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Investigation Of Humidification Dehumidification Unit Designed For Utilizing Solar And Waste Energy

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The current work addressed the thermodynamic performance analysis of novel humidification dehumidification deionization system which utilizes the waste heat of household chimney of kitchen for water heating. Mathematical analysis based upon conservation principle of mass and energy has been done for the components of system. It has been applied to reveal the effect of mass flow rate of air and water on the productivity of potable water. The productivity increases (obtained maximum production of water is 6.5 kg/day) with increases air mass flow rate from 0.6 kg/min to 3 kg/min. Moreover, it also showed substantial dependency of mass flow rate of water on rise in production. The maximum value found 6.7 kg/day and 7.5 kg/day by raising the water mass flow rate in humidifier and dehumidifier respectively. Finally, the performance enhanced by the conceptual system has been assessed in terms of GOR and compared with conventional system. In addition, higher value of GOR of the theoretical system indicates the optimum uses of thermal energy in production of clean and drinkable water.

Keywords: Heat transfer, Solar energy, Deionization, Humidification, Dehumidification, Air heater.

1. Introduction

Natural resources have been utilized by humans for several years to live on earth. Therefore, sun energy and sea water energy are such two means, to resolve water scarcity arise, because of rapid growth in population and industry. Several deionization methods are existing to change the large source of salty water into drinkable water, however, requirement of high energy is the major problem. Therefore, Humidification Dehumidification (HDH) deionization system has appeared an effective technique for drinkable water production. It also fulfills the energy requirement with attribute to couple easily with sun energy [1]. The exist system is upgraded for exploit of solar energy. Moreover, the novelty in the design of the system plays a vital role in enhancement of potable water productivity of HDH deionization systems [2-4]. The present work show case an innovative system development that the waste heat of chimney of kitchen utilizes for water heating, before delivering, to the humidifier of HDH unit. The increase in water temperature results, increase in the moisture content of air thus yield of potable water increases.

Researchers have been developed various technique to improve the cleaned and filtered water production systems based on HDH principle [5-7]. Some of them presented, state-of-the-art of HDH deionization system and assessed the opportunity of renewable energy (solar, wind and geothermal) in water production [8-9]. Moreover, numerically investigated the performance of solar HDH system, to determine the critical factor and their effect on drinkable water production [10-11]. Further, the efficiency of renewable HDH system was numerically evaluated to decide the ideal mass flow rate of waste hot air and water in the system [12-14]. Researchers investigated the effect of ratio of mass flow rate and energy consumption of the HDH system. Also, exhibited the graphical method to determine the optimum value of operating variables [15-16]. Others, studied experimentally of novel solar deionization based on HDH principle [17]. The studied system has been designed and constructed, in order to conduct experimental investigation for various combination of operating conditions. An economic analysis of the constructed system has also been done, to estimate, both the expense of production of clean water and pay-back time period [18]. Researchers presented mathematically studied the efficiency of renewable HDH system by utilizing the dissipating heat of air-conditioners in environment [19-20]. Furthermore, the effect of different design and operating factors on production of potable water has been reported [21].

Therefore, the focus of current work is that, to evaluate the novel renewable HDH system by mathematical modeling and to determine the optimum air and water, mass flow rate. The designed system utilizes the thrown hot air from chimney, to heat unused water. The effect of critical factors of the system on cleaned and filtered water productivity have been evaluated. In addition, thermal efficiency of the conceptual system has also been evaluated, in terms of the gain output ratio (GOR).

2. DESCRIPTION OF DESIGNED SYSTEM

The proposed system (schematic diagram as illustrated in Figure 1) utilizing dissipated heat from chimney, to heat the waste water prior entering to humidifier. The vital components of the designed system are solar air heater, humidifier, dehumidifier and storage tank (which is equipped with tubes for hot air flow). Further, fan and water pump have been used to ensure the appropriate flow of air and water within the designed system.

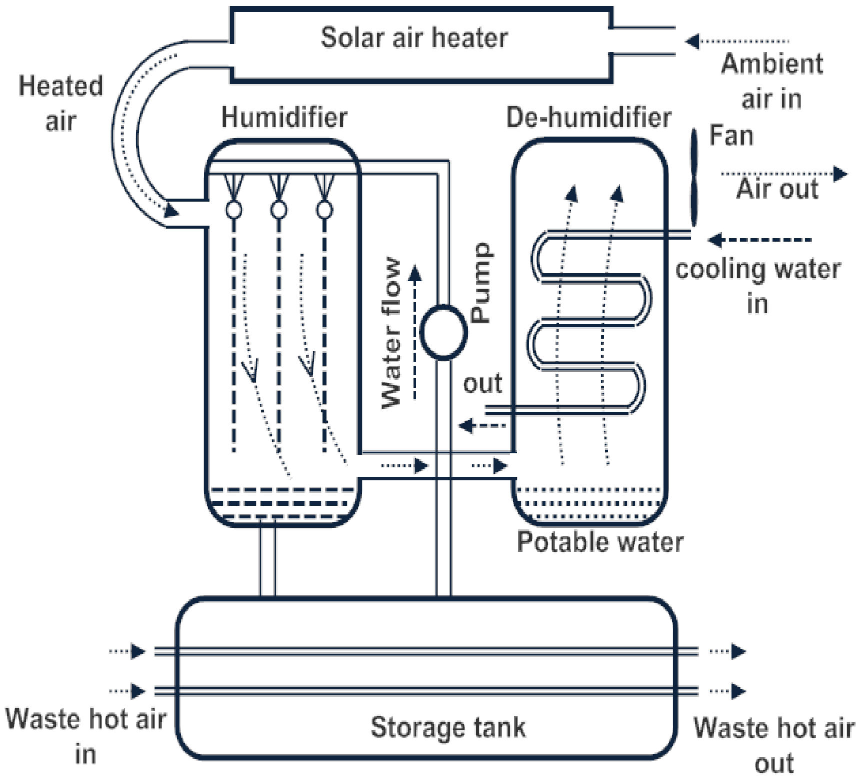

Fig. 1. Schematic arrangement of proposed system

Initially, the ambiance air is allowed to flow through the solar air heater to gain the temperature because of sun rays. The elevated air temperature leads to rise in moisture carrying capacity and thus quantity of potable water increases. After getting preheated, air passes via humidifier in which waste water is sprinkled over it to enrich the air with moisture. Moreover, the waste water is provided from the storage tank, that is designed in such way that, it permits the warm air from chimney without blending with water. Nevertheless, heat is transferred from warm air to water, this results to elevate the water temperature before entering in humidifier. Though, the moisture-laden air is now allowed to flow over the de-humidifier in which cold water pass by the bunch of pipes. Therefore, the moisture condenses into the pipes surface, thus, the cleaned water collected from the bottom of the de-humidifier. However, fan is attached at the exit of de-humidifier to ensure the appropriate flow of air over the designed system.

3. MATHEMATICAL MODELING

The efficiency of the designed system has been evaluated by applying the conservation theory of mass and energy. Therefore, temperature of air and water has been computed at all the vital conditions. Finally, potable water production has also been measured by mass balance in de-humidifier.

3.1 Energy Balance Equation for Humidifier

$$m_{air}.\left(h_{hum\_in} - h_{hum\_out}\right) = M_{w,in}C_wT_{w\_hin} - M_{w,out}C_wT_{w_{hout}} \qquad (1)$$

Here, air temperature at the entry of humidifier is equal to the outlet temperature of air from air heater. The outlet temperature from the air heater depends on the configuration, operating conditions and environmental conditions. In current work, single-pass flat plate air heater is suggested by [21] has been used for the calculations. The input parameters of air heater and hourly temperature variations are provided in Table 1 and Table 2 respectively.

Table 1: Input parameters for air heater

Parameter	Components	Value
Surface area	Absorber Plate	1m^2
Length	Collector	1.25 m
Tilt angle	Collector	30°
Thickness	Insulator	0.05 m
Thermal conductivity	Insulator	0.045 w/m-K
Emissivity	Glass cover	0.88
Emissivity	Bottom plate	0.9
Emissivity	Absorber Plate	0.9

The hourly variation in air temperature at the exit of air heater (or inlet of humidifier) by using the parameters in of Table 1 is given in Table 2.

Table 2: Air temperature at different time intervals (hourly basis)

Time duration	**Temperature(^{0}C)**
8-9	35
9-10	38
10-11	45
11-12	55
12-13	65
13-14	72
14-15	74
15-16	70
16-17	62
17-18	55

3.2 Energy Balance Equation for De-humidifier

$$M_{air}.\left(h_{deH\_in} - h_{deH\_out}\right) = M_{w3ter}C_w\left(T_{wat\_dout} - T_{wat\_din}\right) + M_cC_wT_c \qquad (2)$$

3.3 Equation for mass balance of water in Humidifier

$$M_{w,out} + M_{air}W_{out} = M_{w,in} + M_aW_{in} \qquad (3)$$

3.4 Equation for energy balance in Water Storage Tank

$$m_{ws}.C_w.T_{ws} = M_{ws,in}C_wT_{ws,,in} + M_{mw}C_wT_{mw} - M_{ws,out}C_wT_{ws} \qquad (4)$$

3.5 Equation for production of deionization system (M_{fw}), it is calculated by rate of condensed water vapor in dehumidifier

$$M_{fw} = M_{air}(W_{din} - W_{dout}) \quad (5)$$

3.6 To measure the performance of utilizing waste warm air of chimney in the present HDH deionization system, the GOR has been estimated given by:

$$GOR = \frac{M_{fw} \cdot h_{fg}}{Q_{in}} \quad (6)$$

Where,

M_{fw}= production rate of fresh water

h_{fg} = heat of vaporization at atmospheric condition

Q_{in}= rate of heat entry

4. RESULTS AND DISCUSSION

4.1 Effect of air heater

The proposed system has been analyzed, in Figure 2 shows the effect of mass flow rate of air on potable water production of HDH system. It has been depicted from Figure 2, as the mass flow rate of air rises from 0.5 kg/min to 1.9 kg/min then the productivity of the system also rises from 0.9 kg/day to 6.5 kg/day. However, slight decline in productivity has been observed as the mass flow rate of air increased after 1.9 kg/min. Further, this increase in production has been recorded till air flow rate of 1.9 kg/min, thereafter, observed that the production was decrease to 5.9 kg/day. Moreover, the declining nature of production with mass flow rate of air is because of less retaining time of air in air heater, therefore, it causes reduced exit temperature, thus resulted potable water production decreases.

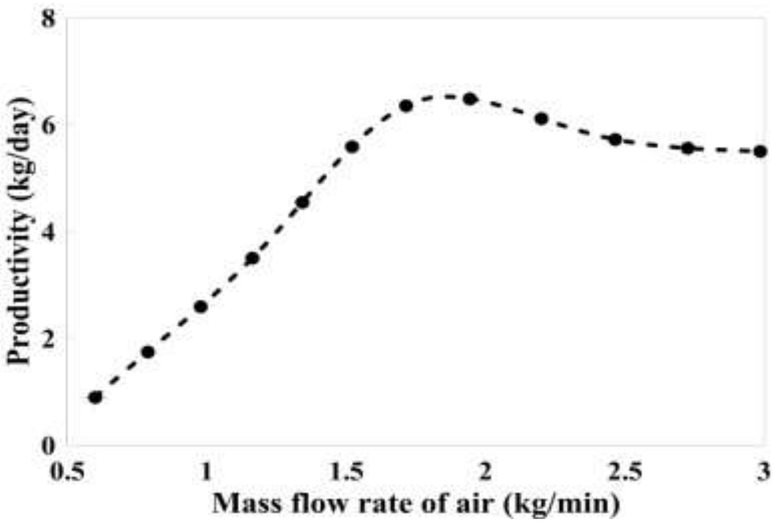

Fig. 2. Variation of mass flow rate of air in production

4.2 Effect of humidifier

The system has been analyzed, in Figure 3 reveals the effect of mass flow rate of water in humidifier. It is observed from Figure 3 that the increase in water mass flow rate established to be favorable as water production rises from 0.8 kg/day to 6.7 kg/day, while the water mass flow rate increased from 0.5 kg/min to 3 kg/min. Therefore, rise in mass flow rate of water provides the situation, that the air has soak higher quantity of moisture consequently yields higher water production.

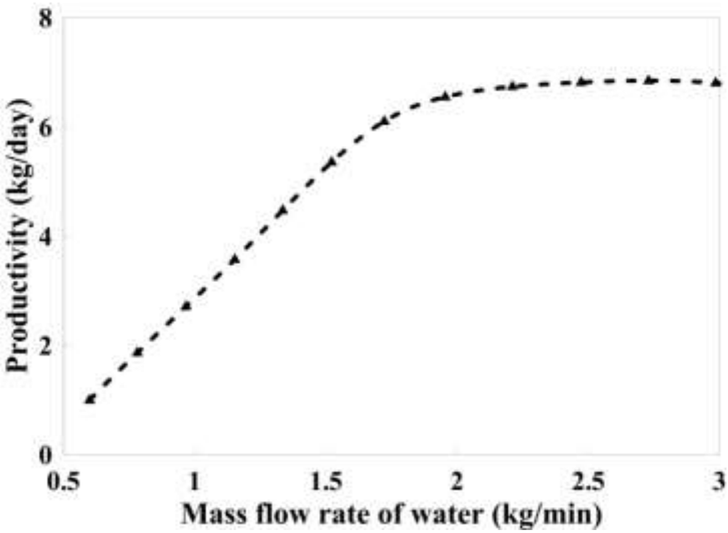

Fig. 3. Variation of water mass flow rate in humidifier in production

4.3. Effect of dehumidifier

Moreover, the system has been analyzed, in Figure 4 shows the effect of cooling water mass flow rate on drinkable water productivity. Further, rise in mass flow rate of cooling water has showed positive trends on production. It has also been observed from Figure 4 that the water production rises from 0.9 kg/day to7.5 kg/day, when cooling water mass flow rate rises from 0.5 kg/min to 3 kg/min. This rise in productivity is because of higher mass flow rate of cooling water leads to more precipitates of moisture as cleaned and drinkable water over the surface of pipe tube, thus, increases water production. Finally, the advantage of using waste heat from chimney has been recorded in terms of GOR. It has been represented in Figure 5, the GOR for proposed system with and without using waste heat for heating the water. It has been observed that the GOR of HDH system is 55% more due to the use of waste heat as compared to regular system.

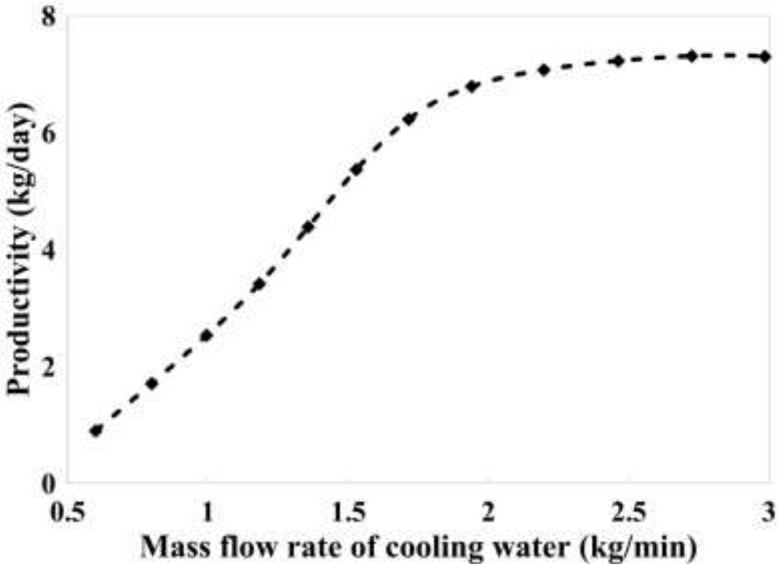

Fig. 4. Variation of mass flow rate of cooling water in production

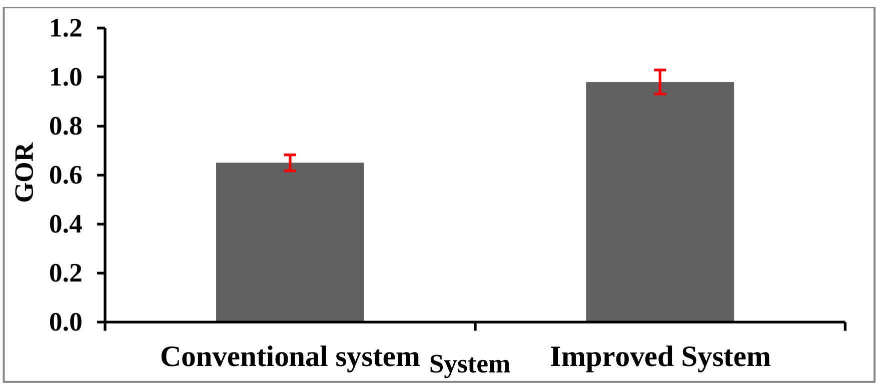

Fig. 5. Comparison of GOR

5. CONCLUSION

Innovative solar humidification dehumidification deionization system has been investigated for productivity variations by mass flow rate of air and water. The obtained results are proved the advantage of using waste heat for heating water and listed below

- The productivity established to rise by maximum water production of 6.3 kg/day, as the air mass flow rate rises from 0.6 kg/min to 3 kg/min.
- The rise in mass flow rate of water in humidifier observed to be favorable. As water production rises from 0.8 kg/day to 6.7 kg/day, the water mass flow rate rise from 0.5 kg/min to 3 kg/min.
- Potable water production increased as 0.9 kg/day to7.5 kg/day, when the cooling water mass flow rate rises from 0.5 kg/min to 3 kg/min
- Gain output ratio (GOR) has been obtained 55% more because of utilizing the dissipated heat as compared to conventional system

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