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Flow Distributions in the Channel of Plate Heat Exchanger Applied in Vacuum Evaporating Distiller System

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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 work, PHE is applied in the fresh water generator system. Fresh water generators or desalinators are installed in ship to convert seawater to fresh water using heat from engines. PHE is an important part of a condensing or evaporating system. Among many of factors which should be concentrated on, the heat transfer and pressure drop is most important parts during sizing and rating the performance of PHE. Flow maldistribution is common but it will significantly reduce the heat exchanger performance. In this paper provide a overview of PHE cover basic of theory and conduct a numerical approach for flow distribution in plate channel. An experimental study on the performance of fresh water generator system which developed by plate heat exchanger will presented in future research. Thus, extensive experiment and analysis is required to study the thermal and fluid flow characteristics of PHE.

Key words: Plate heat exchanger, Flow distributions, Vacuum evaporator

Nomenclature

b	mean channel gap [m]
D_p	port diameter [m]
f	friction factor
h	convective heat transfer coefficient [W/m^2·℃]
k	thermal conductivity [W/m^2·℃]
m^2	maldistribution parameter
n	number of channel
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number

Greek symbols

β	chevron angle
ε	thermal effectiveness
ς_c	channel friction coefficient
υ	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 seawater desalination are based on the multistage flash distillation, multiple effect distillation and reverse osmosis processes.

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In distillation system it is no doubt heat exchanger as a key part it 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. Heat exchangers are used in wide variety of applications. These include power production, process, chemical and food industries, electronics, environmental engineering, waste heat recovery system, manufacturing industry, air conditioning, refrigeration and space applications, as well as being key components of many industrial products. Plate heat exchangers (PHE) was originally developed for use in hygienic applications such as the pasteurization of liquid food products. 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 main problem is since PHE use gaskets for sealing, the air conditioning and refrigeration system did not readily adopt this technology due to concerns over refrigerant leakage.

The traditional concept, PHE consists of plates, gaskets, frames and some additional devices, such as carrying and guiding bars, support column, via ports show in Fig.1. The heat transfer occurred between adjacent channels through plates. 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 [1-6].

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 Focke[7]. The commonly used chevron angle varies between 30° to 60°. This been verified by many researchers according to experimental results and simulations already.

The most common materials are stainless steel (AISI 304 or 316) which considered as safe materials for PHE. Since titanium has a very low corrosion rate in high chloride concentration, so it is selected as the ideal material for extending the lifespan of the system despite it being so expensive for heat exchanger. For the gaskets, in the past were cemented in the grooves but now, snap on gaskets which do not required cementing are common. Some manufacturers offer to special interlocking types to prevent gasket blowout at high pressure difference. Typical materials and their range presented by many researchers, buty1 and nitrile rubber being most common.

The traditional design method for plate heat exchanger logarithmic mean temperature difference (LMTD) andε -number of transfer units (ε-NTU) method. When the inlet or outlet temperature of fluid streams is unknown value, a trial and error procedure could be applied for using the LMTD method in the thermal analysis of heat exchangers. In this case to avoid this problem ε-NTU based on concept of heat exchanger effectiveness may select.

The main objective of this work are discuss main conception of plate heat exchanger and applied in vacuum evaporator for product fresh water on ship. Especially focus on the flow distribution between channel because it is key point of the whole system performance.

2. PHE used in vacuum evaporator

While ship traveling on long voyages must be able to generate their own fresh water for the boilers, machinery and for washing. Fresh water generators or desalinate are installed to convert the seawater from sea to freshwater. most common type makes use of the distillation process using the heat from the engine and the seawater is evaporated into vapor. This vapor is then led into cooling section and it condenses in water again distilled water. The cooling section consists of tubes or plates which uses sea water as the cooling agent. Fig.1 shows schematic diagram of fresh water generator system.

In this experiment used the vacuum evaporator distiller which designed with a capacity of 1ton/day of fresh water. The air inside of the evaporation chamber is evacuated to a vacuum pressure, so that the evaporating point of water becomes lower. It then becomes possible to evaporate the seawater at a temperature of 60 ℃. The diesel engine jacket cooling water is sufficiently hot to boil the seawater. Kim has presented experiment results which used PHE in fresh water generator system. Consequently, this study serves as base for fresh water generator use PHE.

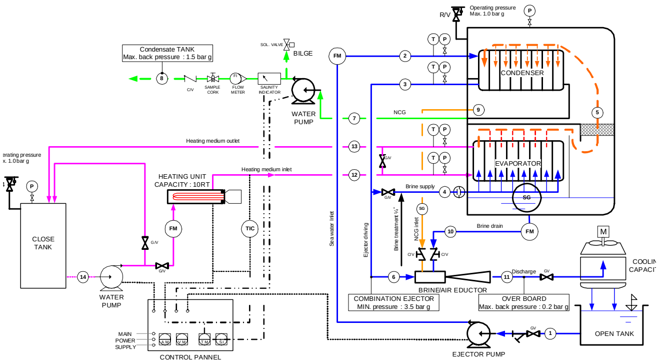


Fig.1 Schematic diagram of vacuum evaporating distiller.

3. Flow distributions

The thermal design of a heat exchanger is directed to calculating an adequate surface area to handle the thermal duty for the given specifications. Fluid friction effects in the heat exchanger are equally important since they determine the pressure drop of the fluids flowing in the system. Consequently the pumping power or fan work input necessary to maintain the flow Pressure drop in a plat heat exchanger consists of three contributions: Pressure drop associated with the inlet and outlet and ports (P1<10%) , the core (plate passage) and due to the elevation change for a vertical flow

To calculate the total pressure drop of a plate heat exchanger and flow distribution from port to channel, equations have been developed by Bassoiuny and Martin for U-type and Z-type flow arrangement considering momentum balance on elemental fluid volume inside inlet and exit port. The continuity and momentum equations are applied to the conduit sections for both dividing and combining flow conduits.

For U-type

$$\frac{d(p-p^*)}{d_z}+\left[\left(2-\beta^*\right)\left(\frac{A}{A^*}\right)^2+\left(2-w\right)\right]\frac{dw}{dz}=0$$

For Z-type

$$\frac{d(p-p^*)}{d_z}-\left[\left(2-\beta^*\right)\left(\frac{A}{A^*}\right)^2+\left(2-w\right)\right]\frac{dw}{dz}=0$$

$$P-P^*=\frac{1}{2}\left(\frac{A}{A_c n}\right)^2\left(\frac{dw}{dz}\right)^2$$

Empirically, 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 ΔP 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

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

where $G_p=\dot{m}/(\pi/4)D_p{}^2$ is the fluid mass velocity in the port, n_p is the number of passes on the given fluid side, D_e is the equivalent diameter of flow passages, ρ_o and ρ_i are fluid mass densities evaluated at local bulk temperature and mean pressure at outlet and inlet, respectively.

A considerable amount of research has been conducted to determine heat transfer and flow friction characteristics of chevron plate. Martin provides comprehensive correlations for friction factors and Nusselt numbers for this geometry. The correlations for the fanning friction factor is

$$\frac{1}{\sqrt{f}}=\frac{\cos\beta}{\left(0.045\tan\beta+0.09\sin\beta+f_0/\cos\beta\right)^{1/2}}+\frac{1-\cos\beta}{\sqrt{3.8f_1}}$$

where

$$f_0=\begin{cases}\dfrac{16}{\mathrm{Re}}\\(1.56\ln\mathrm{Re}-3.0)^{-2}\end{cases}$$

$$f_1=\begin{cases}\dfrac{16}{\mathrm{Re}}\\(1.56\ln\mathrm{Re}-3.0)^{-2}\end{cases}$$

Martin also obtained the Nusselt number correlations as follows, using the momentum and heat transfer analogy from a generalized Leveque solution in thermal entrance turbulent flow in a circular pipe [8]:

$$Nu=\frac{hD_h}{k}=0.205\,\mathrm{Pr}^{1/3}\left(\frac{\mu_m}{\mu_w}\right)^{1/6}\left(f\cdot\mathrm{Re}^2\sin 2\beta\right)^{0.374}$$

As the Reynolds number increases the heat transfer coefficient also increases, but friction factor decreases.

One of common assumption in basic heat exchanger design theory is that fluid be distributed uniformly at the inlet each fluid side and throughout the core. However, in practice, flow maldistribution is more common and can significantly reduce the desired heat exchanger performance. Still, this influence may be negligible in many cases and the goal of uniform flow through the exchanger is met reasonably well for performance analysis and design purpose. In general, the flow maldistribution brings an increase in pressure drop across the heat exchanger.

Flow maldistribution can be induced by heat exchanger geometry and heat exchanger operating conditions. The mechanical geometry include such as the basic geometry, manufacturing imperfections and tolerances. In the other hand, the operating condition means viscosity or density induced maldistribution, multiphase flow and fouling phenomena.

Prabhakara[9] has been indicated that the flow distribution in U-type PHE differs significantly from that one of the Z-type PHE. It is clear that due to flow maldistribution, each channel has a different heat transfer coefficient and hence, it is difficult to define NTU for the entire equipment. However in order to facilitate a comparison with uniform distribution model. NTU is defined on the basis of the heat transfer coefficient with the hypothetical case of equal flow distribution when $m^2=0$.

The effects of parameters such as the heat capacity rate ratio, flow configuration, plate geometry and number of channels are considerably different from the unrealistic paradigm of ‘unequal flow rates but equal heat-transfer coefficient’ used so far. Based on the above results, they made the following recommendations. First, the analysis of a plate heat exchanger should always be carried out with an eye towards flow maldistribution and flow dependence of the heat transfer coefficient in each channel. Secondly the determination of the heat transfer coefficient should be done by solving an inverse problem using experimental values of temperature and a usual definition of NTU to obtain the value of n. This will eliminate the entry of the flow distribution effect into the heat transfer data.

It must be mentioned here that the Reynolds number for PHE is defined on the basis of twice the plate spacing b, as

$$\mathrm{Re} = \frac{U_c(2b)}{\upsilon}$$

Usually in PHE, the transition from laminar to turbulent flow takes place between Re values of 400 to 500. Hence the range of Re chosen is in the turbulent regime. This flow friction data was used in the following channel pressure drop equation to obtain the channel friction coefficient.

$$\zeta_c = \frac{2(\Delta P)_{ch}}{\rho U_c^{\,2}}$$

As a distribution parameter m^2 which is a measure of flow maldistribution. The value of m^2 approaches zero when flow is uniformly distributed among the channels. A considerable flow maldistribution will yield the larger value of m^2. The distribution parameter m^2, mainly depends on the exchanger geometry, configuration, flow frictional characteristics and number of channels. Its value increases as the square of the number of channels. Here ζc is the total frictional resistance of the channel. theoretical value given by Bassiouny and Martin as

$$m^2 = \left(\frac{1}{\zeta_c}\right)\left(\frac{nA_c}{A}\right)^2$$

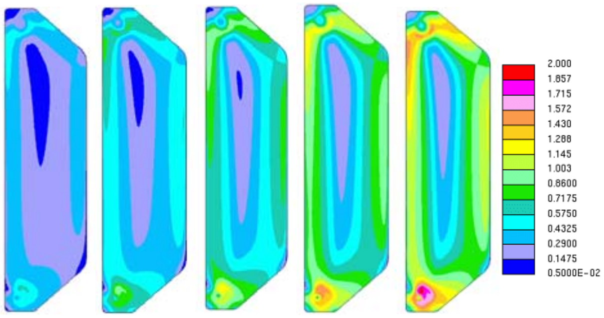
Prabhakara Das has been indicated that as port size decreases, the pressure drop increased due to flow maldistribution. Also the role of flow velocity is found to be crucial and the flow maldistribution is more severe in case of Z-type than U-type PHE in small port sizes. When number of channels is higher and port size is reduced, the m^2 value increases so that the flow maldistribution will be even worse.

In case of consider thermal condition, the factor increase with temperature of fluid decrease the viscosity and bring out increasing the Reynolds number. Consequently the pressure distribution at port area and the flow maldistribution significantly depends on the port cross-sectional area available for the fluid relative to the channel cross-sectional area. According to the importance of port size on the flow maldistribution phenomenon, hence it is recommended that should be kept a maximum permitted size for port selection.

In practice, there are existing scale or deposit on the heat exchanger surface inevitably. As an importance factor fouling have influence on performance and maintenance of heat exchanger. Fouling adds thermal resistance to heat transfer in a heat exchanger as well as increasing pressure drop. Fouling cause a decrease in thermal performance during operation due to reduced overall heat transfer coefficient. Subsequently there is to be note a rapid rise of pressure drop and therefore higher maintenance costs due to higher pumping energy. Fouling has a transient character but for the purpose of thermal design consideration, it is often included into analysis through the concept of fouling unit thermal resistance. However, the phenomena that control the fouling processes are very complex in nature and a comprehensive general theory cannot be defined yet.

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 that simulation or visualization like described in the articles[10-14]. Since the heat exchanger generally made from metallic material, it is difficult to visualize by optical ray. When PHE as an evaporator, between channels there are phase changing occurred. Visualization is one of important method because can get distribution in the plate heat exchanger in order to verify the simulation results. Of cause it is possible indicate distribution between two plate but may via simulation but as we know when the CFD results verified by experiment or visualization results then that will be reliable. But this process very difficult to install and simulate real condition so will cause uncertainty of comparison analysis.



Re=2000, Re=3000, Re=4000, Re=5000, Re=6000

Fig.2 Velocity distributions inside channel according to the Reynolds number.

In this paper, a 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. In the present the plates were modeled as thin plate walls with one channel. The fluid domains were modeled with the properties of water. The simulation was solved use k-ε turbulence model.

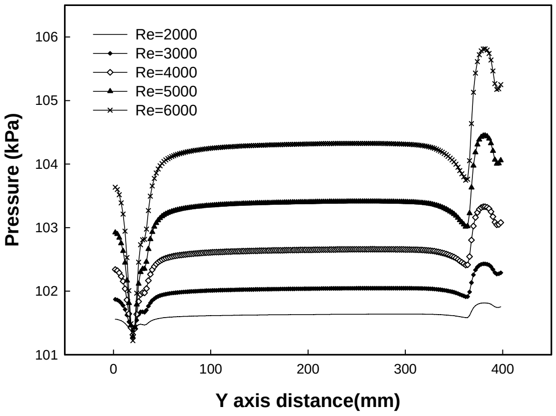


Fig.3 Pressure distributions along y axis of channel.

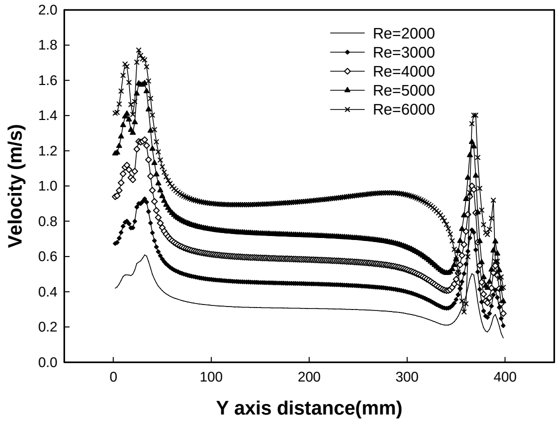


Fig.4 Velocity distributions along y axis of channel.

Fig.2 shows the velocity distributions inside the channel with increasing of Reynolds number. It found that the flow stream on the side area of channel more than middle part of channel. From the figure of plan view we can found out the tendency that the flow enter from port to channel then distribute two ways mainly result into there are few fraction of stream distribute at middle part of channel. This may because used plat without corrugation type of plate. Of cause for further research will consider real condition which include real corrugated configuration and conduct heat transfer characteristics also. From Fig.3 and Fig.4 we can see more detailed variation of velocity and pressure along y direction cross port. the y axis distance meas 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.

CFD is a useful method for optimization of design and analysis. Optimization of PHE problem is formulated as the minimization of the heat transfer area, subject to constraints on the number of channels, pressure drop, flow velocity and thermal effectiveness, as well as the exchanger thermal and hydraulic model. For given process conditions, operational constraints and plate type, the proposed screening design method can obtain the optimal configuration of the PHE, which comprises the number of channels, pass arrangement, fluid locations and relative location of the feed connections. Sensitivity analysis can improve the obtained solution by testing the influence of other process parameters, as plate type, PHE plate capacity or pressure drop constraints.

5. Conclusion

PHE becomes more popular in many industries. Based on many researchers' work, the design of plate heat exchanger is highly specialized in nature considering the variety of design available for the plates and arrangement that possibly suit various duties. Unlike tubular heat exchangers for which design data and methods are easily available, PHE design continues to be proprietary in nature.

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. In other way from the figure of plan view we can found out the tendency that the flow enter from port to channel then distribute two ways mainly result into there are few fraction at center of channel.

Using a CFD tool can obtain the temperature and velocity distribution inside of channel. The results from CFD were enables to analysis of velocity and temperature distribution inside the PHE. In fact, it is very difficult to obtain experimental result for comparison with the simulation result. Therefore, extend detailed comparison with the original experiment and analysis data should carried out within the near future in order to test and further improve the performance of system. That can contribute to the propagate application of plate heat exchanger and it can be practice effective utilization of energy that conserve limited energy.

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