Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Vol II
IMECS 2009, March 18 - 20, 2009, Hong Kong

A New Process of Solar Desalination Based on Humidification-Dehumidification Cycle

Lixi Zhang, Guangping Cheng

***Abstract*— It is introduced a solar desalination process using air humidification and dehumidification. In order to increase the output of freshwater, multi-technologies are adopted, the double-pass solar air heater and tubular solar collector are used to heat the air and seawater respectively. The air is humidified by bubbling in the seawater pool, and dehumidified in the inorganic heat pipe condenser. Moreover, the heat transfer performance of the solar air heater with double vacuum glass-covers and double air passes is analyzed, and the theoretical model of its heat transfer and the calculating method are given.**

***Index Terms*— solar desalination, humidification, solar air heater, dehumidification.**

Ⅰ. INTRODUCTION

The process of humidification-dehumidification（HD）desalination has many advantages, such as the simple equipments, working under normal pressure, the cost of investment and operation is moderate, the flexible scale, the low-grade energy available, and so on. Therefore, it has a good developing prospect.

Many researches about the process and the equipments of HD desalination are carried out at present. Cemil Yamal1[1] et al. studied the effects on freshwater output under different conditions by experiment. It is obtained that the freshwater output can be increased 15% if solar air heater is used. In addition, the output also be enhanced with the rising of the seawater temperature in the water tank, with the rising of the spraying speed and the flow velocity of cooling water, but affected hardly by the changing of air speed. Y.J. Dai [2] researched the honey-comb paper material used as heat transfer element to humidify the air. It concluded that heat transfer area and thermal efficiency are increased by using the honey-comb material. S.A. EI-Agouz [3] studied by bubbling air in the seawater pool to humidified it, the humidifying effect is better than single-stage spraying humidification, and corresponding to a multi-stage one[4,5]. A.A.Mohamad[6] developed a high efficiency double-pass air heater, comparing with conventional double-covers single-pass collector, which adds an air pass between up and down glass cover forming a U-return flue line, and uses absorbing heat plate with filled porous medium in air pass to increase the heat transfer area. It decreases the heat loss from the front cover, and enhances the thermal efficiency which more than 75% under normal operating condition. If the U-return line is designed reasonably and high porous medium is used, the pressure drop in the two air passes will be not high. K.Sopian [7] studied the thermal efficiency of the double-pass solar air heater with or without porous medium in the lower channel, and given the theoretical model of the air heater. The results show if the porous medium is filled in the lower air pass, the outlet temperature of airflow through the porous media and the thermal efficiency of collector are increased, but the pressure drop is higher at the same time.

In order to use solar energy fully to produce freshwater, the authors combine the above and selves' researches and design a new desalination process. In the process, there is a solar air heater with double glass covers and double-pass to improve heating efficiency and reduce the heat loss from the cover; there is a tubular solar collector to heat seawater, in avoid to the temperature and the saturation moisture content of air reducing when it contacts with the seawater. In addition, the simple humidification structure by air bubbling is used to increase the air moisture content and avoid the possibility of water pollution by using honeycomb paper. For dehumidifying the air fully and recovering a part of condensing latent heat of the vapor, the high efficiency inorganic heat pipe condenser which is researched by our project team is used.

Manuscript received December 30, 2008. This work was supported by the Chinese foundation committee of nature and science, under the project No.50576078; and was supported by natural science fundamental research project of shaanxi province, under the project No:2007E$_2$27

L.X. Zhang: PhD student, Institute of Air-condition & Solar Energy, School of Engine and Energy, Northwestern Polytechnical University, Xi'an, ShaanXi, 710072, China (Tel:86-029-88492440; Fax: 86-029-8849-5911; E-mail: zhanglixi@nwpu.edu.cn)

G.P. Cheng: Master's degree student, Institute of Air-condition & Solar Energy, School of Engine and Energy, Northwestern Polytechnical University. Xi'an, ShaanXi, 710072, China (Tel: 86-029-88492440; Fax: 86-029-88495911; E-mail:chengguangping@mail.nwpu.edu.cn)

Ⅱ. PROCESS FLOW

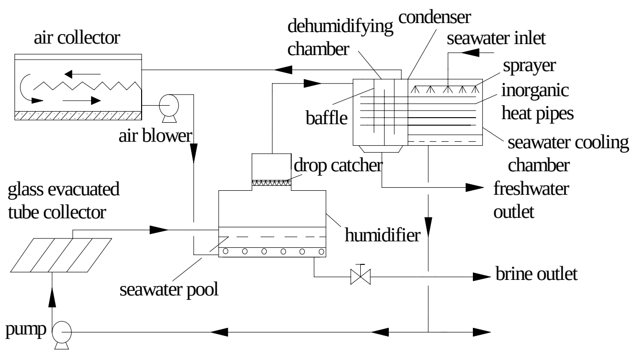

Fig.1 The process flow scheme of solar desalination

The process flow of solar desalination is shown in Fig.1. It mainly includes the solar air heater, tubular solar collector, air bubbling humidifier, inorganic heat pipe condenser, seawater pump, air blower and so on. There are two cycles in it, one of them is the seawater cycle, another is the air cycle. The condenser is separated into two parts by a

ISBN: 978-988-17012-7-5

division plate, one of them is seawater cooling chamber, another is air dehumidifying chamber. Inorganic pipes are placed near horizon with 4° gradient in the condenser. When the process unit is operated, the seawater flows into the condenser, sprays from up to down, and absorbs the heat coming from the dehumidifying chamber on the outside of the pipes.

The seawater which is discharged from the seawater cooling chamber is divided into two parts: the lesser part enters the tubular solar collector by pumping, then be heated to a certain temperature and sent to seawater pool to make up the evaporated seawater, and keep the level of seawater in the relative stability; the major part is discharged from the unit. Moreover, the air cycle is adopted the closed cycle. Firstly, the air flows into the solar air heater and be heated, then it enters into the air tubes, which have many small holes and be sited on the bottom of the seawater pool, by the air blower. Air from the holes contacts with seawater fully by bubbling, and be humidified to saturation state. Then the humidified air rises to the top of humidifier and passes the drop catcher, then gets into the air dehumidifying chamber of the condenser, where the water vapor in air be condensed into freshwater. Finally, the dry air flows into the solar air heater to recycle again, while the condensing freshwater is taken out of the air dehumidifying chamber.

Ⅲ. HEAT TRANSFER MODEL OF SOLAR AIR HEATER

A. The structure and heat transfer performance analysis of collector

The flat plate collector has a simple structure, absorbs the scattered radiation and direct radiation of the sun at the same time. However, the heat loss which comes from the cover is considerable. In order to reduce the heat loss and increase the area of heat-absorbing plate, a collector with evacuated double-glass cover, a double-pass and V-groove absorber with selectivity absorbing coat is designed. The structure is shown in Fig.2.

The sunshine goes through the evacuated double-glass cover, shining on the heat-absorbing plate (p), so the plate is heated. The air flows into the air heater through the top channel of p, and makes a convection heat transfer between p and the lower layer of glass cover (g2), then it flows into the lower channel of P, also makes a convection heat transfer further between P and insulation bottom board (b). Meanwhile, P is making a radiation heat transfer with g2 and b respectively. The state between g2 and top layer of glass cover (g1) is in vacuum, which only has radiation heat transfer. The heat dissipates into the environment by the convection and radiation heat transfer. The coefficient of total heat loss is U_t. It is the same that the convection and radiation heat transfer exists between (b) and (a), the coefficient of total heat loss is U_b.

The heat transfer network of the air heater is shown in Fig.3. The physical meanings of the following symbols are: T—temperature, K; h—coefficient of heat transfer, W/(m^2.K); U—coefficient of heat loss, W/(m^2.K); S—the actual absorbing radiation energy, W/m^2. The meanings of subscript: g1, g2—the top layer, lower layer of the glass

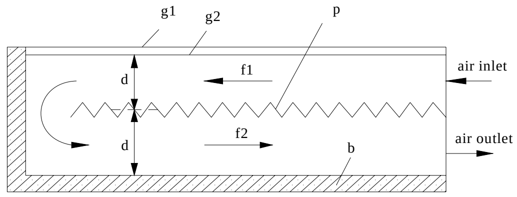

Fig.2 The structure of the air heater

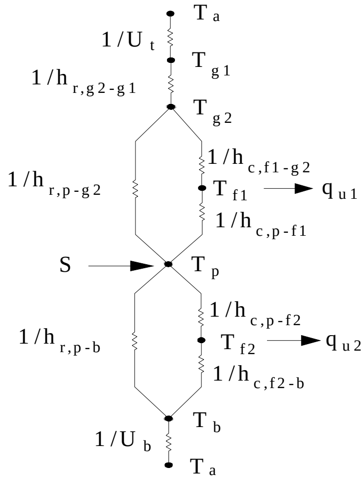

Fig.3 The heat transfer network of the air heater

cover; p—heat-absorbing plate; b—insulation bottom board; a—air; f1,f2—the air flows in the top channel and lower channel; c—convection heat transfer; r—radiation heat transfer; t—total radiation and convection heat transfer.

For every node of the heat transfer network in the above figure, the energy balance equations can be listed under steady working state as following.

The top layer of glass cover (g1):

$$U_t(T_a-T_{g1})+h_{r,g2-g1}(T_{g2}-T_{g1})=0 \qquad (1)$$

The lower layer of glass cover (g2) :

$$h_{c,f1-g2}(T_{f1}-T_{g2})+h_{r,p-g2}(T_p-T_{g2})+h_{r,g2-g1}(T_{g1}-T_{g2})=0 \qquad (2)$$

The heat-absorbing plate (*p*):

$$S+h_{c,p-f1}(T_{f1}-T_p)+h_{c,p-f2}(T_{f2}-T_p)+h_{r,p-g2}(T_{g2}-T_p)+h_{r,p-b}(T_b-T_p)=0 \qquad (3)$$

Insulation bottom board (*b*):

$$h_{r,p-b}(T_p-T_b)+h_{c,f2-b}(T_{f2}-T_b)+U_b(T_a-T_b)=0 \qquad (4)$$

The heat transfer capacity between heat-absorbing plate and the air of the top channel q_{u1}:

$$q_{u1}=h_{c,p-f1}(T_p-T_{f1})+h_{c,f1-g2}(T_{g2}-T_{f1}) \qquad (5)$$

The heat transfer capacity between heat-absorbing plate and the air of the lower channel q_{u2}:

$$q_{u2}=h_{c,p-f2}(T_p-T_{f2})+h_{c,f2-b}(T_b-T_{f2}) \qquad (6)$$

Based on equation (5) and (6), the heat transfer capacity between the air and heat-absorbing plate can be calculated by the following formula qu (W/m2) :

$$q_u=h_{c,p-f1}(T_p-T_{f1})+h_{c,f1-g2}(T_{g2}-T_{f1})+h_{c,p-f2}(T_p-T_{f2})+h_{c,f2-b}(T_b-T_{f2}) \qquad (7)$$

The coefficient of convection heat transfer can be calculated by relevant formula.

The coefficient of radiation heat transfer can be calculated by the following formula:

$$h_r=\frac{\sigma(T_1+T_2)(T_1^2+T_2^2)}{\frac{1}{\varepsilon_1}+\frac{A_1}{A_2}(\frac{1}{\varepsilon_2}-1)} \qquad (8)$$

Where T_1, T_2, ε_1, ε_2, A_1, A_2 are the temperatures, emissivities, areas of object 1 and object 2 respectively.

B. The calculation of temperature for each node

Aimed to compute the temperatures (T_{g1}, T_{g2}, T_p, T_b) of the air heater's top and lower layer of the glass cover, heat-absorbing plate and the bottom board, on the assumption that the average temperature of air in the collector is T_f, and $T_f = T_{f1} = T_{f2} = \frac{T_{f,in} + T_{f,out}}{2}$, where $T_{f,in}$, $T_{f,out}$ are the air temperature of inlet and outlet of air heater.

According to the process's designing, $T_{f,in}$, $T_{f,out}$, T_a are the known parameters, so T_f can be treated as known number. Arranging (1)~(4), those can be transformed into the following quaternion linear equations:

$$\begin{bmatrix} a_{11} & a_{12} & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{bmatrix} \quad (9)$$

In above equation:

$a_{11}=U_t+h_{r,g2-g1}$, $a_{12}=-h_{r,g2-g1}$, $a_{13}=0$, $a_{14}=0$;
$a_{21}=h_{r,g2-g1}$, $a_{22}=h_{r,p-g2}-h_{r,g2-g1}-h_{c,f1-g2}$, $a_{23}=h_{r,p-g2}$, $a_{24}=0$;
$a_{31}=0$, $a_{32}=-h_{r,p-g2}$, $a_{33}=h_{c,p-f1}+h_{c,p-f2},+h_{r,p-g2}+h_{r,p-b}$, $a_{34}=-h_{r,p-b}$;
$a_{41}=0$, $a_{42}=0$, $a_{43}=h_{r,p-b}$, $a_{44}=-h_{r,p-b}+h_{c,f2-b}+U_b$;
$d_1=U_tT_a$, $d_2=-h_{c,f1-g2}T_f$, $d_3=S+(h_{c,p-f1}+h_{c,p-f2})T_f$,
$d_4=-U_bT_a-h_{c,f2-b}T_f$;
$T_1=T_{g1}$, $T_2=T_{g2}$, $T_3=T_p$, $T_4=T_b$

The coefficient matrix of equation (9) is a special tridiagonal matrix, where the majority coefficients are the function of the unknown parameters. It is difficult to solve them when using the chasing method directly, so using the Gauss-Seidel iterative method. The program flowchart is shown in Fig.4.

After solving the temperatures, the value of q_u can be calculated.

The momentary efficiency factor η_i can be calculated by the following formula:

$$\eta_i = \frac{Q_u}{A_c G_T} = \frac{A_v q_u}{A_c G_T} \quad (10)$$

Where Q_u is the effective utilization energy of air heater, W; A_c is the area of air heater, m^2; A_v is the area of V-groove heat-absorbing plate, m^2; G_T is the solar radiation density, W/m^2.

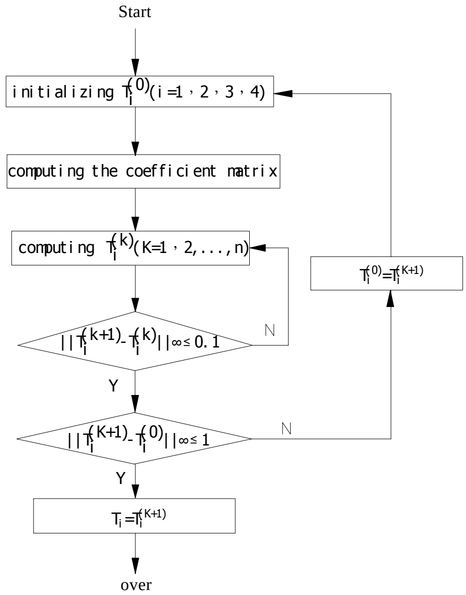

Fig.4 The program flowchart

IV CONCLUSION

In this paper, a new process of solar desalination using humidify and dehumidify cycle is advanced. Meanwhile, the heat transfer performance of the solar air heater with double vacuum glass-covers and double air passes is analyzed, and the theoretical model of its heat transfer and the calculating method are given. It can be used to the analysis of heat transfer performance, and designing of this kind collector.

REFERENCES

[1] C.Yamal1, I.Solmus, "A solar desalination system using Humidification-dehumidification process: experimental study and comparison with the theoretical results," *Desalination*, vol.220, 2008, pp. 538-551.
[2] Y.J.Dai,H.F.Zhang,"Experimental investigation of a solar desalination unit with humidification and dehumidification," *Desalination,* vol.130, 2000, pp. 169-175.
[3] S.A.El-Agouz,M.Abugderah,"Experimental analysis of humidification process by air passing through seawater," *Energy Conversion and Management*, vol.49,2008, pp. 3698-3703.
[4] Chafik E, "A new seawater desalination process using solar energy," *Desalination*, 2002, pp. 153:25–37.
[5] Chafik E, "A new type of seawater desalination plants using solar energy," *Desalination*, 2003, pp. 156:333–48.
[6] K.Sopian,M.A.Alghoul, "Evaluation of thermal efficiency of double-pass solar collector with porous-nonporous media," *Renewable Energy*, vol.34, 2009, pp. 640-645.
[7] J.Orfi, M.Laplante, et.al, "Experimental and theoretical study of a humidification-dehumidification water desalination system using solar energy," *Desalination*, vol.168, 2004, pp.151-159.