

Performance of A Fresh Water Generator Applied Plate Heat Exchangers and Flow in the Channel

판형열교환기를 적용한 청수제조장치의 성능 및 채널내 유동

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Key Words : 청수제조기(Fresh Water Generator), 판형열교환기(Plate Heat Exchanger), 압력강하(Pressure Drop), 세브론각(Chevron Angle)

Abstract : 본 연구에서는 판형열교환기를 적용한 청수제조장치의 성능에 대하여 연구를 수행하였다. 판형열교환기는 자체의 높은 열전달 성능과 컴팩트한 장점으로 하여 산업에서 점차 널리 사용되고 있다. 또한 사용, 유지보수가 다른 종류의 열교환기에 비하여 편리하여 유연성 있게 사용할 수 있다. 본 실험에서는 세브론 각도가 60도인 전열판을 사용하였으며 이젝터의 작동으로 열교환기를 장착하고 있는 탱크내부에 진공압력을 유지함으로써 내부유체가 51℃~57℃에서 증발현상이 발생하는 것을 확인하였다. 또한 수치해석적 방법을 통하여 복잡하며 좁은 세브론 전열판으로 이루어진 유로내의 유동특성을 파악할 수 있었다.

Nomenclature

b mean channel gap [m]
 De equivalent diameter [m]
 Dp port diameter [m]
 f friction factor
 G mass velocity[kg/m²·s]
 h heat transfer coefficient [W/m²·℃]
 k thermal conductivity [W/m²·℃]
 n number of channel
 Re Reynolds number

Superscript

β chevron angle
 μ viscosity

Subscript

c channel

1. Introduction

In desalination system it is no doubt heat exchanger is extremely important as a key point. The importance of heat exchanger has increased immensely from the view point of energy conservation, conversion, recovery and successful implementation of new energy sources¹⁾.

Nowadays Plate Heat Exchanger (PHE) widely used in different industries such as chemical, food and pharmaceutical process and refrigeration. The heat transfer occurred between adjacent channels through plates. Alternate plates are assembled such that the corrugations on successive plates contact and cross each other to provide mechanical support to the plate pack through a large number of contact points. This resulting flow passages are go through a narrow, highly interrupted and tortuous so that will enhance the heat transfer flow and increasing the level of turbulence. At the same time, pressure drop will be accompanied inevitably. True flexibility is unique to the plate heat exchanger both in initial design and after installation. In the initial design

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the basic size, geometry, total number and arrangement of standard plates can easily be selected to precisely fit the specific duty. An existing plate heat exchanger can very easily be extended or modified to suit an increased or changed duty. Moreover, it is very compact and low in weight in spite of their compactness^{2~5)}.

Plate patterns have great influence on both of thermal and hydraulic performance, the final design is certainly depends on the initial choice of plate pattern. Although many types have been used in the past, the chevron type plate has proved to be the most successful model during last decades. A comprehensive step of design method was presented by Shah and Focke⁶⁾. The commonly used chevron angle varies between 30° to 60°. This been verified by many researchers according to experimental results and simulations already. An analytical study has been made by Martin⁷⁾ to predict the performance of chevron type plate heat exchanger.

The main objective of this paper is discussing plate heat exchanger applied in vacuum evaporator for produce fresh water. Simulation conducted flow distribution in a PHE channels and used k- ϵ standard turbulence model.

2. Experimental apparatus and procedure

2.1 Experimental setup

The concept of a fresh water generator is simple the sea water is evaporated using a waste heat source, separating pure water from salt, sediment and other elements. Fresh water generators usually attempt to use existing heat to run it in order to reduce cost of operation. There are two main elements in a fresh water generator, one heat exchanger evaporates the sea water and another one condenses the fresh water vapour into liquid phase for usage. In the condenser element, the vapour is condensed by cold seawater. We built schematic diagram of fresh water generator experimental device as Fig.1.

2.2 Experimental procedure

The heat transfer part contains corrugated plates with 60degree of chevron angle which verified by many researchers and commonly apply. Moreover the plate package arranged with U type configuration. The air inside the evaporation chamber is evacuated to a near vacuum, hence the saturation point of water becomes lower much more. It then becomes possible to evaporate the seawater at a temperature around 60°C. The engine jacket cooling water is sufficiently hot to evaporate the water and it is commonly used. In present system saturation temperature located in the range of 5 1°C ~57°C. The system may divide to main circuits. One is cold water circuit that cold fluid is supplied to the heat exchanger where it receives heat from the hot fluid across the plates. Finally the cold water delivered to cooling tower where temperature cool down and maintain at the inlet condition of heat exchanger. This experiment used city water. Since it assumed that the water temperature is constant. In the other hand, the hot fluid is flowing to the plate heat exchanger and fed back to hot water tank where is keep at a constant temperature using boiler.

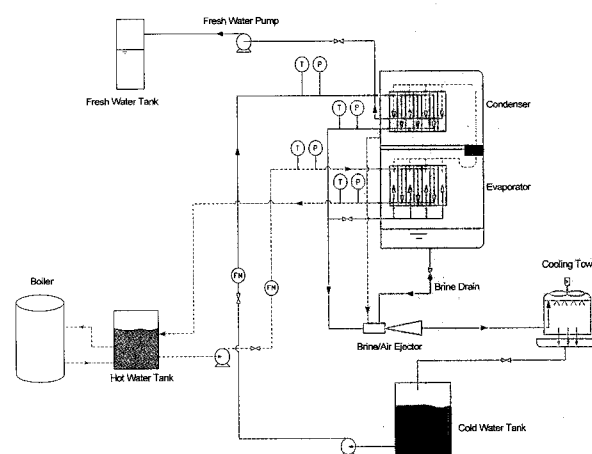


Fig. 1 Schematic diagram of the facility of fresh water generator system

The procedure of experiment is, firstly operate cold fluid circuit to obtain near vacuum condition in the tank which contains the heat exchanger.

Further step is operating hot water circuit to supply hot water to heat transfer with the cold fluid between alternate plate channels of heat exchanger. It should be noticed that there is bypass line connected from outlet of cooling water provided to evaporator. The pre heated cooling water is supplied to absorb heat from hot water so that can be evaporating much more quickly and use the heat energy sufficiently. The temperature and pressure at inlet and outlet of fluids are recorded respectively till the steady state is reached. Same procedure has been repeated with different flow rate and supply temperature of hot fluid.

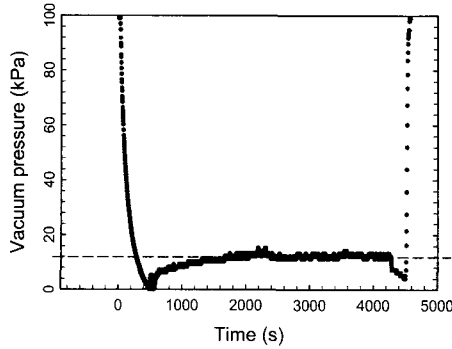


Fig. 2 Variation of vacuum pressure in the vessel

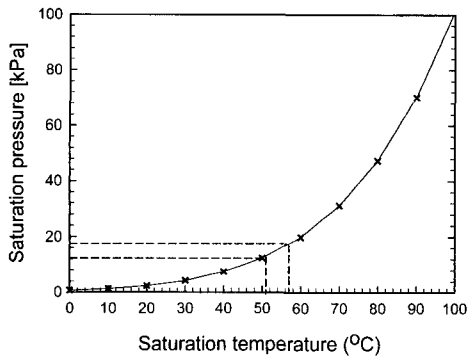


Fig. 3 Saturation temperature and pressure

As mentioned above the vessel contains two units of exchanger are maintained with vacuum condition while the system is operating. The pressure variation in the inside of vessel is show in Fig.2. This is one of experimental results with the system operate ejector and then entrain the inside air so the pressure decrease rapidly within 10 minutes. At this condition flowing hot stream

and cold stream start to exchange heat. We can see inside pressure increase gradually since vapour is occurred. However through some period it maintains the steady state along 12 kPa vacuum pressure relatively. It showed sharp increasing at end of pressure profile this because stoped ejector and it recovered to atmosphere condition. In this way one circle of experiment is completed.

Table 1 Geometry and analysis conditions

Parameter	Value
Plate length	405 mm
Plate width	105 mm
Equivalent diameter($De=2b$)	7.0 mm
Port size	25 mm
Corrugation angle	60 deg
Volumetric flow rate	3.0 m ³ /h, 3.5 m ³ /h
Temperature of hot stream	60°C, 65°C, 70°C

3. Results and discussion

According to above mentioned concept and procedure, the experiments conducted at the range of 60°C, 65°C and 70°C for the setting temperature at hot fluid respectively. Meanwhile the flow rate of fluid is set at 3.0 m³/h and 3.5 m³/h.

First look at pressure drop that it is calculated as approximately 1.5times the inlet velocity head per pass. Since the entrance an exit losses in the core cannot be determined by experimentally, they are included in the friction for the given plate geometry. Although the momentum effect is negligibly small for liquids, it is also included in the following expression. The pressure drop or rise caused by elevation of change for liquids. Summing all contributions, the pressure drop on one fluid side in a plate heat exchanger is given by

$$\Delta P = \frac{1.5G_p^2 n_p}{2g_c \rho_i} + \frac{4fLG^2}{2g_c D_e} \left(\frac{1}{\rho} \right)_m + \left(\frac{1}{\rho_0} - \frac{1}{\rho_i} \right) \frac{G^2}{g_c} \pm \frac{\rho_m gL}{g_c}$$

$$f = 0.8 \text{Re}^{-0.25}, \quad \text{Re} = \frac{GD_e}{\mu},$$

$$G_p = m/(\pi/4)D_p^2$$

where G_p is the fluid mass velocity at the port and n_p is the number of passes in the given fluid side, D_e is the equivalent diameter of flow passages namely twice of pressing depth(b), ρ_o and ρ_i are fluid mass densities evaluated at local bulk temperature and mean pressure at outlet and inlet, respectively. The Reynolds number is based on hydraulic diameter of the corrugated channel which is equivalent to twice of pressing depth of the plate.

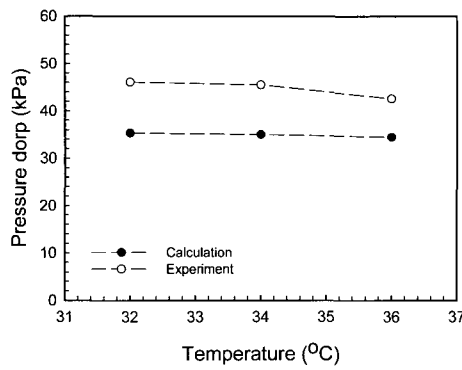


Fig. 4 Pressure drop by experiment and calculation

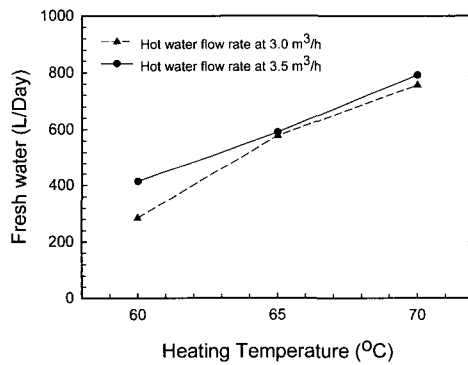


Fig. 5 Fresh water generation with temperature and different flow rate

As the Reynolds number increases the heat transfer coefficient also increases, but friction factor decreases. Fig.4 shows comparison of pressure drop between experimental and theoretical results based on the above equations. It is observed that there is difference between experimental results and calculation method which according to equation suggested by R. K. Shah⁸⁾. The calculation results ignored the third term of right side of the equation since it is difficult to

measure exact the density at each point. Additionally, in experiment friction loss through pipeline is the inevitable. Thus this may result into the gap compare to experimental results.

Fig.5 presents the fresh water generation at each supply temperature of hot water and flow rate. The line depicts the effect of flow rate and supply temperature of hot water on the fresh produce. It is showed that compare two lines it clear that fresh water generation rate is increasing proportionately by increase of hot water supply temperature. According to different flow rate that affect to the fresh water quantity shows less at 65°C and 70°C. However, the difference of fresh water quantity is become large at 60°C of hot water temperature case. The reason for the difference might be due to when the hot water temperature is lower, the cold water outlet temperature will be lower too so that for evaporating the temperature gap is large than other case at high temperature, similarly there need much more amount of heat and time to accumulate then it can be evaporated. Since the supply temperature is lower relatively. Hence, resulted into evaporating was not happened sporadically with this condition.

4. Numerical analysis

A large number of optimization techniques are available from literature and quite a lot of commercial optimization software. CFD can provide another method approach to modeling and investigate performances. Moreover, there are a number of papers trying to approach other way namely numerical simulation like described in the articles^{9~10)}.

The numerical simulation solved the flowing continuity equation, momentum equation and energy equations use commercial software Fluent 6.3.26. In this paper, a CFD model taken to simulate flow distribution in the corrugated plate channel. The dimension of plate model in length of 405mm and width of 105mm, equivalent

diameter is 7mm and the port diameter is 25mm as show in Fig6. The chevron angle same as 60degree. The fluid domains were modelled with properties of water. The simulation was solved use k- ϵ turbulence model.

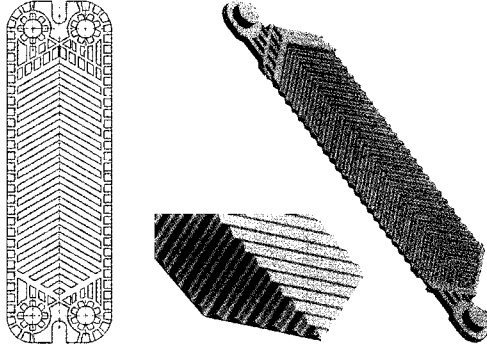


Fig. 6 Corrugate plate model

For the grid construction used Gambit 4.1 and final number of cell elements was 548,047. Simulation for the flow behavior in the test region was carried out with flow rate from 0.0879 kg/s to 0.0754 kg/s that same condition with experiment according to a single channel.

The simulation was solved use k- ϵ turbulence model. The numerical simulation solved the flowing continuity equation, momentum equation and energy equations.

The continuity equation:

$$\frac{\partial(\rho u_j)}{\partial x_j} = 0$$

The momentum equation:

$$\frac{\partial}{\partial x_i}(\rho U_i U_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_h} - \frac{\partial}{\partial x_j}(\rho u_i u_j)$$

The energy equation:

$$\frac{\partial}{\partial x_i}(\rho U_i \theta) = -\frac{\partial J_i}{\partial x_i}(\rho u_i \theta)$$

From Fig.7 and Fig.8 we can find more detailed variation of velocity and pressure along y direction cross port and plate channel. The y axis distance means location from bottom of channel. This data represent the cross port section along y direction. The solid line depict value with 3.5 m³/h flow rate and the dotted line show the

results with 3.0 m³/h. As presented in the Fig.8, it can be divide in to three section. In the middle zone where across corrugated channel located, velocity of stream appears periodical variations due to the narrow, highly interrupted and tortuous channel flow. Therefore will enhance the heat transfer flow and increasing the level of turbulence. At the same time, pressure drop will be accompanied inevitably.

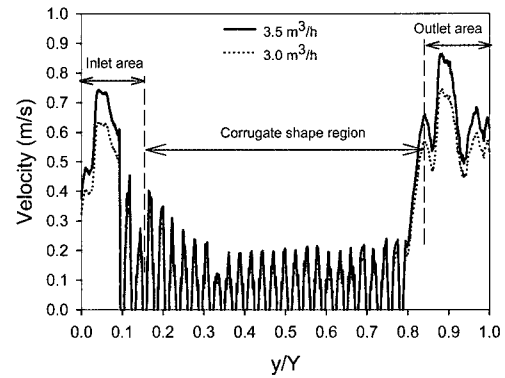


Fig. 7 Velocity variations in the corrugation channel

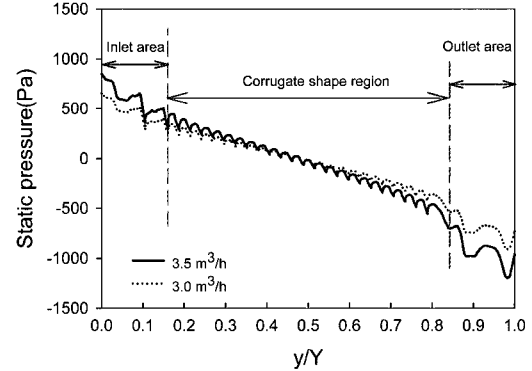


Fig. 8 Pressure variations in the corrugation channel

Similarly, the periodic pressure variation pattern can be observed as show in Fig.9. However, in the Fig.8 there are two pick point at both sides that are inlet and outlet respectively. As you can see from the simulation model in this area the shape is simple and no significant resistance. The simulation results indicate that pressure and velocity varied sharply around port due to changing of flow area. However, along the other area the distribution of pressure and velocity varies step by step and periodically. Moreover, there are less influence by flow rate on the

velocity and pressure distributions. But, it shows a little bit larger difference appears flowing through inlet and outlet region.

5. Conclusions

In the present work, we discussed about fresh water generator system which used plate heat exchanger to evaporate and condense with vacuum conditions. Experiments have been carried out on the fresh water generation according to the supply temperature and flow rate of heating medium and show the influence on the performance of product fresh water as outcome of the system.

The experiment show that with higher hot water supply temperature can produce more quantity of fresh water. With different flow rate affect to the fresh water quantity is less at 65°C and 70°C. However, the difference of fresh water quantity is become large at 60°C of hot water temperature case. Because there need much more amount of heat and time to accumulate then it can be evaporated. Since the supply temperature is lower relatively even though theoretically it can evaporate at this condition but some heat loss are inevitably. Hence, resulted into evaporating is happened sporadically at this condition.

Moreover, this study also provided the possibility of application of numerical simulation of flow behavior in the PHE narrow channel.

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