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Efficiency investigation of an enhanced air heater used in a Humidification–Dehumidification desalination system

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ABSTRACT

Background: Humidification dehumidification (HDH) desalination was proved to be economical for producing potable water. But there was a need to increase the productivity of the (HDH) desalination systems. **Objective:** This paper presents performance of the enhanced air heater in the (HDH) desalination system with the experimental and theoretical analysis. Experiments were conducted with the half perforated circular inserts arranged in series with different orientation angles (β=45º, 90°, 180º), pitch ratios (PR=1.5, 3) and different air mass flow rates (14 to 21 kg/h) in the air heater. **Results:** Maximum productivity of 850 ml/h in the HDH desalination system is obtained for an air heater's exergetic efficiency of 96% with baffle settings of 180 º orientation and pitch ratio of 1.5 with an air mass flow rate of 14 kg/h. **Conclusion:** Exergetic efficiency of the air heater progressively increases with the reduction in pitch ratio, increase in orientation angle between the plate and decrease in mass flow rate of air supplied to the unit.

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INTRODUCTION

Clean water is one of the most essential and integral part for the sustainable development of the community, but shortage of fresh water availability is the one of the biggest hindrances in the development of human race. Only around 1% of total available water is used to meet the needs of all living things in the planet, where the rest of the available water is distributed among saline streams in oceans and sea (97%) or polar ice caps (2%).

G. Tiwari, *et al*. (2003). pointed out that the thermal distillation and reverse osmosis are two major established technologies for producing clean water on the large scale and both these technologies are expensive, whereas (HD) desalination technology is an economically viable innovative process to meet the drinking water demands.

Several researchers worked on improving the performance of the HDH desalination system with different approaches and techniques. Dai and Zhang (2000) investigated the humidification-dehumidification desalination system and found that the performance of the system was strongly based on the mass flow rate of the process air, the temperature of the inlet salt water of the humidifier and the mass flow rate of the salt water. Al-Hallaja *et al*. (2006) has performed an extensive study of the mechanisms involved in humidification–dehumidification desalination processes and presented along with economical evaluation. Several mathematical models (2005,2003,2006) on this process were conducted for optimizing both the design and operational parameters. The productivity of the desalination systems can be improved by increasing the efficiency of individual components associated with it.

Suresh *et al*. (2011) experimentally studied the heat transfer and friction factor characteristics of Cuo/water nano fluid under turbulent flow in a helically dimpled tube.Akansu (2006) presented the numerical analysis on heat-transfer and pressure drop for an air heater containing porous rings with various pitch ratios (0.5, 1, and 2) and confirmed that increase in pitch ratio led to the decrease in heat transfer. Kangaitpaiboon *et al*. (2010) analysed the performance of circular ring turbulators with different pitch ratios and diameter ratios inserted in the air heater on a uniform heat flux and found that heat transfer coefficient for small pitch ratio enhanced up to 195% compared to that of plain tube. Muthusamy *et al*. (2013) observed that the enhancement of thermal performance of air heater integrated with internally finned conical cut-out turbulators with three pitch ratios (3,4,5) and two different modes (convergent and divergent). Maximum heat transfer rate is obtained for lower pitch ratio on the divergent mode. Huang *et al*. (2007) performed the local heat transfer measurement in a

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baffled channel by varying the number of perforations in the baffles. The heat transfer coefficient increased with increasing Reynolds number, baffle height and number of perforations.

Several works have been carried out for identifying the losses by using exergy analysis. Hou *et al*. (2008) conducted exergy analysis on a multi effect HDH system and derived that lowest exergetic efficiency is obtained for solar collectors, thereby concluded that large scope for improvement in HDH plant especially on heating surfaces. Gormi (2009) conducted the Exergy analyses for the desalination unit with flat plate collector (FPC) and absorption heat transformer (AHT) as main components. Exergy losses in the heat transfer surfaces have a direct effect on overall performance of the desalination unit. Heat transfer rate in these surfaces are enhanced with providing the inserts on the path of fluid flow causing turbulence.

Most of the paper deals about the effect of varying the operational parameters on the productivity of the HDH desalination system. Even though some of the works discussed about the effect of augmentation of heat transfer rate in air heater using different inserts, there is the lot of scope is available to study the effect of such increase in heat transfer rate on the overall productivity of the HDH desalination system. In this work, the effect of half perforated circular inserts equipped in the air heater of the HDH desalination system investigated using the exergy analysis. Performance analysis of HDH system is conducted for various mass flow rates of air (14 to 21 kg/h) in the air heater fitted with half perforated circular baffles with two pitch ratios (PR=1.5, 3) and three orientation angles (β=45º, 90°, 180º). Along with the overall performance analysis of the system, analysis on the exergetic efficiency of the air heater is also conducted.

Experimental Process:

The schematic diagram of the HDH desalination system is shown in Fig. 1. The parts of the system are air heater, water heater, humidifier and shell and tube heat exchanger (condenser).

The test section of air heater unit is made up of galvanized iron pipe with 33mm inner diameter and 500mm in length. The entire test section was completely insulated by asbestos rope to restrain heat losses. The air flow through the air heater unit is heated by a band heater of capacity 500 W, which is attached around the test section. Constant heat input is maintained by the heat flux controller. The air flow rate controlled by adjusting the valve V_1 fixed in the path of the air heater.

Half perforated circular baffles made up of aluminium sheet with a diameter of 33mm, are connected in series through rigid circular rod to form a linear chain. These assembled units of inserts are placed inside the test section to enhance heat transfer as shown in Fig. 2. In each circular insert, 15 small holes are drilled on one half of the plate in semi-circular pattern. For analysis, two pitch ratios (pitch to tube inlet diameter; PR = 1.5 and 3) and three baffle orientation angle (β=45º, 90° and 180º) are considered. The details of combinations of baffles used in the present study are represented in Table 1. The first three digits represent the baffle orientation angles in degrees and the next three digits represent its pitch distances in mm.

The humidifier chamber is made of a plastic cylinder of 152 mm in diameter and 800 mm in height. This humidifier chamber is provided with well oriented gunny bags as packing material in order to improve the contact period between the process air and the saline stream. Air heater is connected to the humidifier at the bottom to supply hot process air. The Saline water is supplied from a storage tank to the water heater. Water heater is made up of galvanized iron (GI) pipe of 13 mm in diameter and 500 mm in length of 1000 W capacity is connected at the top of the humidifier chamber.

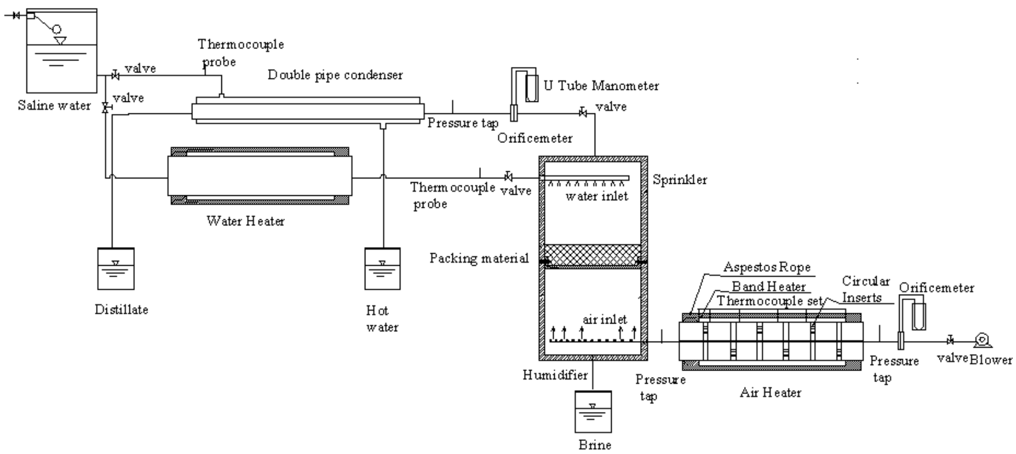

Fig. 1: Experimental setup

Table 1: Characteristics of baffle inserted tubes

Baffle types	Orientation angle (β) in degrees	Pitch distance (H) in mm	Pitch ratio (PR)
180050	180	50	1.5
180100	180	100	3
090050	90	50	1.5
090100	90	100	3
045050	45	50	1.5
045100	45	100	3

The output of the humidifier is connected to the double pipe condenser, with its condensation zone made of an aluminium pipe with 32 mm diameter and 1000 mm long. The moist air from the humidifier chamber is passed to the double pipe condenser. The cold saline water in the cold water tank flows in the outer tube channel of 63.5 mm diameter and 1000 mm length. This cold saline water in the outer pipe absorbs heat from the humid air flowing in inner pipe of the condenser. Counter flow is maintained between two fluids to achieve maximum rate of heat transfer.

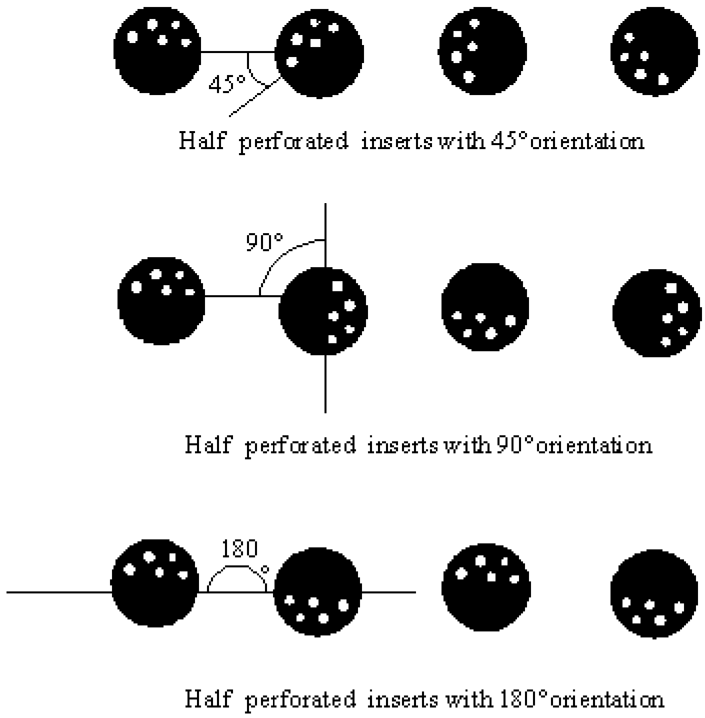

Fig. 2: Half perforated baffle inserts with various orientations

The process air is supplied by the blower at the ambient temperature to the air heater unit, where it gains heat and supplied to the humidifying unit. Constant heat flux was induced in the test section by the heat flux controller. The mass flow rate of air supplied from the blower is controlled and varied by the valve V_1

The hot water is sprinkled from the top of the humidifying chamber and hot air is supplied from the bottom of the humidifier. Humidifier works as a mixing chamber with heat and mass transfer takes place between hot air and water. The contact period between hot water and hot air increases by using the packing material, which in turn boosts the amount of humidity carried by the process air. This humid process air from the humidifier is send to the shell and tube condenser. Water from the storage tank is delivered at the room temperature to the condenser and it is passed in counter flow direction to the humid air in order to enhance heat transfer rate. As the result of condensation, distilled water is obtained at the outlet of the condenser.

Four thermocouples of k-type are inserted in the test section to measure the surface temperatures. Two more thermocouples are fixed at the entrance and exit sections of the pipe to measure the inlet and exit temperatures respectively. The temperatures along the pipe, temperatures at the inlet and the outlet of air were noted at a steady state. An orifice meter is used to measure air flow rates. Pressure taps are located at the upstream and downstream of the test section and connected to the manometer to monitor the pressure drop across it. The pressure drop across the test section was measured by the manometer for evaluating the friction factor.

The calculations (7).pointed out that the maximum uncertainties involved are $\pm$ 0.5% for Reynolds number, $\pm$ 1.4% for friction factor and $\pm$ 0.14% for Nusselt number. The experimental results are reproducible within these uncertainty ranges

Applying energy balance at the test section, the heat generated in the test section was found to be equal to the sum of the heat transferred to the air and the losses.

$$Q_{gen} = Q_{air} + \text{Losses} \tag{1}$$

The losses are due to convection and radiation from the test section to the surrounding. The air flowed through the circular tube with uniform heat flux conditions. At steady state, the heat absorbed by the air is assumed to be equal to the convective heat transferred from the test section. Considering negligible heat losses due to perfect insulation, for finding out the internal convective heat transfer coefficient, only the heat absorbed by the air is considered (7)

$$Q_{air} = Q_{con} \tag{2}$$

Heat absorbed by the air can be written as (7)

$$Q_{air} = m\, C_p (T_o - T_i) \tag{3}$$

Heat transferred to the air by the convection can be determined by(7),

$$Q_{con} = h\, A\, (T_w - T_b) \tag{4}$$

Using Eq.(2), the average heat transfer coefficient can be calculated and the fully developed Nusselt number is evoluated by using the relation (7),

$$Nu = \frac{hD}{\kappa} \tag{5}$$

The friction factor can be determined by

$$f = \frac{2D\Delta P}{\rho L V^2} \tag{6}$$

The Reynolds number is given by (7),

$$Re = \frac{\rho V D}{\mu} \tag{7}$$

All the thermo physical properties of the air are determined by the overall bulk mean temperature of air.

Mathematical formulations are used to calculate the exergy at inlet and outlet of the air heater Exergy at inlet

$$E_{X1} = (h_1 - h_o) - T_O (S_1 - S_O) + \left(\frac{V_1^2}{2}\right) \tag{8}$$

Further, difference in enthalpy and entropy at the inlet conditions are derived with the formulations shown in equations (4) and (5)

$$h = U + p\, v \tag{9}$$

$$U_1 - U_0 = C_v (T_1 - T_0) \tag{10}$$

$$(h_1 - h_o) = C_v (T_1 - T_O) + RP_O \left(\frac{T_1}{P_1} - \frac{T_O}{P_O}\right) \tag{11}$$

$$(S_1 - S_O) = C_{pa} \log_e \left(\frac{T_1}{T_2}\right) - R \log_e \left(\frac{P_1}{P_O}\right) \tag{12}$$

Similar mathematical formulae are derived for exergy at exit of air heater as shown in equation (8), Exergy at exit

$$E_{X2} = (h_2 - h_1) - T_O (S_2 - S_O) + \left(\frac{V_2^2}{2}\right) \tag{13}$$

Exergy efficiency of the air heater is obtained based on the amount of exergy retrieved from total energy supplied to the unit. Increase in exergy gained by the system with various combinations of inserts was studied and corresponding efficiencies evaluates the performance of air heater

$$\eta_{ex} = \frac{E_{X\ airheater}}{P_{input}} \tag{14}$$

$$E_{Xairheater} = m_a\left(E_{X1} - E_{X2}\right) \tag{15}$$

RESULTS AND DISCUSSIONS

The detailed performance analysis of the HDH desalination system is conducted by considering individual performance of each components. The effect of half perforated circular inserts on the exergetic efficiency of air heater and its effects on the overall improvement in the performance of the HDH system is discussed below. The experimentation on HDH desalination system is conducted by varying the mass flow rate of air flow in the heater between 14 kg/h and 21 kg/h, orientation angle of the inserts (β=45 º, 90 º, 180 º) and pitch ratio (PR= 1.5, 3).inserted in the air heater.

Effect of Performance of The Inserts In The Air Heater:

Fig. 3 shows the comparison of the Nusselt number for pitch ratios 1.5 and 3 for the Reynolds number ranges of 6700 to 9800. The Nusselt number quantifies the amount of heat transfer take place in the air heater unit It was found that the heat transfer coefficient of the air heater with the circular inserts increases with the increase in Reynolds number and the angle of orientation and decrease in pitch ratio.

As the pitch ratio decreases from 3 to 1.5 the friction factor and there by pressure drop increases which increase the contact time of air in the air heater. Higher orientation angle creates more turbulence effect on air resulting in the higher air inlet temperature. From the experimentation, the maximum heat transfer rate was shown for Reynolds number of 9800 with a pitch ratio of 1.5 and the orientation angle of 180^{o}. The maximum order of the enhancement of the circular inserts was found to be 9 times of the plain tube.

The variation of friction factor with the Reynolds number for the orientations of all the flow geometries for the PR=1.5 and 3 as shown in Fig 4. The friction factor decreases with the increase in Reynolds number. At the same Reynolds number, the friction factor in the tube fitted with circular inserts is higher than that of the smooth tube for all the flow geometries. The presence of inserts generates the flow disturbance leading to the increase of friction factor. The maximum friction factor is found in the 180º baffled circular inserts. In the observation, comparing the inserts with three orientations of 45º, 90°,180º, the higher flow disturbance is observed in the 180º orientation of baffled circular inserts.

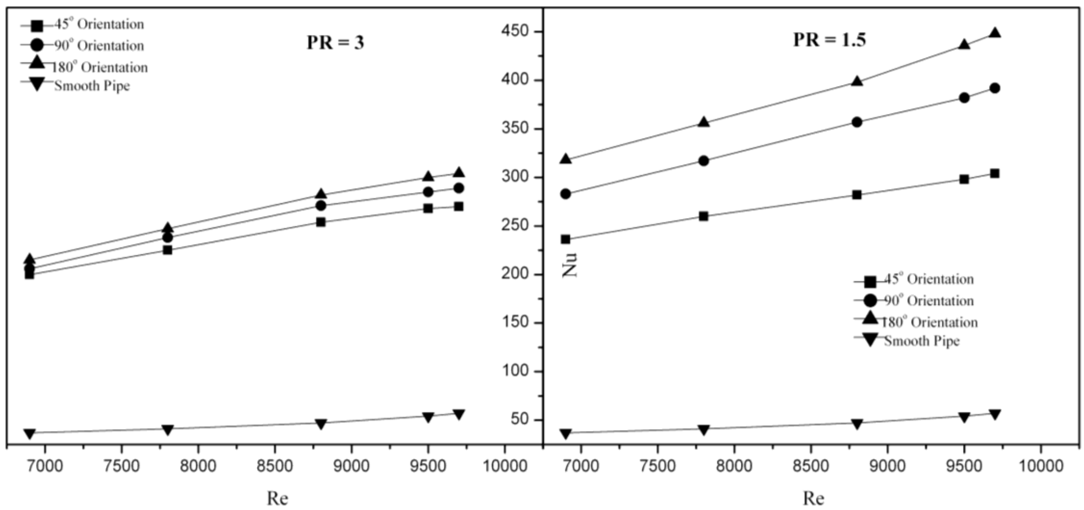

Fig. 3: Nusselt number with Reynolds number

The friction factor increases with decreasing pitch ratio. Due to the more number of circular inserts in the pitch ratio of 1.5 compared to the pitch ratio of 3, the flow field disturbs more and the pressure drop increased.

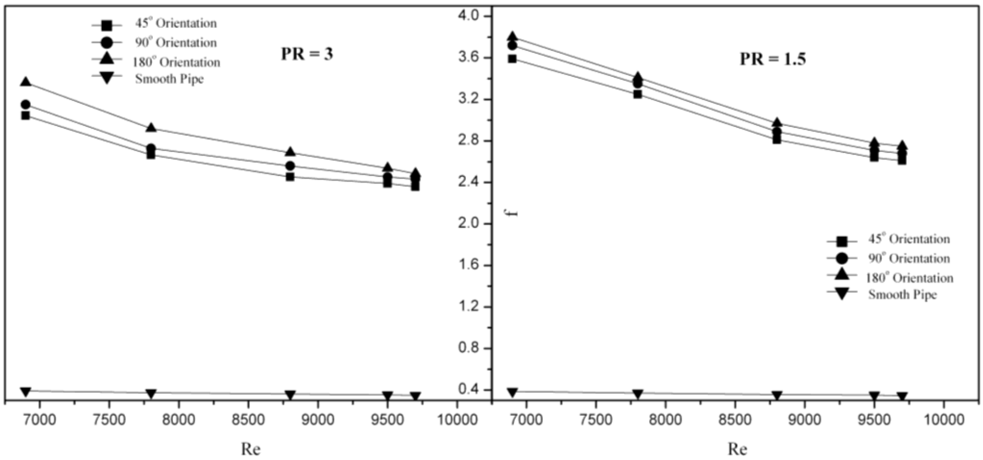

Fig. 4: Friction factor with Reynolds number

3.2 Exergy Analysis of An Enhanced Air Heater:

Exergy analysis is a process of evaluating the available energy of thermal systems based on the second law of thermodynamics and identifies losses takes places inside the air heater and it helps in evaluating the performance of air heater. This analysis is conducted with the experimental values recorded during the process after the system attaining steady state and its performance is determined in terms of exergetic efficiency, enhancement of heat transfer rate and efficiency. Exergetic efficiency of the air heater progressively increases with the changes in following factors: Reduction in pitch ratio between baffle plates, increase in orientation angle between the plate and decrease in mass flow rate of air supplied to the unit.

Highest exergetic efficiency of 96 % is obtained for a pitch ratio of 1.5, mass flow rate of 0.04 kg/s and the orientation angle (β) of 180º. Exergy analyses for various inserts are shown in Fig.7 whenever the mass flow rate increases, the exergy decreases and for the higher orientation of 180º more exergy takes place due to the complete flow disturbance it is happened. In all the cases exergy conversion with the inserts has more value compared to the plain tube.

Fig.8 shows that exergy power produced by using the inserts with the various orientations. . The smaller pitch ratio with larger orientation gives the higher exergy power. The larger pitch ratio with smaller orientation gives the lowest exergy power. Fig.5 shows the exergy efficiency for the various mass flow rates for the inserts with various orientation and different pitches. The exergy efficiency of the air heater increases with the increase of mass flow rate.

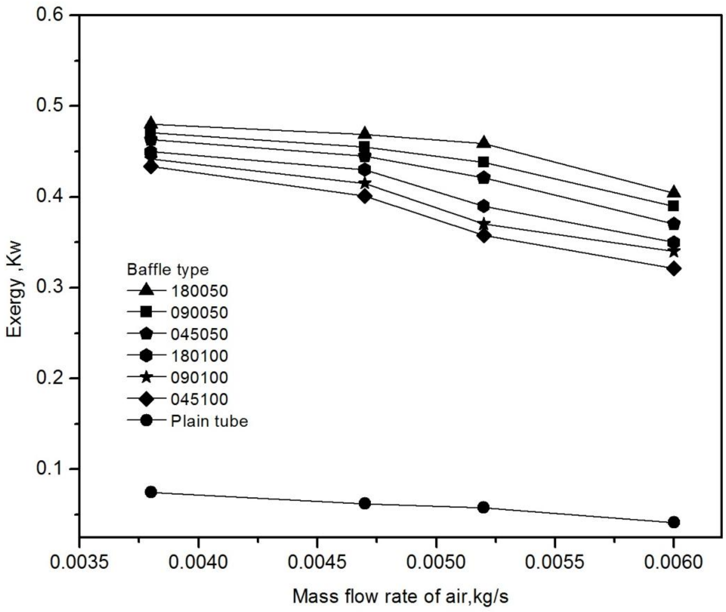

Fig. 5: Exergy analysis for baffles types with different mass flow rates

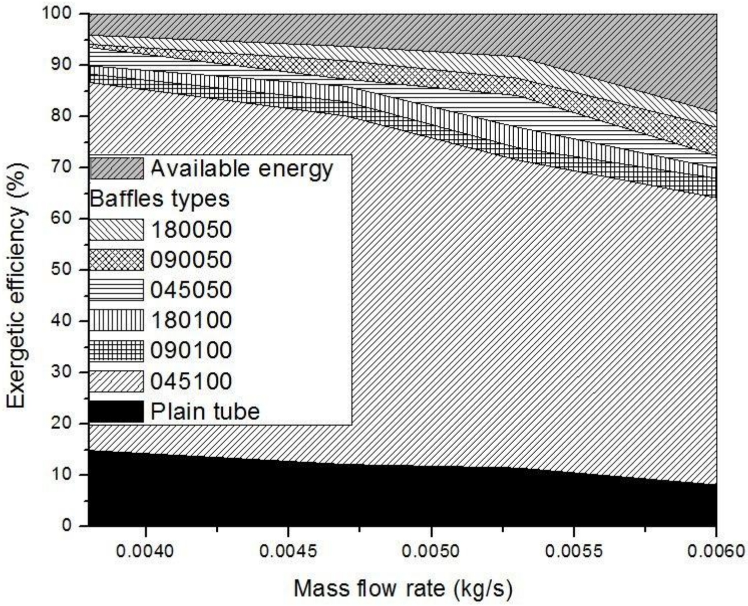

Fig. 6: variation of Exergetic efficiency

Overall performance analysis of HDH:

Fig.9 shows the overall performance of HDH desalination system in a three dimensional form, where both the effects of exergetic efficiency and mass flow rate of air heater on the productivity of HDH desalination are analyzed, it is evident that exergetic efficiency of air heater has a direct influence on the overall performance of HDH system.

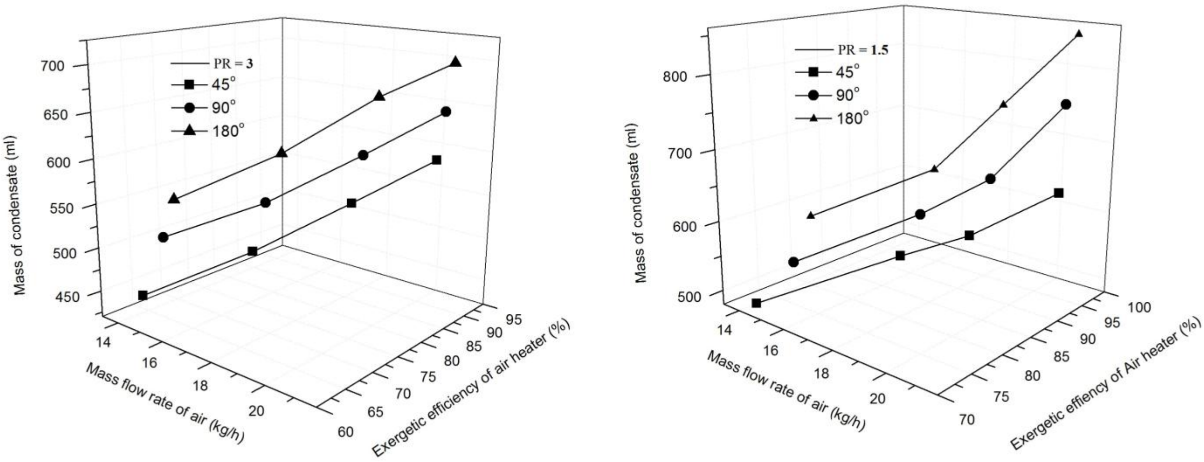

Fig. 7: Impact of Exergy efficiency of air heater on HDH desalination system

Conclusion:

An experimental analysis of HDH desalination system is conducted by varying the aof half circular perforated inserts (PR=1.5, 3) and (β=45º, 90º, 180º) inside the air heater. Performance of individual components are evaluated in the HDH desalination process based on their measuring parameter. Maximum performance of individual components are achieved at baffle settings of 180 º orientation and pitch ratio of 1.5 with an air mass flow rate of 14 kg/h

- Air heater's performance is evaluated based on exergy analysis. Exergetic efficiency of air heater analyzed for different alignment of baffles by varying the mass flow rate of air.. An exergetic efficiency raise of 82% is achieved in the air heater by fixing baffles in maximum performance condition.
- Amount of moisture added to the hot air during the humidifying process is evaluating the factor for the performance of humidifier. Moist air with a maximum relative humidity of 90% is achieved.
- Overall productivity of HDH system is based on the moisture content, temperature of process air entering the condenser and type of condensation area. A maximum productivity of 6.8 liters/ day is achieved by continuous supply of moist air with 90% relative humidity.

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REFERENCES

Tiwari, G., H. Singh, T. Rajesh, 2003. Present status of solar distillation, Sol. Energy, 75: 367-373.

Dai, Y.J., H.F. Zhang, 2000. Experimental investigation of a solar desalination unit with humidification and dehumidification, Desalination, 130: 169-175.

Said Al-Hallaja, Sandeep Parekha, M.M. Faridb, J.R Selmana, 2006. Solar desalination with humidification–dehumidification cycle: Review of economics, Desalination., 195: 169-186.

Hisham Ettouney, 2005. Design and analysis of humidification dehumidification desalination process, Desalination, 183: 341-352.

Mousa, K. Abu Arabi, Kandi Venkat Reddy, 2003. Performance evaluation of desalination processes based on the humidification/ dehumidification cycle with different carrier gases, Desalination, 156: 28 l-293.

Rihua Xiong, Shichang Wang, Zhi Wang, 2006. A mathematical model for a thermally coupled humidification– dehumidification desalination process, Desalination., 196: 177-187.

Suresh, S., M. Chandrasekar, S. Chandrasekar, 2011. Experimental studies on heat transfer and friction factor charecteristics of Cuo/water nano fluid under turbulent flow in a helically dimpled tube, Experimental Thermal and Fluid Science, 35: 542-549.

Selahaddin Orhan Akansu, 2006. Heat Transfer and Pressure drops for porous-ring turbulators in a circular pipe, Applied Energy, 83: 280-298.

Kongkaitpaiboon, V., K. Nanan, S. Eiamsa-ard, 2010. Experimental investigation of convective heat transfer and pressure loss in a round tube fitted with circular ring turbulators, Int. Commun. in Heat Mass Transfer, 37: 568-574.

Muthusamy, C., M. Vivar, I. Skryabin, K. Srithar, 2013. Effect of conical cut-out turbulators with internal fins in a circular tube on heat transfer and friction factor, Int. Commun. in Heat Mass Transfer., 44: 64-68.

David Huang, K., Sheng-Chung Tzeng, Tzer-Ming Jeng, Jee-Ray Wang, Sen-Yao Cheng, Kuo-Tung Tseng, 2008. Experimental study of fluid flow and heat transfer characteristics in the square channel with a perforation baffle, Int. Commun. in Heat Mass Transfer, 35: 1106-1112.

Shaobo Hou, Dongqi Zeng, Shengquan Ye, Hefei Zhang, 2007. Exergy analysis of the solar multi-effect humidification–dehumidification desalination process, Desalination, 203: 403-409.

Rabah Gomri, 2009. Energy and exergy analyses of seawater desalination system integrated in a solar heat transformer, Desalination., 249: 188-196.

Nomenclature:

E_x-exergy, kJ/kg
m- mass flow rate, kg/s
h- enthalpy, kJ/kg
T- temperature, K
S-entropy, kj/kgK
V-velocity, m/s
U-internal energy, kj/Kg
R-Gas constant
P-Pressure, N/m^2
S-power input, kw
Subscripts
0-ambient condition
1-inlet
2-exit
a-air