

Simulation of Evaporator for Two-phase Flow in the New Plate-fin Desalination Unit

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Abstract: In this study a new desalination unit is established. It has four cells such as cooling cell, heating cell, evaporation cell and condensation cell. Seawater is pumped into cooling cell to be preheated and then goes to evaporation cell. In the new desalination unit the evaporation and condensation cell is heated and cooled by the heating and cooling cells respectively. The heating of the evaporation cell is ensured by hot water flowing upward along heating cells. The cooling of the condensation cell is ensured by seawater in cooling cell. Fluent 6.3 is used to simulate gas-liquid two-phase flow of boiling evaporation numerically. A simulation calculation to get fluid in a new desalination unit under the influence of the flow, pressure distribution and heat transfer performance of the evaporator.

Keywords: Desalination, evaporation, unit simulation

INTRODUCTION

The lack of potable water poses a big problem in arid regions of the world where freshwater is becoming very scarce and expensive. Shortage of fresh water is a major problem affecting many countries. Clean drinking water is one of the most important international health issues today.

Desalination is one of mankind's earliest forms of water treatment and it is still a popular treatment. Desalination uses a large amount of energy to remove a portion of pure water from a salt water source. Salt water is fed into the process and the result is one output stream of pure water and another of wastewater with a high salt concentration.

A number of seawater desalination technologies have been developed during the last several decades to augment the supply of water in arid regions of the world. Due to the constraints of high desalination costs, many countries are unable to afford these technologies as a fresh water resource. However, the steady increasing usage A variety of desalination technologies has been developed over the years on the basis of thermal distillation, membrane separation, freezing, electro-dialysis, etc. (Akili *et al.*, 2008). J.R. Lara (Lara *et al.*, 2008) practice to operate mechanical vapor-compression (MVC) seawater desalination systems at temperatures lower than 80°C. This study presents the detail engineering and economics of a MVC system. Luopeng Yang (Luopeng and Shengqiang, 2007) presents an economic analysis of the energy cost of water production for dual-purpose plants by the Equivalent Enthalpy Drop Theory (EEDT) and the off-design analytical theory on steam turbines.

Thin liquid films falling under the influence of gravity along vertical or inclined solid surface are encountered in a wide range of desalination industrial process equipments which include wetted-wall absorbers, falling film reactors, condensers and vertical tube evaporators.

Lee and Kim (Lee and Kim, 2008) developed a theoretical model by improving Siddique's analytical model and investigated steam condensation heat transfer in the presence of air or nitrogen gas in a vertical tube. Their results showed that the effects of the noncondensable gas became weak as the condenser tube diameter decreased because of interfacial shear stress. Also, Lee and Kim (Lee and Kim, 2010) developed four simple models using empirical correlation. They compared the theoretical model and simple models with various data obtained from the cooling jacket method and showed that the predictions of the theoretical model and the simple model based on Lee and Kim's correlation was in good agreement with the experimental results. In these calculations, the inner wall temperature profiles were given as boundary conditions.

Zhang Ming (Zhang, 2009) designed novel grooved vapor chamber. The grooved structure of the vapor chamber can improve its axial and radial heat transfer and also can form the capillary loop between condensation and evaporation surfaces. The effect of heat flux, filling amount and gravity to the performance of this vapor chamber is studiedly experiment.

Costa (Costa and Enrique, 2002), Prost I, Alam and Gupta (Prost *et al.*, 2006) and Miranda and Chen (Chen and Zhiming, 2004). These models are generally based on a set of linear or non-linear equations and can

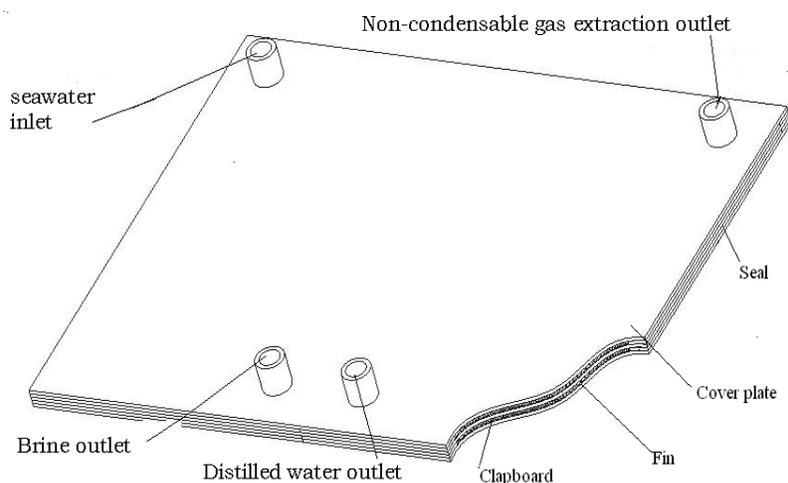


Fig. 1: Front side of integrated plate-fin desalination unit

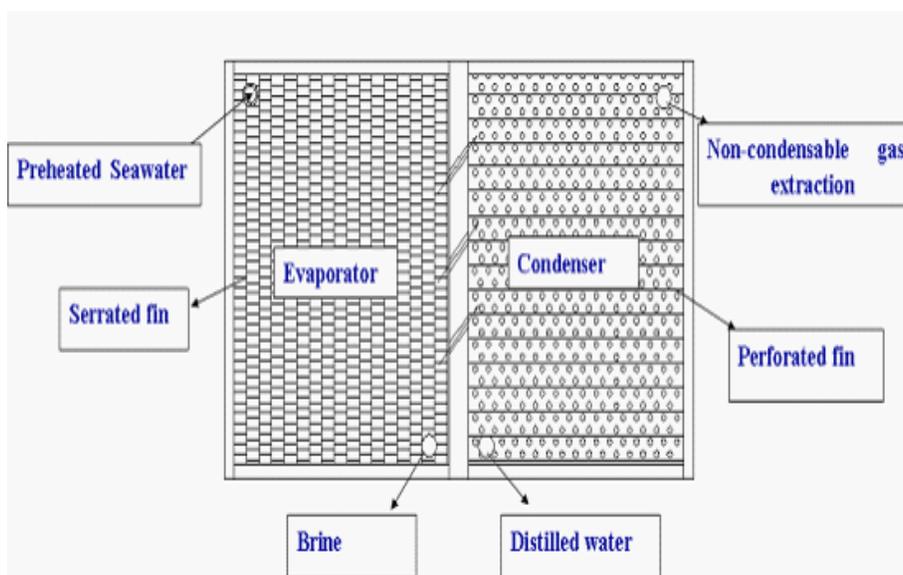


Fig. 2: Internal structure of evaporator and condense in plate-fin desalination unit

accommodate effects of varying physical properties of vapor/steam and liquor with change in temperature and concentration. Oh and Revankar developed a pure steam condensation model and an empiricism-free or minimum empirical mechanistic model for the vapor/noncondensable mixture condensation. In the model for the mixture, they used general momentum, heat and mass transport relations derived using an analytic method and considered the surface suction effect.

In all of the above mentioned references the vapor pressure drop and vapor velocity were not considered in the mathematical formulation. The objective of this study is to study the performance characteristics of a

film evaporator and try to find an optimum evaporator performance from size point of view, in other words, to find an optimum volumetric cooling rate for a certain distance between the vertical plates. Moreover this study presents an attempt to improve upon the models described earlier and eliminate some of their limitations.

DESCRIPTION OF THE DESALINATION UNIT

The integrated plate-fin desalination unit is a patented distillation unit and it has two layers (Fig. 1). Fin, cover plate, clapboard and seal are brazed into a plate-fin. Its material is stainless steel to prevent

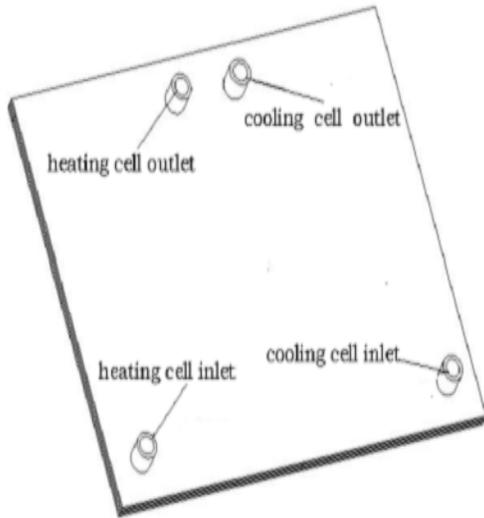


Fig. 3: Back Front side of integrated plate-fin desalination unit

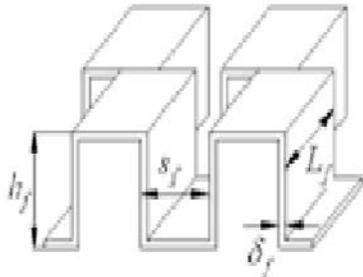


Fig. 4: Serrated fins

Table 1: Dimension of the serrated fins

h_f (mm)	s_f (mm)	δ_f (mm)	L_f (mm)
6	4	0.2	5

corrosion and its size is 1m (Height) \times 0.5m (Width) \times 3cm (Thickness).

The Fig. 2 is the front side of integrated plate-fin desalination unit. The above two nozzles are seawater inlet and non-condensable gas extraction outlet. The lower two nozzles are for brine outlet and distilled water outlet.

Removing plate, we can see internal structure of evaporator and condenser (Fig. 3). In the evaporator, serrated fins are used and in horizontal mode. The seawater to be evaporated flows as a falling film along fins heated by hot water in the heating cell. Some sloped holes are machined in the strip seal to ensure steam go into condenser thus reducing thermal losses and complex piping. Perforated fin are used and also in horizontal mode. The cooling of the condenser is ensured by cold seawater in the cooling cell.

Their major surface geometries in Fig. 4 are described by the fin height h_f , fin space s_f , fin thickness δ_f , fin length L_f . The fins are uniformly offset by half the fin spacing and designed to be of equal size and shape to maintain the geometric periodicity. For the present study, the numerical serrated fin scheme is chosen in Table 1.

PLATE-FIN DESALINATION UNIT MODEL

Boiling heat transfer: Boiling heat transfer of gas liquid two phase flow and phase change heat transfer is two kinds of complicated physical phenomena coupled, in view of the problems of heat transfer is affected by many factors and is complex, such as boiling heat transfer and heating surface, heat transfer path configuration, system pressure, temperature distribution, boiling medium physical properties; at the same time phase change problems involving two-phase flow, in its flow patterns and phase interface are difficult to identify, so far, it has not yet been fully understand the boiling heat transfer, also did not establish a mature model to describe the boiling heat transfer parameters in the relationship between the.

According to the experimental boiling curve relationship, pool boiling heat transfer characteristics and can be expressed as the exponential relationship between:

$$T_w - T_s = \psi q^n \tag{1}$$

n in Type is 0.25 ~ 0.5.

When the heat of formation of small bubbles continues to be heated up to a certain size, the bubble from the heating surface boundary layer formed liquid phase perturbations and cold, heat medium of exchange to form a pool boiling.

Bubble departure diameter:

$$D_b = 0.0208 \left(\frac{\sigma}{\rho_l - \rho_g} \right)^{0.5} \tag{2}$$

According to the recommendations of the Rohsenow, boiling heat transfer mathematical description is expressed as:

$$Nu_b^* = f(Re_b', Pr_l) \tag{3}$$

$$\frac{c_{pl}(T_w - T_s)}{\lambda} = C \left[\frac{q}{\lambda \mu_l} \left(\frac{\sigma}{g \Delta \rho} \right)^{0.5} \right]^m \cdot (Pr_l)^k \tag{4}$$

VOF model: Euler Lagrange and Euler method are the current study of multi-phase flow method. In the Eulerian method, different phase to each other throughout the continue treatment. Due to a phase took control unit body space cannot be other possession, it is introduced the concept of volume fractions. The volume fraction of time and space of continuous functions, each phase volume fraction and. In the Fluent software provides three Eulerian multiphase model, namely VOF (Volume of Fluid) model, hybrid (Mixture) model and Euler (Eulerlan) model.

The VOF model is obtained by solving the separate momentum equation and processing through the region of each fluid volume fraction to the simulation of multiphase fluid. Typical application: jet, perfusion, shaking, the gas-liquid interface of the steady and transient process, fluid bubbles movement. In the VOF model, interface tracking is achieved by solving with the volume fraction of the continuity equation to complete and arbitrary control in all phase volume fraction.

The I phase continuity equation:

$$\frac{\partial \alpha_i}{\partial t} + v_i \cdot \nabla \alpha_i = \frac{S_{\alpha_i}}{\rho_i} + \frac{1}{\rho_i} \sum_{i=1}^n \left(\dot{m}_{ji} - \dot{m}_{ij} \right) \quad (5)$$

Momentum conservation equation:

$$\frac{\partial}{\partial t} (\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) = -\nabla \rho + \nabla \cdot [\mu (\nabla \mathbf{v} + \nabla \mathbf{v}^T)] + \rho \mathbf{g} + \mathbf{F} \quad (6)$$

Energy conservation equation:

$$\frac{\partial}{\partial t} (\rho \mathbf{E}) + \nabla \cdot (\mathbf{v} (\rho \mathbf{E} + \rho)) = \nabla \cdot (k_{eff} \nabla T) + S_h \quad (7)$$

Type is j phase and I phase mass transfer, is the I phase to j phase mass transfer, property and (effective heat transfer rate) is the sharing, source phase includes the radiation, the volumetric heat source.

In Fluent, the control volume formula for solving is to draw phase interface of convective and diffusive flux, but also to ensure the control volume of the internal source phase equilibrium. For the VOF model, Fluent provides four solutions: geometry reconstruction, material acceptance, Euler explicit and implicit.

- **Geometry reconstruction:** The geometric reconstruction scheme, using the standard interpolation method to obtain interface flux and by piecewise linear representation between the phase interface. Fluent this program is the most accurate and suitable for general unstructured grid.

In this scheme, two phase flow solution are dependent on time. The first step is to calculate the relative to each section with unit linear interface location, based on the volume fraction and the unit leads out the information. The second step is to calculate the fluid through each level of flow, using the calculated linear interface description and on the surface of normal and tangential velocity distribution information. The third step is to use the preceding steps in computation of flux balance is calculated for each unit of volume fraction.

- **The material receiving scheme:** In the material receiving scheme, Fluent uses standard interpolation method for solving interface flux. In this scheme, the interface is considered as a substance between the adjacent two units the donation and acceptance relation. Material receiving scheme for solving time dependent and only in the quadrilateral and hexahedral meshes are used in.
- **Euler explicit scheme:** The Euler explicit scheme, Fluent uses standard finite difference method on time step unit volume fraction interpolation processing. The Euler explicit scheme only depends on time for solving.
- **Implicit scheme:** In the implicit scheme, Fluent uses standard finite difference method for computing domains of all the elements of the surface fluxes, including near the interface unit. Implicit schemes can be used to solving the time-dependent and steady state problem.

UDF subroutine: The refrigerant is heated from the liquid phase to a gas phase process; two phase mass transfer phenomenon exists. In the Fluent software of multi phase flow model assumes that the phase constant quality principles, so essential in two-phase flow properties increase describe evaporation during the phase transition process of mass transfer of the UDF subroutine.

Li Wen he and mass transfer model is adopted, which assumes that mass transfer is carried under the at constant pressure quasi-static heat balance condition of. Mathematical description is as follows:

$$\dot{m}_v = \begin{cases} r_v \alpha_l \rho_l (T_l - T_{sat}) / T_{sat} & , T_l \geq T_{sat} \\ 0 & , T_l < T_{sat} \end{cases} \quad (8)$$

$$\dot{m}_l = \begin{cases} r_l \alpha_v \rho_v (T_{sat} - T_v) / T_{sat} & , T_v \leq T_{sat} \\ 0 & , T_v > T_{sat} \end{cases} \quad (9)$$

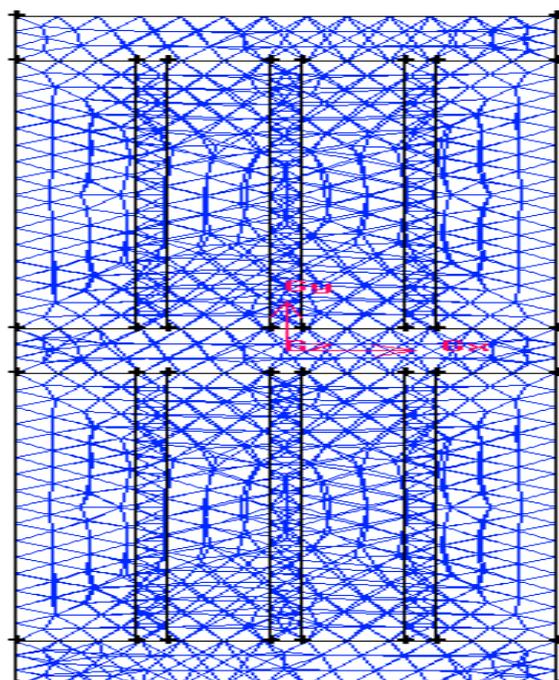


Fig. 5: Grid of the cross section

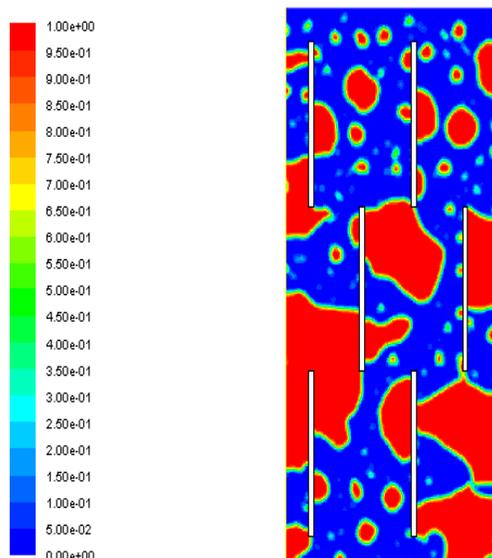


Fig. 6: Boiling simulation

Meshing: Mesh is generated in software GAMBIT 2.3. In this study the hybrid grid is used, as shown in Fig. 5. The simulations are carried out in a portion of plate-fin thermal storage. A three-dimensional computational domain is employed and divided into 555,520 cubic cells.

BOILING STATE

The blue part is a liquid; the red part is vapor in Fig. 6. However the flow velocity is low, with a large bubble aggregates such as square arrangement model, before and after the tube between the areas.

Figure 6 described the seawater in the desalination unit wall is heated to evaporate the bubble formation process. At the same time away from the wall surface liquid low temperature and wall temperature of liquid form temperature difference, the two-phase fluid to produce convection flow. Because of the buoyancy and fluid convection took effect, the bubble departure wall into the fluid passageway; along with the heating time increased, surface air bubbles that can grow quickly and by the high temperature liquid convection taking effect is more apparent, so that air bubbles along the fluid toward the development of evaporation. The evaporator side flow constant amounts of bubble formation, growth and detachment, thereby realizing the boiling heat transfer.

CONCLUSION

The thickness of the liquid film in the film is mainly influenced by pressure of vapor and liquid beside liquid-vapor interface. At the vapor-liquid interface, then magnitudes of variations of the vapor and liquid pressure and the pressure differences

between vapor and liquid increase with the heat flux. The liquid film in heat source region is very thin and this can enhance the performance of vapor chamber. But if the starting point of the liquid film out of the heat source region, the vapor chamber may dry out. The heat flux spreads along with the flow of vapor. The vapor condensates on whole condensation surface, so that the condensation surface achieves a very uniform temperature distribution. The optimal filling ratio should maintain a steady thin liquid film in heat source region of the vapor chamber. The agreement between the experimental results and numerical simulation results verifies.

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REFERENCES

- Akili, D.K., K.K. Ibrahim and W. Jong-Mihn, 2008. Advances in seawater desalination technologies. *Desalination*, 221: 47-69.
- Chen, F.C. and G. Zhiming, 2004. An analysis of black liquor falling film evaporation. *Int. J. Heat Mass Trans.*, 47: 1657-1671.
- Costa, A.O.S. and E.L. Enrique, 2002. Modeling of an industrial multiple effect evaporator system. In *Proceedings of the 35th Annual Congress and Exhibition deCelulose and Paper (Purtugal)*, pp: 1256-1264.
- Lara, J.R., G. Noyes and M.T. Holtzapple, 2008. An investigation of high operating temperatures in mechanical vapor-compre. *Desalination*. 227: 217-232.
- Luopeng, Y. and S. Shengqiang, 2007. Assessment of energy requirement for water production at dual-purpose plants in China. *Desalination*, 205: 214-223.
- Lee, K.Y. and M.H. Kim, 2008. Analysis of steam condensation heat transfer with a non-condensable as in a vertical condenser tube. *Nucl. Technol.*, 163: 261-272.
- Lee, K.Y. and M. Kim, 2010. Experimental and empirical study of steam condensation heat transfer with a noncondensable gas in a small-diameter vertical tube. *Nucl. Eng. Desalination.*, 238: 207-216:
- Prost, J.S., M.T. Gonzalez and M.J. Urbicain, 2006. Determination and correlation of heat transfer coefficients in a falling film evaporator. *J. Food. Eng.*, 73: 320-326.
- Zhang, M., 2009. The experimental and numerical investigation of a grooved vapor chamber. *Appl. Therm. Eng.*, 29: 422-430.