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A Study on the Performance and Flow Distribution of Fresh Water Generator with Plate Heat Exchanger

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ABSTRACT: Nowadays Plate Heat Exchanger (PHE) is widely used in different industries such as chemical, food and pharmaceutical process and refrigeration due to the efficient heat transfer performance, extreme compact design and efficient use of the construction material. In present study, discussed main conception of plate heat exchanger and applied in vacuum. PHE and aimed apply in the fresh water generator which installed in ship to desalinate seawater to fresh water use heat from engines. The experiment is proceeded to investigate the heat transfer between cold and hot fluid stream at different flow rate and supply temperature of hot fluid. Generated fresh water as outcome of the system. PHE is an important part of a condensing or evaporating system. One of common assumptions in basic heat exchanger design theory is that fluid is to be distributed uniformly at the inlet of each fluid side and throughout the core. However, in practice, flow mal-distribution is more common and can significantly reduce the heat exchanger performance. The flow and heat transfer are simulated by the k-ε standard turbulence model. Moreover, the simulation contacted flow maldistribution in a PHE with 6 channels.

Nomenclature

b mean channel gap [m]
De equivalent diameter [m]
D_p port diameter [m]
f friction factor
G fluid mass velocity [$kg/m^2 \cdot s$]
h convective heat transfer coefficient [$W/m^2 \cdot ℃$]
k thermal conductivity [$W/m^2 \cdot ℃$]
n number of channel
Re Reynolds number

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Greek symbols
β chevron angle
ε thermal effectiveness
μ viscosity

Subscript
c channel

1. INTRODUCTION

Many countries in the world suffer from a shortage of nature fresh water. Increasing amounts of fresh water will be required in the future as a result of the rise in population rates and enhanced living standards, together with the expansion of industrial and agricultural activities. Most commercially applied technologies of desalination are based on the multistage flash distillation, multiple effect distillation and reverse osmosis processes. In distillation system it is no doubt heat exchanger as a key point that is extremely important. The importance of heat exchanger has increased immensely from the view point of energy conservation, conversion, recovery and successful implementation of new energy sources [1].

However, the range of applications of this type of exchanger largely expanded in the last decades due to the continual design and construction improvements. Nowadays PHE widely use in different industries such as chemical, food and pharmaceutical process and refrigeration.

The traditional concept, PHE consists of plates, gaskets, frames and some additional devices, such as carrying and guiding bars, support column, via ports. The heat transfer occurred between adjacent channels through plates. Alternate plates are assembled such that the corrugations on successive plates contact or cross each other to provide mechanical support to the plate pack through a large number of contact points. This resulting flow passages are narrow, highly interrupted and tortuous so that enhance the heat transfer flow and increasing the level of turbulence.

True flexibility is unique to the plate heat exchanger both in initial design and after installation. In the initial design the basic size, geometry, total number and arrangement of standard plates can normally be selected to precisely fit the required 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].

The main objective of this paper is discussing main conception of plate heat exchanger applied in vacuum evaporator for product fresh water. Especially focus on the evaporating and condense in performance for product fresh water.

2. Experiment Setup and Method

A fresh water generator is increasingly used in desalination plants, typically located in coastal areas, which provide fresh drinking water to the local community. These have become very common in the Middle East, and are also in use in some other place. More desalination plants are likely to be built as a response to drought and concern over availability of water in growing cities. However, the costs involved in desalination plants are high and are considered by communities only when faced with water shortages from traditional sources.

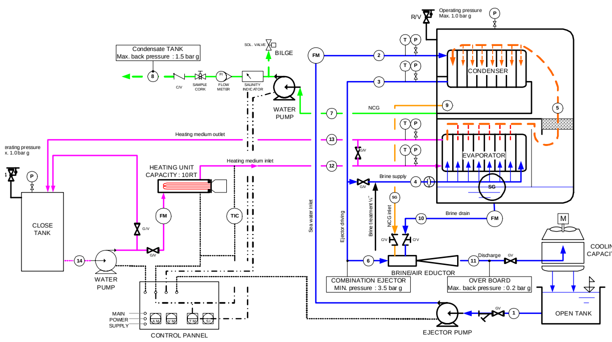

Fig.1 Schematic diagram of vacuum evaporating distiller.

The concept of a fresh water generator is simple the sea water is evaporated using a heat source, separating pure water from salt, sediment and other elements. Fresh water generators often use the diesel engine jacket as a heat source, although steam can also be used as a heat source. Because freshwater generators often use existing heat to run, the cost of operation is low. There are two main elements in a fresh water generator, one heat exchanger evaporates the sea water and another one condenses the fresh water vapor into liquid phase for use. In the condenser element, the vapor is condensed through cooling, often simply using cold seawater.

The heat transfer part contains corrugated plates with 60 degree 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, so that the saturation point of water becomes lower much more. It then becomes possible to evaporate the seawater at a temperature around 60 ℃. The diesel engine jacket cooling water is sufficiently hot to evaporate the seawater and it is commonly used. In present system can reach the vacuum between two dotted line shows in Fig.2. It means that for the saturation temperature located in 51℃-57℃.

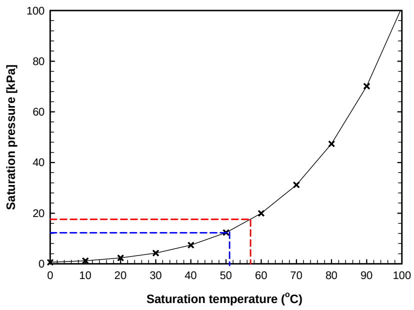

Fig.2 Saturation temperature and pressure.

For the procedure of experiment 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 notice that there is bypass line connected from outlet of cooling water to evaporator. The already heated cooling water provided to absorb heat from hot water so that can be evaporating much more quickly and use all the 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.

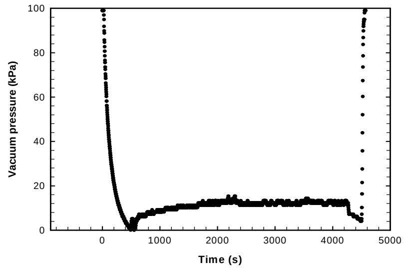

Fig.3 pressure distribution inside of the vessel.

As mentioned above the vessel contains two unit of exchanger is maintained with vacuum condition while the system is operating. The pressure variation in the inside of vessel is show as Fig.3. This is one of experimental results with operate system exactly operate ejector entrain the inside air so that pressure decrease rapidly within 10 minutes. At this condition flowing hot stream and cold stream to start to exchange heat. We can see inside pressure increase gradually since there are vapor occurred. However through some period it maintain at steady state along 12kPa vacuum pressure relatively. It showed sharp increasing at end of part this because stop ejector and it recovery to atmosphere condition. In this way one case of experiment is complete.

Schematic diagram of freshwater generator experimental facility is shown in Fig.1. The system can be separate 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 sent to cooling tower where temperature cool down and maintain at the inlet condition of heat exchanger. This experiment used city water and not installed on ship yet. However, in real state this system will be installed on ship so the cold water instead by seawater then cooling tower is unnecessary. Since it assumed that the seawater temperature is constant. In 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 instead of engine cooling water. Results and Discussion.

3. Results and Discussion

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

First look at pressure drop that it is calculated as approximately 1.5 times 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

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

$$f = 0.8\,\mathrm{Re}^{-0.25}, \qquad \mathrm{Re} = \frac{G D_e}{\mu},$$

$$G_p = \dot{m}/(\pi/4) D_p^{\,2}$$

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, 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.

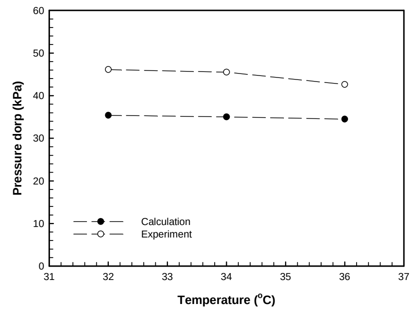

Fig.4 Comparison of pressure drop between experiment and calculation cold water side

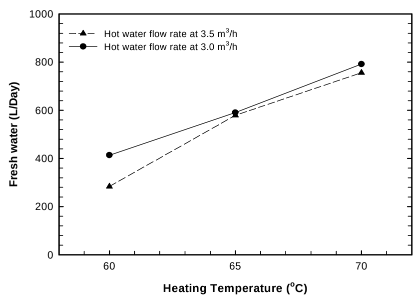

Fig.5 Fresh water generation rate with temperature and different flow rate.

Fig.4 shows the comparison of pressure drop between experiment and theoretical results based on the above equations. It is observed that there is difference for experimental results and calculation method which according to equation suggested by R. K. Shah. The calculation results ignored the third term of right hand side of equation since it is difficult to measure exact the density at each point. Additionally, in experiment friction loss through pipeline is inevitable. Therefore this may result into the gap compare to experimental results.

Since the supply temperature is lower

relatively. Hence, resulted into evaporating is not happened sporadically at this condition.

Fig.5 shows 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. For the different flow rate affect to the fresh water quantity is less at 65 ℃ and 70℃. However, the difference of fresh water quantity is become large at 60 ℃ 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 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.

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 [6-8].

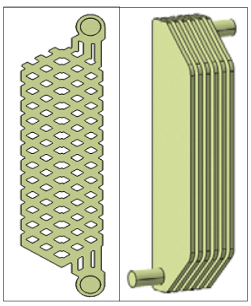

Fig.6 Corrugate plate and flat multi channel model.

In this paper, CFD model taken to simulate flow distribution in the plate channel. The dimension of plate model in length of 400 and width of 100mm, equivalent diameter is 7mm and the port diameter is 24mm. The fluid domains were modelled with the properties of water. The simulation was solved use k-ε standard turbulence model.

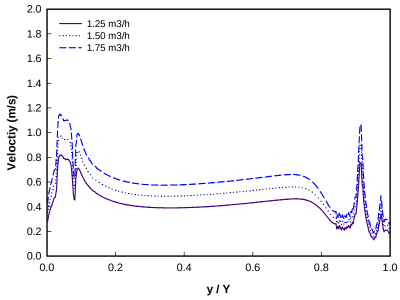

Fig.7 Velocity distributions at the last channel in 6 channel unit.

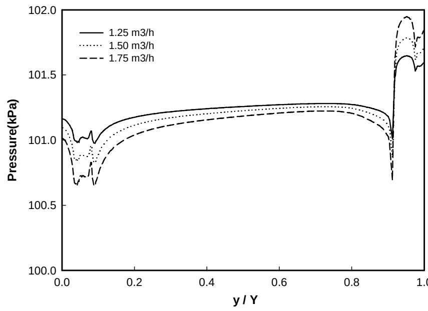

Fig.8 Pressure distributions at the last channel in 6 channel unit.

Simulation model is corrugated plate and 6 channel model with only plat shape as shown in Fig.6. In the simulation with corrugated model conduct 5 case which the Reynolds number increasing from 2000 to 6000. Fig.6 shows pressure drop according to increasing of Reynolds number. Fig.7 and Fig.8 show velocity and pressure distribution with corrugated model.

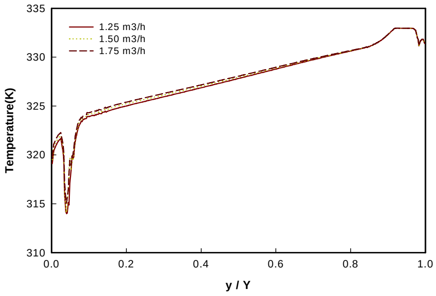

Fig.9 Temperature distributions at the last channel in 6 channel unit.

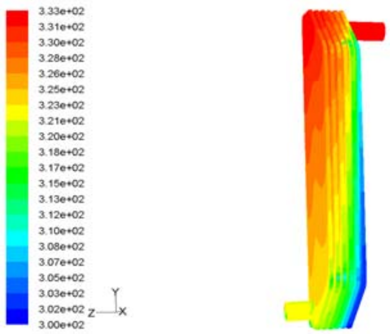

Fig.10 Temperature distribution in 6 channel unit with 1.5m^3/h flow rate.

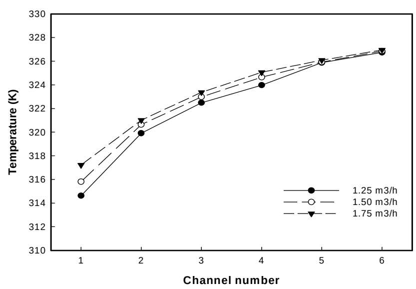

Fig.11 Temperature distributions in the each channel.

We can see 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 simulation results indicate that pressure and velocity varied sharply around port due to changing of flow area. However at other area the distribution of pressure and velocity is near uniform. Fig.9 shows the variation of temperature in the last channel which with 6 channel model. Here indicate that less influence of flow rate on the temperature distribution in this channel. However, Fig.11 shows a little difference of temperature when the flow approach to end of channels the influence is increasing. Moreover we can see the temperature distribution within 6 channels that there happens maldistribution as estimated. In the first channel bottom area temperature appears lower than other area. Since small amount of fluid flowing to this channel relatively. Therefore it considered if the channel made in various deferent depth size for heat transfer more sufficiently. This work will be continued in further research.

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 generating 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. Using a CFD tool can obtain the temperature and velocity distribution inside of PHE channel. In fact, it is very difficult to obtain experimental result for comparison with the simulation result.

The experiment show that with higher hot water supply temperature can produce more quantity of fresh water. The flow rate of hot water supply temperature affect less to the produce of fresh water in the range of high temperature. However, it can achieve more fresh water at lower flow rate. Because at lower flow rate heat transfer sufficiently between hot medium and cold medium through adjacent plates. The simulation results indicate that pressure and velocity varied sharply around port due to changing of flow area.

However at other area the distribution of pressure and velocity is near uniform state. It observed that pressure drop significant with increasing of Reynolds number. In the 6 channel model the flow rate is less effect on temperature but approach to end of channel the more the influence is increasing.

Unlike tubular heat exchangers for which design data and methods are easily available, PHE design continues to be proprietary in future. Extend detailed research with wide range of experimental condition will carried out in the near future in order to test and further improve the performance of system. That can contribute to the propagate application of PHE and it can be practice effective utilization of energy that conserve limited.

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