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Fabrication and Analysis of Solar Powered and Peltier Model Based Device for Desalination of Marine Water

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ABSTRACT

A solar-powered desalination system using condenser integrated with concave solar collector and centrifugal pump was developed for producing fresh water under different operational conditions. Systems temperatures added to ambient temperature were measured with hour intervals, under all experimental conditions for both solar desalination systems. Heat and mass transfer regimes were conducted for the condenser and heat exchanging tubes. Performance of the two systems was studied as a function of change in water salinity level and water tank flow rate and evaluated in terms of recorded temperatures, water productivity and cost. The experimental results may reveal that the developed system increases water productivity for all water salinities compared with the ordinary system due to the presence of centrifugal pump. The same results may also reveal that water productivity increased and cost decreased by increasing water flow rate using the developed system while the vice versa. Results obtained from two systems are analyzed for suitability of drinking by measuring the minerals.

Key Words: *Passive Desalination, Solar desalination, Concentrator desalination, Peltier based desalination.*

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1. INTRODUCTION

The world's water consumption is increasing day by day for the purpose of agriculture, industries and daily usage. But the available fresh water in the world is only 1%, which are available in lakes, rivers and underground [3]. The water reaching the humans is around 1/3rd of that fresh water. One more reason for the increase in demand for water is the increasing population of the world. Approximately, over a billion people around the world do not have adequate access to safe drinking water. Over 20 countries do not have enough water to maintain and develop themselves.

In India, the scarcity of desalinated water is high in the coastal regions. The use of renewable energy based desalination plants can solve this problem without causing any problem to the environment. Solar energy has the potential for meeting and supplementing various energy requirements and the solar energy systems can be installed in any capacity required.

Desalination being the oldest form of removing salt from water, has gained importance in the modern era. Nowadays for the availability of pure and safe drinking water, desalination has gained much importance, as it can solve the problems of the availability of fresh water without any large expenses being involved. Using solar energy for the purpose of desalination is widely used, as the source is available in nature itself.

Our setup works using the solar energy. We use a parabolic reflector which concentrates the solar radiations into a single focal point, where we get the heat. That heat is used to boil the water, which is flowing through the copper pipes with the help of a pump. The heated water then goes to the steel tank which contains the saline water. There the heat gets transferred from the hot water in the pipes to the cold saline water in the tank. The saline water gets heated up and starts to boil and it evaporates. That evaporated water is of the pure form, which gets condensed with the help of aluminium foil, which is kept over the steel tank which is conical in shape. The PH level of the water is checked after it is collected from the tank through the channel. If the water has a PH level of 7, then the water is safe for drinking. Then that water is tested to see if it contains any harmful minerals in it for the daily usage of humans.

The science behind our project is that, it has a conduction process, where the heat gets transferred from one metal body to another when they are in contact with each other. Convection process, where the heat gets transferred from a metal body surface to a flowing fluid which is also in contact with each other. Condensation process, where the hot vapour gets cooled down when they come in contact with a much cooler surface than their own and forms in a liquid.

In this process the water is made to flow through the pipe where heat is transmitted from the reflector to the circulating water. This water flow is achieved by using the pump which runs with the help of motor connected to a battery, which is powered by the Peltier module working with see beck effect.

2. **DESALINATION TECHNOLOGIES**

The two main commercial desalination technologies are those based on thermal and membrane process.

2.1. Thermal Desalination

Thermal process is similar to the natural process of producing rain. In this process the Saline water is heated to vaporize it and then is condensed to form distilled water. This process includes multi-stage flash (MSF), vapour compression (VC), and low temperature evaporation (LTE). In all these processes, condensing steam is used to supply the latent heat needed to vaporize the water.

2.2. Reverse Osmosis

RO is used for both brackish water and seawater desalination as well as for waste water treatment and water recovery/reuse. A typical RO desalting plant consists of three sections, namely pre-treatment section, membrane section and post treatment section. Conventional pre-treatment section typically consists of particulate filtration, micron filtration and chemicals additions. Membrane section consists of membrane elements housed in pressure vessels through which pre-treated saline water is passed under pressure in excess of its osmotic pressure with the help of a high pressure pump coupled with energy recovery device. The post treatment section consists of lime treatment for pH correction and chlorination for disinfection as required to meet public health standards and to make the water noncorrosive to the water distribution systems.

2.3. Hybridization

Hybrid thermal/membrane combinations offer several advantages including the use of warm seawater from the thermal plant as feed to RO for having an optimized feed temperature and production of water of different qualities for different uses such as high quality boiler feed make up water, process water and potable water. Combined post treatment, use of common seawater system and brine discharge facility, reduced seawater requirement, sharing the manpower and facilities are other advantages of hybridization.

2.4. Co-generation Using Nuclear Energy

Co-location of desalination and power plants has the benefit of sharing the resources such as common intake of sea water/ outfall and other infrastructural facilities. Dual purpose (power & water) plants have inherent design strategies for better thermodynamic efficiency besides economic optimization. The production of potable water from seawater in a facility in which nuclear reactor is used as the source of energy for the desalination process is termed as nuclear desalination. Electrical and/or thermal energy is used in desalination process on the same site.

3. MATHEMATICAL MODELING

3.1. Characterization parameters

Solar concentrators are characterized based on the following parameters 1) aperture area 2)acceptance angle 3) rim angle, 4) absorber area, 5) concentration ratio, 6) intercept factor, optical efficiency and instantaneous thermal efficiency [5].

The aperture area (A_a) is the area through which the solar radiation is incident. The acceptance angle (θ_{lim}) defines the angular limit to which the incident ray may deviate from to the aperture plane and still reach the absorber. The rim angle (ψ_r) is the angle between the edge and the centre of curvature from the focal point. These angles are represented in Fig. 3.1, where A and B represents the position of the sun in the generic instants A and B. The intercept factor (γ) is defined as the ratio of the energy intercepted by the absorber to the total energy redirected by the focusing device. The geometrical concentration ratio (C) is the ratio of the aperture area to the absorber area. The optical efficiency (∈o) depends on the optical properties of the materials involved [12], the geometry of the collector, and the various imperfections arising from the construction of the collector [13]. Eq. (1) represents this term.

$$\in_0 = \rho_m \tau_m \alpha_m \gamma \left[\left(1 - A_f tan\theta\right) cos\theta\right] \text{-- (1)}$$

Considering that the angle of incidence (h) is equal to 0^0 because the implemented system is provided of solar tracking, the equation is simplified to Eq. (2).

$$\in_0 = \rho_m \tau_m \alpha_m \gamma \quad \text{-- ----------------------- (2)}$$

Where ρ_m is the reflectivity of the reflector material, τ_m is the transitivity of the aluminium foil, α_m is the absorptivity of the absorber and (γ) is the intercept factor. The instantaneous thermal efficiency (η) of a solar concentrator can be calculated from an energy balance across rate the absorber simultaneously exposed to solar radiation and convection, which also serves to predict the equilibrium temperature and heating ramp.

This illustration can be represented mathematically as Eq. (3), where q_{ri} is the reflected radiation intercepted by the absorber, q_r is the rate of incident energy reflected by the absorber q_e is the rate of radiant energy exchanged between the absorber and the environment and q_{conv} is the rate of radiation loss by convection.

$$\rho_s V c_{ps} \frac{dT}{dt} = q_{ri} - q_r - q_e - q_{conv} \quad \text{-- (3)}$$

The following simplifying assumptions were considered:

- The focus remains centered on the absorber.
- The specimen used as absorber is copper coil.
- The temperature in the absorber is distributed evenly, considering the high thermal conductivity of the copper and the finite dimensions of the absorber.

Therefore, Eq. (3) is rewritten as:

$$\frac{dT}{dt} = \frac{1}{\rho_s V c_{p_s}} \{\in_0 A_a I_b - A_{abs}[\sigma(T^4 - T_\infty^4) + h(T - T_\infty)]\} \text{----------------- (4)}$$

This ordinary differential equation (ODE) represented by Eq. (4) can be solved numerically by applying the approaches of the Euler Method. The initial value, or boundary condition, is T (0) =T_∞. The convective heat transfer coefficient (h) is calculated using the empirical correlation recommended by [3] for vertical plates and external free convection flows (Eq. (5)) provided it meets the condition Ra≤ 10^9.

$$Nu_L = 0.68 = \frac{0.670 Ra_L^{1/4}}{[1+(0492/\text{Pr})^{\frac{9}{6}}]^{4/9}} \quad \text{-- (5)}$$

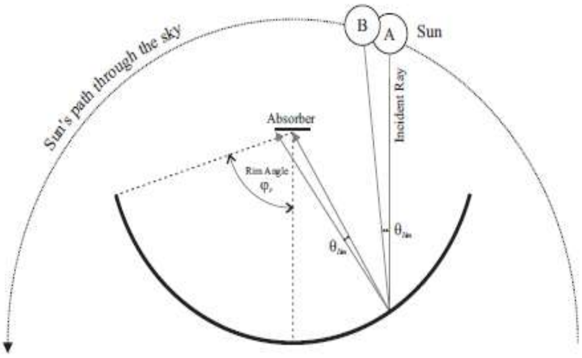

Figure1. Acceptance and rim angle [5].

This equation can also be applied to vertical cylinder of height L, provided the thickness of the boundary layer is much smaller than the cylinder diameter, D. This condition is satisfied when:

$$\frac{D}{L} \geq \frac{35}{Gr_L^{1/4}}$$

The dimensionless numbers can be calculated using the following equations [14].

$$Ra_L = Gr_L Pr \qquad \text{--} \ (6)$$

$$Gr_L = \frac{g\beta(T_s - T_\infty)L^3}{V^2} \qquad \text{--} \ (7)$$

$$\beta = \frac{1}{T_s} \qquad \text{--} \ (8)$$

$$Pr = \frac{v}{\propto} \qquad \text{--} \ (9)$$

$$h = \frac{Nu_L K}{L} \qquad \text{--} \ (10)$$

The thermo physical properties of air were based on tables [3] with correlation coefficients (r^2) greater than 0.99. When heat is removed and supplied at the same rate, the fluid temperature does not vary over time:

$$\frac{dT}{dt} = 0 \qquad \text{--} \ (11)$$

Thus, Eq. (11) is able to indicate the maximum temperature attained by a heating system considering heat loss, i.e., when it is at equilibrium. Eq. (4) describes the temperature variation of an absorber over time, which enables one to predict the heating ramp rate. Therefore, it could be solved numerically by inserting radiation values, ambient temperature, and the absorber characteristics. The useful thermal energy (q_u) directed by the solar concentrator is given by Eq. (12).

$$q_u = \epsilon_0 \, A_a I_b - [\sigma(T^4 - T_\infty^4) + h(T - T_\infty)] \qquad \text{------------} \ (12)$$

Therefore, the instantaneous thermal efficiency can be written by Eq. (13).

$$\eta = \frac{q_u}{I_b A_a} \qquad \text{---} \ (13)$$

3.2. Heat transfer governing formulations

There are five major concepts involved in this project experimental process for heat transfer and they are as follows;

3.2.1. Conduction

Conduction is the passing of heat energy between two objects that are in direct physical contact. Metal is a good conduction of heat. This conduction process will be taking place in the Peltier module where heat is transferred from the aluminium metal to the module.

$$Q = KA\nabla T \qquad \text{---} \ (14)$$

$$\nabla = \frac{d}{dx}$$

Where:

Q=Rate of heat transfer in joules

K=Thermal conductivity of the material

A=Surface area of the pipe in contact

∇T=Temperature gradient,

3.2.2. Convection

Convection is the process where the hot stuff rises and cold stuff sinks to take place its position, that stuff must be a fluid either a liquid or a gas. Here forced convectional process will be occurring [8]. This process will be taking place in the tank where the hot water is passing through spiral copper pipe and this heat is transmitted to the saline water in the tank.

$$Q = h_c A dT \text{ --- (15)}$$

Where:

Q=Rate of heat transfer in joules

h_c=Convection co-efficient

A=Area of the surface

dT=Temperature difference

3.2.3. Radiation

Radiation type of heat transfer travels through electromagnetic waves. This kind of heat transfer will be taking place over the parabolic reflector where the heat is transmitted to the coiled copper pipe placed at a focal point from the reflector.

$$P = \sigma e A(T^4 - T_c^4) \text{ --- (16)}$$

Where:

P=Power dissipated through radiation

σ=Stefan-Boltzmann constant ($5.67*10^{-8} W/m^2K^4$)

e=Surface emissivity of the material

A=Surface area of package and PCB

T=Surface temperature of package and PCB

T_c=Ambient temperature

3.2.4. Condensation

Condensation is the process of a substance in a gaseous state transforming into a liquid state. This change is caused by change in pressure and temperature of the substance [7]. This process will be taking place over the surface of the conically shaped aluminium sheet fitted over the tank.

$$(\text{RH}) = \frac{Actual\ vapour\ density}{Saturated\ vapour\ density} * 100\% \text{ --- (17)}$$

3.2.5. Heat flux

Heat flux or thermal flux is the rate of heat energy transfer through a given surface per unit time. For most solids in usual conditions, heat is transported mainly by conduction and the heat flux is adequately described by Fourier's law [7].

The heat flux associated with a temperature profile T(x) in a material of thermal conductivity K is given by Fourier’s law in one dimension is

$$q' = -K \frac{dT(x)}{dx} \text{ --- (18)}$$

The negative sign shows that the heat flux moves from higher temperature region to lower temperature region.

3.3. Flow governing equation

This principle is derived from the fact that mass is always conserved in the fluid systems regardless of the pipeline complexity or direction of flow [6].

The floe is assumed to steady flow and the principle of conservation of mass is applied to the system.

$$Q = \rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

Since water is incompressible fluid $\rho_1 = \rho_2$

Therefore, $Q = A_1 V_1 = A_2 V_2$ --- (19)

Where:

Q is volumetric flow rate

A is the cross sectional area of flow

V is the mean velocity

This is a statement of the principle of mass conservation for a steady, one-dimensional flow, with one inlet and one outlet.

4. EXPERIMENTATION

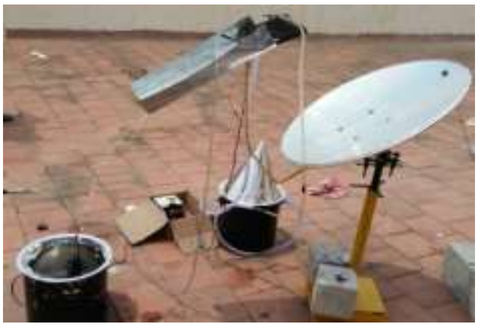

Figure 2.Desalination setup

Figure 3: Main components of the setup

i. Peltier module: The electricity is generated by maintaining the hot and cold sides on the peltier, which is a reverse process called see-beck effect.

ii. Spiral Copper pipe: Here the copper pipe works as a heat exchanger where the heat is transferred to the saline water to form steam.

iii. Parabolic reflector: this concentrates the direct sunlight into a single focal point, where the heat is generated to heat the water flowing through the coiled copper pipe.

iv. Centrifugal pump: This pumps the water through the copper pipe.

v. Absorber: Reflected radiation from the reflector incident on this absorber through which water is flowing through it, get heated up.

5. RESULTS AND DICUSSION

He conducted experiment by considering five different percentage of salt in water (0, 1, 2, 3, and 4) and this experiment will be performed from 9:00AM to 4:00PM in May. The distilled water yields were replicated and the averages for each sea salt concentration are shown in Fig 4. The average solar radiation of the experimental test was 791 W/m^2 with a standard deviation of 1.43%. The results are comparable with the Gustavo Otero Prado et al [5].

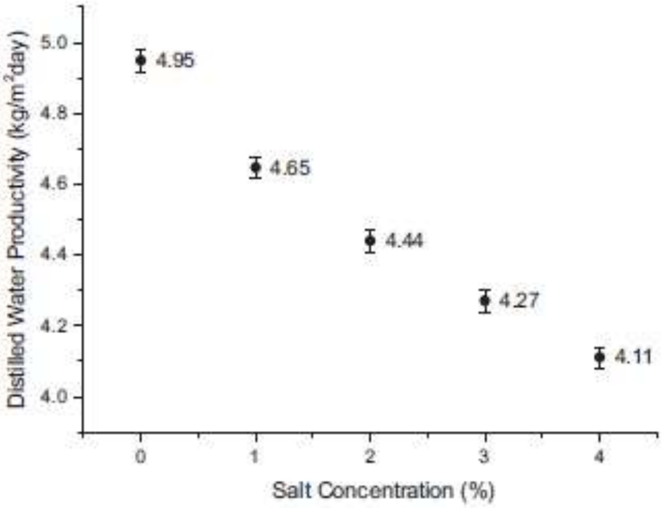

Figure 4. Distilled water yield at different concentrations of sea salt.

Figure 5 illustrates the production of distilled water throughout the day, considering the studied time. It was found that at the time of the highest incidence of solar radiation, between 12:00 and 13:00 h, the production of distilled water was approximately the same at all the salt concentrations, indicating that the influence of the colligative properties diminished as the heat increased.

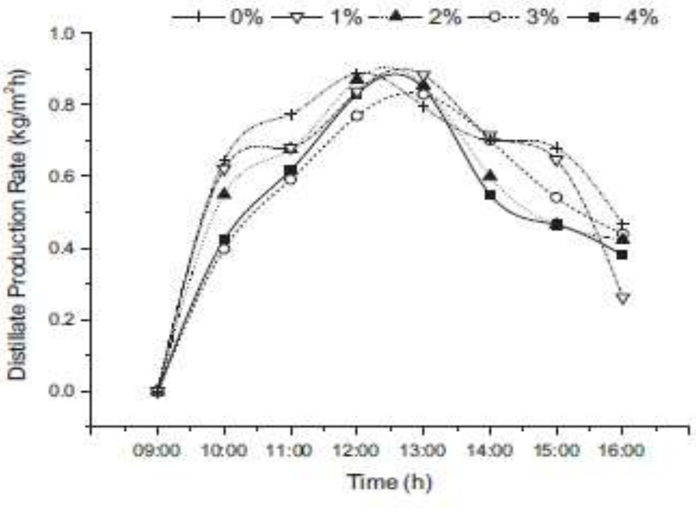

Figure 5. Distilled water Production in a day.

6. CONCLUSION

Heat and mass transfer regimes were conducted for the condenser and heat exchanging tubes. The heat transfer study may reveal the extent of desalination based on the salinity of water. As you see from Figure 5 the distilled production rate is higher at mid of the day. To increase effectiveness of heat transfer, the material consideration should be taken care. The marine water can be distilled and desalinated by use of solar radiation effectively. 4.5 litres of desalinated water can be desalinated with 3.5% salinity per day in average buy using parabolic reflector method. This water desalination can be increased by coating high reflective material like mirror glass.

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