A Process of Low Temperature Distilling Desalination Unit Using Inorganic Heat Pipes

Lixi Zhang, Penghui Gao, Hefei Zhang

***Abstract*—It is designed a process of desalination unit by low temperature distilling, in which the evaporator and condenser with inorganic heat pipes, and the multiphase-ejector jet pump are used. It is mainly introduced the process of unit; educed the expression of K_H, which is the total-heat-transfer coefficient of inorganic heat pipe exchanger; and obtained by analyzing that the value of the inorganic heat pipe exchanger's K_H is bigger than the general heat pipe exchanger's one; calculated the value of the evaporator's K_H with inorganic heat pipe, and approved it is bigger than the general falling-film evaporator's one in the same condition. The results show if using the waste heat of flue gas for desalination or energy recovery, the inorganic heat pipe exchanger has more advantages than other ones.**

***Index Terms*—desalination, low temperature distillation, inorganic heat pipe, evaporator**

I. INTRODUCTIONS

Low temperature distillation is widely considered as one of the most promising ways of desalination. The technique improvement of it is the developing of high efficiency heat exchange equipment and fluid equipment.

The inorganic heat pipe, which is a new heat transfer element, differs from general heat pipe in heat transfer principle and effect. The heat transfer ability of it is 44kW/m^2 in radial direction and 8600 kW/m^2 in axes direction, which are better than general heat pipe's. The center of the pipe is filled with little mineral powder, and pumped for vacuum. The two ends of pipe are closed. The cool and hot fluid exchanging heat through the outside of the two ends of pipe. The heat is transferred quickly from one end to another through pipe wall.

In this paper, a new one-stage process of desalination is designed based on low temperature distillation, using 80 smoke(or hot water) as the heat source (the heat may comes from the waste heat of flue gas, solar energy or engine discharged heat). The high efficiency inorganic heat pipe is used as heat transfer pipe of horizontal falling-film evaporator and condenser; and the multiphase-ejector jet pump is instead of vacuum pump and brine pump.

Up to the present, there is little research about inorganic-heat pipe exchanger. In this paper, it is educed the general expression of the total heat exchange coefficient of inorganic heat pipe exchanger, and analyzed and compared the total heat exchange coefficients of both inorganic heat pipe and general pipe exchanger. Using evaporator for example, it is calculated the total heat exchange coefficients of evaporators respectively using inorganic heat pipe and general steel pipe under the same condition.

II. PROCESS OF UNIT

A. Process flow

The process flow of the unit is shown as Fig.1. According to the performances of the inorganic heat pipe, the heat exchange pipes are placed closely to level, its gradient is 3°～5°. All of the pipes are divided into two parts along the length. In the evaporator, the longer section is used as the seawater evaporating one, and the shorter section as the heating one by hot water; in the condenser, the longer one is used as vapor condensing one, and the shorter one as the cooling one by cold seawater.

The working process of the unit is that: the smoke (or hot water), more than 80℃, is made as heat source. It enters the heating section of evaporator from lower place, heats the pipes, and then comes out from higher one. The heat is transferred fastly to the other end of pipes, used as the heat for seawater evaporating. The cold seawater is pressed from 0.1MPa to 0.4MPa, and imported into the cooling section of condenser in 28℃. Where it sprays down from nozzles, and absorbs the potential heat of condensing transferred from other side of the pipes. The temperature of the seawater is risen. Then the seawater flows out of condenser, and separated into two branches. One of them enters the ejector jet pump to draw out the incondensable gas on the top of the unit and the brine on the bottom of it, in order to keep the unit working pressure at 0.01MPa and the depth of seawater in the pool at shallow layer; another fluid is decompressed, and imported to the top of evaporator, then sprayed down by nozzles. It absorbs the heat transferred from the other end on the outside of pipes, then rises to its boiling point temperature and vapors.

For the density of vapor is relative small than the water, the vapor will run upwards with some brine drops. When the vapor goes through the gas-liquid separating space with a certain height between evaporator and porous bevel funnel, most of brine drops are separated from vapor by gravity, and falling into seawater pool. On the other hand, the vapor runs upwards continuously, passes through the porous bevel funnel and the folded-plate mist catcher in orderly, so the remainder of brine drops in the vapor are separated out completely. All of the separated brine drops flow from the

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porous bevel into the center pipe connected with it, then into the seawater pool. The brine in the seawater pool is drawn out by the multiphase-ejector jet pump. The pure vapor goes up to the outside of pipes in the condenser, and be condensed into freshwater. Then the freshwater flows in catch basin, and be pumped out.

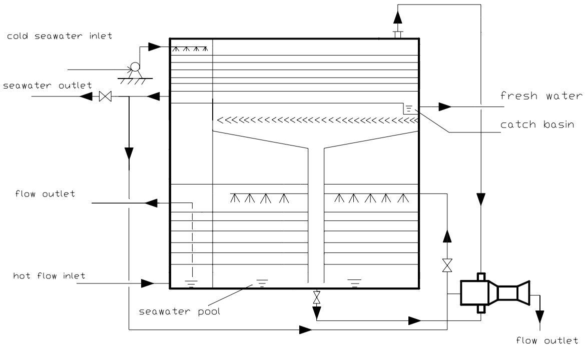

Fig.1 The process flow sheet of desalination unit

B. Main working parameters

The output of freshwater in the unit is 110kg/h. The working pressure is 0.01MPa. The evaporating temperature of seawater is 45.8℃. Taking 80℃ smoke(or hot water) as the heat source. The temperature of cold seawater into the condenser is 28℃, and its pressure is 0.4MPa. The inlet pressure of working fluid in multiphase-ejector jet pump is 0.4 MPa, and the outlet pressure is 0.11MPa.

III. THE TOTAL-HEAT-TRANSFER COEFFICIENT K_H FOR INORGANIC HEAT PIPE EXCHANGER

A. The expression of K_H

So far, the researches on inorganic heat pipe exchanger is fewer. There are no ready-made methods for calculating the total-heat-transfer coefficient of it. Whereas, the heat exchange mode of inorganic heat pipe exchanger is similar to general heat pipe exchanger, which transfers heat from hot section to cold section along pipes. So we can deduce K_H for inorganic heat pipe exchanger according to the corresponding methods for gengral heat pipe exchanger. The heat transfer equations for hot/cold section can be expressed respectively as follows:

$$Q = K_h A_h (t_h - t_m) \qquad (1)$$

$$Q = K_c A_c (t_m - t_c) \qquad (2)$$

In above equations: Q is the heat-transfer capacity; K is the heat-transfer coefficient; A is the heat exchange area, t is temperature; Subscript h expresses the heating section, c expresses the cooling section, m expresses the medium in the pipes.

Eliminating the parameter t_m from equations (1) and (2), and taking the outside area A_h of heating section as the basic one in calculation, the corresponding total-heat-transfer coefficient K_H can be expressed as follows:

$$K_H = \frac{1}{\dfrac{A_h}{K_h A_h} + \dfrac{A_c}{K_c A_c}} = \frac{1}{\dfrac{1}{K_h} + \dfrac{A_h}{K_c A_c}} \qquad (3)$$

When the circular pipes are used as the heat transfer pipes, K_h, K_c can be expressed as follows:

$$\frac{1}{K_h} = \frac{1}{\alpha_{h,o}} + R_{h,y}\frac{A_h}{A_{h,y}} + R_{h,w}\frac{A_h}{A_{h,w}} + \frac{A_h}{\alpha_{h,i}A_{h,i}} \qquad (4)$$

$$\frac{1}{K_c} = \frac{1}{\alpha_{c,o}} + R_{c,y}\frac{A_c}{A_{c,y}} + R_{c,w}\frac{A_c}{A_{c,w}} + \frac{A_c}{\alpha_{c,i}A_{c,i}} \qquad (5)$$

In the formulas above, R is thermal resistance; α is the convection heat exchange coefficient. The subscript w expresses pipe wall, y expresses fouling, o expresses outside of pipe, and i expresses inside of pipe.

The state inside the inorganic heat pipe is vacuum.The weight of working substance in pipe is only several grams. According to the experiment, during the heat transfer process, from hot section to cold section, the outside surface of pipe is nearly isothermal. Therefore, in the process of actual computation, both the thermal resistance of working substance in pipe and pipe wall can be neglected completely. The heat-transfer coefficients of cold and hot section can be expressed as follows:

$$\frac{1}{K_h} = \frac{1}{\alpha_{h,o}} + R_{h,y}\frac{A_h}{A_{h,y}} \qquad (6)$$

$$\frac{1}{K_c} = \frac{1}{\alpha_{c,o}} + R_{c,y}\frac{A_c}{A_{c,y}} \qquad (7)$$

If taking the heat transfer area of exchanger equal to the area of fouling, order $A_h = A_{h,y}$, $A_c = A_{c,y}$, and taking the (6), (7) into (3),

$$K = \frac{1}{\dfrac{1}{K_h} + \dfrac{A_h}{K_c A_c}} = \frac{1}{\dfrac{1}{\alpha_{h,o}} + R_{h,y} + \left(\dfrac{1}{\alpha_{c,o}} + R_{c,y}\right)\dfrac{A_h}{A_c}} \qquad (8)$$

In the formula, $\alpha_{h,o}$, $\alpha_{c,o}$ can be calculated by the common heat transfer criteria relations in the similar conditions. $R_{h,y}$, $R_{c,y}$ can be confirmed by experiments or experiences.

The heat transfer equation for the inorganic heat pipes is:

$$Q = K_H A_h \Delta t_m \qquad (9)$$

In the formula above, Q is the total amount of heat transfer, Δt_m is the log means temperature difference, and it can be calculated by the temperature differences of hot section and the temperature differences of cold one in the heat exchanger.

The A_h can be gotten after calculating Q, K_H and Δt_m.

B. The main influencing factors for K_H

General speaking, in the low temperature distillation systems, the fouling thermal resistance is little. Under no phase change conditions, the heat exchange coefficients $\alpha_{h,o}$ and $\alpha_{c,o}$ are lesser, and the corresponding thermal resistance of them are larger. They are called control resistances. For the inorganic heat pipe exchanger, when $R_{h,y}$, $R_{c,y}$, A_h/A_c are given, from formula (8), the thermal resistances of $\alpha_{h,o}$, $\alpha_{c,o}$ are main acting factors for K_H. For reduceing the control resistances in the evaporator and condenser, the heat exchange coefficients without phase change should be increased as far as possible. There are some concrete methods to realize it for exchanger, such as the cooling mode for outside surface of pipes can be changed to spray, and the circular pipes can be changed to finned pipes, and so on. In inorganic heat pipe exchanger, if hot or cold fluid is gas, it is easy to increase corresponding $\alpha_{h,o}$ or $\alpha_{c,o}$ of it than any other types of exchanger.

C. Comparing with general heat pipe's K_H

In the general heat pipe, the working substance such as water or ammonia etc is loaded, if it is not considered the effects of heat transfer by the suction liquid core and the vapor flows inside the pipes, the thermal resistance items of heat pipe exchanger are the same with them in formulas (4), (5), and ($\frac{1}{\alpha_{h,o}} + R_{h,y}\frac{A_h}{A_{h,y}}$), ($\frac{1}{\alpha_{c,o}} + R_{c,y}\frac{A_c}{A_{c,y}}$) are control resistances, which occupies the total thermal resistance more than 90%.

Compared the formulas (4) and (5) with (6) and (7), the thermal resistance items exists obviously inside the general heat pipe. Therefore, under the same conditions of heat transfer in the outside of pipes, the total thermal resistance of general heat pipes is higher than the inorganic heat pipes, that is to say, the K_H of the inorganic heat pipes is higher than the general heat pipes. When the waste heat of flue gas or other low-grade gas's energy is used for seawater desalination or energy recovery, the inorganic heat pipes can be used to instead of the general heat pipes.

IV. COMPUTING AND COMPARING OF INORGANIC HEAT PIPE EVAPORATOR'S K_H

The cold end of evaporator is used as the end of seawater falling-film evaporation, where the working pressure is 0.01MPa, the temperature of seawater out of spray thrower is 45.8℃, the output of freshwater is 110kg/h; the working pressure of the hot end of evaporator is 0.1MPa. The heating source is simulated by 80℃ hot water, which flows from the bottom to the top, and leaves the unit in 65℃.

A. The cold end heat exchange coefficient $\alpha_{c,o}$

The falling-film evaporation heat exchange coefficient for the outside of horizontal pipes is computed by the Sernas' relations:

$$\alpha = C\lambda_f \left(\frac{g}{\upsilon_f^{\ 2}}\right)^{\frac{1}{3}} \left(\frac{4\Gamma}{\mu_f}\right)^{0.24} \left(\frac{\upsilon_f}{a_f}\right)^{0.66} \tag{10}$$

Where λ_f is the thermal conductivity of fluid, W/(m·K); v_f is the kinematic viscosity of fluid, m^2/s; μ_f is the dynamic viscosity of fluid, kg/(m·s); α_f is the thermal diffusivity of fluid, m^2/s; Γ is the spray density, kg/(m·s); C is constant, C=0.01925 when the external diameter of pipe D= 25mm.

Looking up in related tables, it is gained:

λ_f=0.654W/(m·K), ρ=985.6kg/m^3, C_P=4.176kJ/(kg·K), v_f=0.517×10^{-6} m^2/s, μ_f=5.1×10^{-4} kg/(m·s)

Computing results: $\alpha_f=\lambda_f/\rho C_P$=1.59×$10^{-7}$$m^2$/s, Γ=0.1 kg/(m·s), $\alpha_{c,o}$= 4515W/(m^2·K)

B. The total-heat-transfer coefficient K_H

Taking the fouling thermal resistance of outside surface:

$R_{h,y}=R_{c,y}$=0.86×10^{-4}(m^2·K)/W

Obtained by Computing: $\alpha_{h,c}$=4001W/(m^2·K)

Putting above datas into equation (8), it is gained:

K_H ＝2516 W/(m^2·K)

C. The total-heat-transfer coefficient of general falling- film evaporator

Choosing the general steel pipes as the heat exchange pipes for falling-film evaporator, making the hot wate flowing inside the pipes, and the cold seawater evaporating in the outside of pipes in falling-film. All the working parameters are same with the inorganic heat pipe evaporator's. Using the computing method for general evaporator, the computing results of the total-heat-transfer coefficient is: K_o=1220.6 W/(m^2·K). The results show: in the same working conditions, the K_H is higher than K_o.

V. CONCLUSIONS

In this paper, inorganic heat pipe is adopted as a heat transfer element; a new type of efficient seawater desalination unit is designed. After theoretical analyzing and computing, the calculations are following:

Compared with the general heat pipe exchanger, the inorganic heat pipe exchanger has a higher total-heat-exchange coefficient in the same condition.

In the inorganic heat pipe evaporator, both cold and hot water exchanged heat in the outside surface of pipes. For the cold/hot end surface of pipes is independent relatively, it is easier to control the thermal resistance in there. Compared with the general exchanger, the inorganic heat pipe exchanger has more advantages for desalination and energy recovery in using the waste heat of flue gas and other low-grade gas's energy.

The cold/hot part of pipes can be isolated effectively in the inorganic heat pipe evaporator. The pressure of each part can be differed in terms of requirement, so it can ensure that the system works stably and safely.

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