desalination technologies approaching conventional desalination water costs [7].

III. METHODOLOGY

Rayleigh number for the length and the tube is required for the calculation of convection heat transfer coefficient:

$$R_{aL} = g \cdot \beta_{air} \cdot cos(\theta) \cdot \Delta T \cdot \frac{L^3}{\vartheta_{air} \cdot \alpha_{air}}$$
 (1)

Rayleigh number is non dimensional number which is used to determine the grashof number which is useful to determine the nusselt number. In this case the convection happens naturally because of the direct sunlight absorbed by black coloured pipe. But inside the pipe the flow is forced because of the feed pump and it fulfils the condition of $R_a > 10^9$.

Natural convection heat transfer coefficient:

$$h_w = 0.524 \cdot k_{air} \frac{R_{aL}^{0.25}}{I} \tag{2}$$

this equation came from natural convection of turbulent flow flowing inside tube.

$$nu = K(Gr \cdot Pr)^a \tag{3}$$

Here the value k=0.525 and a=0.25.

This equation validity increases because it gives better result if PR>0.5 in our case the primary fluid is greater than 0.5.

Heat transfer to primary fluid which is flowing in primary circuit:

$$\begin{aligned} Q_{in} &= A_{mirror} \cdot \rho_{mirror} \cdot 1000 - A_{pipe} \cdot \varepsilon_{pipe} \cdot \sigma \cdot T_{0sur}^4 \quad (4) \\ &- h_w \cdot A_{pipe} \cdot \Delta T \end{aligned}$$

This equation basically heat transformed from the sun radiation to primary fluid and it is derived by energy balance.

Energy = Energy absorbed by glass mirror of parabolic collector - Radiation from surrounding atmosphere - convection from water.

Primary fluid prandtl, Reynolds and nusselt number is calculated for turbulent flow.

$$R_{efb} = \dot{m} \frac{D_{1\,coil}}{A_{cross\,coil} \cdot \mu_{fb}} \tag{5}$$

$$V_{Dfb} = 0.0265 \cdot R_{efb}^{(\frac{4}{5})} \cdot Pr_{fb}^{0.3}$$
 (6)

here in this equations we use is turbulent flow equation inside the pipe re>10000 so we have to use equation to find nusselt number.

Energy equation for primary fluid:

$$Q_{fb} = \dot{m} \cdot C_{pfb} \cdot (T_{finB} - T_{foutB}) \tag{7}$$

Total thermal resistance for primary fluid and coil thickness [8]:

Now in our pipe we have resistance due to conduction and convection both so,

$$R = R_{conduction} + R_{convection}$$

$$R_{total\,FSB} = \frac{ln[\frac{r_2\;coil}{r_1\;coil}]}{2\pi k_{coil}\; \cdot L_{coil}} + \frac{1}{2\pi r_1\;coil}\; \cdot L_{coil}\; \cdot h_{fb} \eqno(8)$$

Nucleate boiling [9]:

$$Nu = C_1 R e^x P r^y (9)$$

Nusselt number is defined as follows where the bracketed term is the bubble departure diameter, designated as the characteristic length

$$Nu = \frac{\alpha_{nb}}{K_L} \left[\frac{\sigma}{g(\rho_L - \rho_g)} \right]^{\frac{1}{2}} \tag{10}$$

 α_{nb} is nucleate pool boiling heat transfer coefficient. In terms of superficial velocity Reynolds number is defined.

$$Re = \frac{q}{h_{LG}\rho_L} \left[\frac{\sigma}{g(\rho_L - \rho_g)} \right]^{\frac{1}{2}} \frac{\rho_L}{\mu_L}$$
 (11)

 h_{LG} is latent heat

 μ_L is liquid dynamic viscosity.

An empirical constant C_{sf} introduced for the influence of the liquid-surface combination observed in his database as follows

$$Nu = \frac{1}{C_{sf}} Re^{(1-n)} Pr^{-m}$$
 (12)

The Rohsenow correlation is presented in the following form

$$\left[\frac{C_{pL}\Delta T}{h_{LG}}\right] = C_{sf}\left[\frac{q}{\mu_L h_{LG}}\left(\frac{\sigma}{g(\rho_L - \rho_g)}\right)^{\frac{1}{2}}\right]^{\frac{1}{3}} P r_L^{m+1}$$
(13)

By solving the equation (13) we get our code equation

$$q_{s} = \mu_{fwater} \cdot \Delta h_{vap} \left[g \cdot \left(\frac{\rho_{fwater} - \rho_{gwater}}{\sigma_{fwater}} \right) \right]^{0.5}$$

$$\cdot \left[C_{p \ water} \left(\frac{T_{cbs} - T_{sat}}{C_{SF} \cdot \Delta h_{vap} \cdot Pr_{water}} \right) \right]^{3}$$
(14)

In the boiler (heat exchanger) because of the hot primary fluid flow in the tubes of boiler. The salt water is starting to evaporate so we get vapour in boiler and with the help of the vacuum pump we can condense the vapour to get fresh water. So nucleate boiling heat transfer equation we used for finding the mass of vaporised fluid.

COP of water desalination system:

$$COP = \dot{m}_v \cdot \frac{\Delta h_{vap}}{Q_{sym}} \tag{15}$$

SYSTEM DESIGN

This is a possibility to purify water with the help of solar energy. The following system (Fig.1) gives us a possibility on generation of sufficient amount of water vapour.

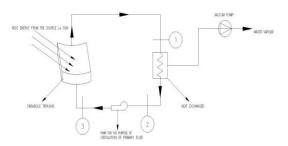


Fig. 1. solar water purifier schematic

The parabolic troughs gather the solar energy and direct the same to a pipe from which a primary fluid flows which gets heated up. The pipe for primary fluid is located at the focii of the parabolic trough to get maximum solar energy. The heated primary fluid transfer heat to the impure salted water in heat exchanger. This causes vaporization of water in heat exchanger. The pure water vapour is taken out of heat exchanger by vacuum pump and further condensed to get drinkable water. Whereas the unwanted salts and contaminants are flushed out from heat exchanger regularly. In order to increase the absorptivity of the pipe which is carrying the primary fluid (in order to get primary fluid getting heated up quickly), it is to be painted in black. Now the total heat received and calculations required can be understood from following. Depending upon pressure in heat exchanger saturation temperature of contaminated and salty water is related. It is assumed that steady state conditions prevail considering that there are longer hour solar energy received like in India where there is a possibility of longer duration solar energy received. Since, we need to vaporize the contaminated salty water in heat exchanger, nucleate boiling is needed. So. there has to be high heat input to the primary fluid and this heat added to primary fluid must also be transferred quickly to the brackish water. This requires high flow rate of primary fluid. The mean solar irradiation on earth is $1000 \frac{W}{m^2}$.

Inlet temperature of primary fluid & mass flow rate of primary fluid inside $T_{p,in}$, $m^*_{p,in}$

Outlet temperature of primary fluid & mass flow rate of primary fluid outside

 $T_{p,out}$, $m^{\cdot}_{p,out}$

Mass flow rate of vapour outside m'vapour,out

Mass flow rate of water inside m'water.in

Primary fluid which is heated transfer absorbed heat from the solar collector by solar energy to vaporized brackish water (salty water). It is assumed that the heat which absorbed by primary fluid is transferred to brackish water considering the steady state heat transfer. Using this analysis, it is possible to consider various designing aspects and it is possible for consider various change and doing parametric analysis mean that changing one constrain and observing the performance of system for that change. In the start of the day, the pipes in which primary fluid is flowing is having very low temperature which is almost equal to surrounding. Here, it takes certain amount of time for the pipe and hence primary fluid for gain high temperature. But we will assume steady temperature and plot ideal characteristics curves of the performance of system. The discussion is from assumption side. Now, in order to vaporize water from heat exchangers, it is necessary to get saturation temperature of water in heat exchangers Fig.2. Here for, in the beginning it takes time for reach the saturated temperature. This require boiling of brackish water in heat exchangers. For this purpose, there must be quite a large amount of heat input required by primary fluid [10].

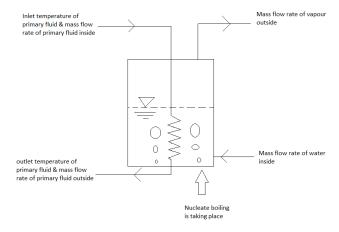


Fig. 2. Heat balance in heat exchanger

In addition to assuming steady state analysis, there are certain other assumption too. The solar irradiation and surrounding atmospheric temperature is constant. In order to calculate Nusselt number for wind, Zukauskas correlation used in code to find heat transfer to primary working fluid.

$$Nu_{wind} = CRe^{m}Pr^{n}(\frac{Pr}{Pr_{s}})^{\frac{1}{4}}$$
 (16)

$$\Delta T = T_{surface} - T_{surrounding}$$

In order to understand heat transfer refer to Fig.3 given below:-

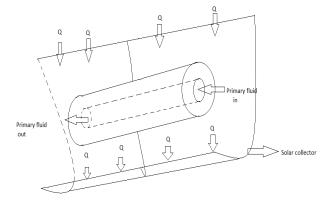


Fig. 3. Schematic of solar collector

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Q = solar heat transfer from sun

Out of the total solar energy received , some energy is always wasted in form of convection , radiation and heat taken by wind or lost due to wind.

$$Q_{Heat \ transfer \ to \ primary \ fluid} = Q - Q_{HT \ by \ radiation}$$
(17)
$$-Q_{HT \ by \ convection} - Q_{HT \ by \ wind}$$

Assuming solar irradiation on earth's surface as 1000 $\frac{w}{m^2}$

Assuming fully developed flow in the pipe by primary fluid following Graetz problem,

$$Nu = 3.66 = \frac{h_f \ D_{inner,diameter \ of \ pipe}}{k_{primary \ fluid}} \tag{18}$$

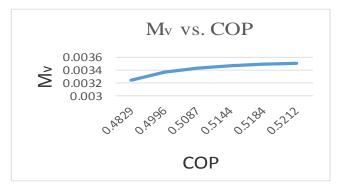


Fig. 4. Increase in mass of vapourized fluid

 h_f = convection heat transfer coefficient for primary fluid $(\frac{W}{m^2-k})$

In fact in the heat exchanger helical coil. In this helical coil, the heated primary fluid flows. Which boil the brackish water in heat exchanger.

The heat received by primary fluid form solar energy is transformed to brackish water through wall of pipe. This heat vaporize water which is then pumped out of heat exchanger. Here too an assumption undertaken is consideration of constant water level in heat exchanger with insulated walls of heat exchanger heat transferred by primary working fluid to brackish water is given as follows:-

$$Q_{FW} = \dot{m} C_p (T_{p,in} - T_{p,out})$$
(19)

IV. RESULTS AND DISCUSSIONS

From Fig.4 Q_{cf} is the convective energy available in surrounding and absorbed by the pipe. As Q_{cf} increases, the rate at which primary fluid Duratherm 450 is heated up at very high temperature. So, when the heated fluid is entered into the heat exchanger salt water gets evaporated and by the heat transfer vapour will be generated and mass of vapour will increase and it will definitely increase the COP of system.

From Equation 15 we can understand the significance of mass of vapourized fluid this equation indicates as the Q_{cf} increases then the value of M_v will also increase. So, from the previous Fig.4 as the heat transfer increases in heat exchanger more mass of vapour will be generated and the system will be more efficient Fig.5.

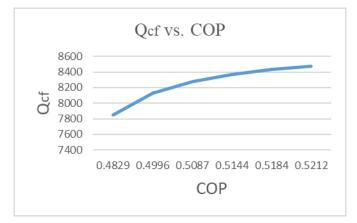


Fig. 5. Heat absorbed by pipe

From Fig.6 L_{coil} is length of tubes of heat exchanger in which heat transfer takes place as we increase the length of coil, Reynolds number will decrease. The heat transfer coefficient increases, the heat transfer between salt water and tube increases which creates large amount of evaporation. So, it is preferable to have long length of coil.

From Fig.7 In summer the surrounding temperature is very high and Q_{cf} is low, by adjusting the flow we can get higher Q_{cf} but if surrounding temperature is low Q_{cf} will increase. The system doesn't get affected in cloudy conditions it gives continuous output.

The Fig.8 shows that as the length of collector is increased the heat absorption capacity of working fluid also increases because the working fluid is flowing in to the copper pipeline and copper is good conductor of heat and does not corrode at high melting point and has high thermal conductivity. We have considered wind effect in this case.

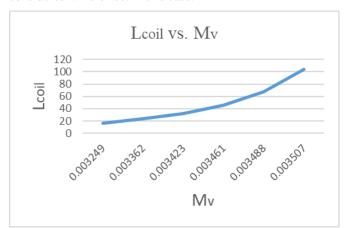


Fig. 6. Increase in length of coil

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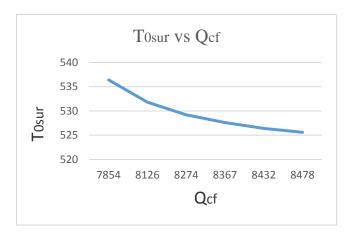


Fig. 7. Decrease in heat transfer



Fig. 8. Increase in heat absorbption capacity

This Fig.9 shows that the temperature of outer surface of copper pipe gradually decreases by increasing the length of collector, this occurs when the working fluid is coming out from the heat exchanger after purification of water where the outer surface of pipe temperature decreases. Here also we have considered wind effects.

Fig.10 is similar to Fig.9 but difference in both figures are in previous Fig.9 where wind effect was considered and in this figure we have neglected wind effect. The peak temperature is more as compared to considered wind effects.

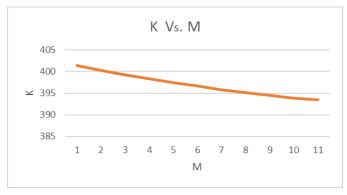


Fig. 9. Considering wind effect

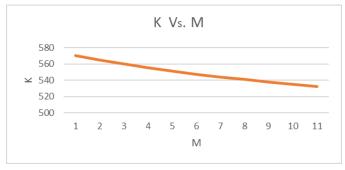


Fig. 10. Neglecting wind effect

The Fig.11 and Fig.12 shows that the effectiveness of the heat exchanger increases and then decreases. As the heat transfer fluid, mass flow rate increases. Thermal energy absorbed by HTF increases the mass flow rate as it passes through parabolic trough. Due to energy absorption to HTF is very high and heat losses to surrounding is very low. The diamond points are the values that we have obtained from our analysis and the curved lines are obtained from the reference research paper, by comparing our research paper graph and reference researched graph we got almost identical results. So, our generated code is valid [11].

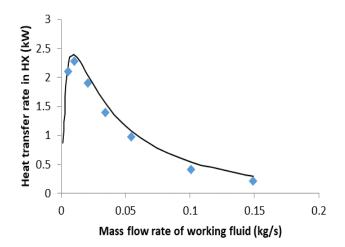


Fig. 11. Decrease in heat transfer rate

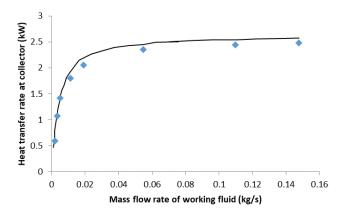


Fig. 12. Increase in heat transfer rate

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V. CONCLUSION

By installing solar water desalination fuel can be saved which is used to produce electricity and prevent from the global warming, a mathematical model was developed and simulated in computer based software. In the first condition mass flow rate of primary fluid was kept constant and pressure of primary fluid (HTF) and changes were observed by changing different parameters. In the second condition length of collector was kept constant and pressure of HTF, by applying both conditions changes in different parameters were observed, by collection of the data graphs of various parameters were plotted. The best mass flow rate to run the system is $0.05 \frac{kg}{sec}$ and the highest HTF temperature is 384.6 K (112 °c) which was achieved in first condition, this temperature causes the evaporation of water so our aim is achieved, the system is economically efficient only in smaller plants if the plant size is big then large parabolic collectors are needed, to accumulate the solar heat so that system is not economical efficient.

REFRENCES

- [1] Kim, Y.D., Thu, K. and Choi, S.H., 2015. Solar-assisted multi-stage vacuum membrane distillation system with heat recovery unit. *Desalination*, 367, pp.161-171.
- [2] Kumar, P.V., Kumar, A., Prakash, O. and Kaviti, A.K., 2015. Solar stills system design: A review. *Renewable and sustainable energy reviews*, 51, pp.153-181.
- [3] Li, C., Goswami, Y. and Stefanakos, E., 2013. Solar assisted sea water desalination: A review. *Renewable and Sustainable Energy Reviews*, 19, pp.136-163.
- [4] Al-Kharabsheh, S. and Goswami, D.Y., 2003. Experimental study of an innovative solar water desalination system utilizing a passive vacuum technique. *Solar Energy*, 75(5), pp.395-401.
- [5] Hawlader, M.N.A., Dey, P.K., Diab, S. and Chung, C.Y., 2004. Solar assisted heat pump desalination system. *Desalination*, 168, pp.49-54.
- [6] Chandrashekara, M. and Yadav, A., 2017. Water desalination system using solar heat: a review. Renewable and Sustainable Energy Reviews, 67, pp.1308-1330.
- [7] Ali, M.T., Fath, H.E. and Armstrong, P.R., 2011. A comprehensive techno-economical review of indirect solar desalination. *Renewable and Sustainable Energy Reviews*, *15*(8), pp.4187-4199.
- [8] Bergman, T.L., Incropera, F.P., DeWitt, D.P. and Lavine, A.S., 2011. Fundamentals of heat and mass transfer. John Wiley & Sons.
- [9] Beitelmal, A.H. and Fabris, D., 2015. Off-the grid solar-powered portable desalination system. *Applied Thermal Engineering*, 85, pp.172-178.

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