Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Vol II
IMECS 2009, March 18 - 20, 2009, Hong Kong

The Process Researches for The Desalination Using Residual Heat of Flue Gas

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Abstract—**In this paper, a desalination process is designed. It uses the flue gas residual heat as the heat source and the inorganic heat pipes as the heat-transfer element in the evaporator. Taking residual heat of flue gas from a 4t/h boiler** as an **example, the main operating parameters, the amount of saving energy, and the freshwater output of the system are calculated. The results show that the energy conservation and economic benefits of the process are both obvious, so the process can be used to recover the flue gas residual heat from the ship engine or the industrial boiler for desalination.**

Index Terms—**flue gas residual heat, desalination, inorganic heat pipe, evaporator.**

Ⅰ. INTRODUCTION

The heat pipe exchanger has many advantages, such as compact construction and efficient heat transfer. It has been widely used in the petrochemical, metallurgy and electric power industries, and has made significant effect in the heat transfer and energy-saving. Heat pipe exchanger has been used in desalination to recover the residual heat of flue gas(300℃~500℃) from the diesel engines of ship, and reported that the total thermal efficiency of diesel is increased from 10% to 15% by using this technology.

Inorganic heat pipe is a new heat transfer element. Its working principle is different from general heat pipe. It has more simple structure and better heat transfer performance. There is no doubt that the desalination unit will transfer heat more efficiently and more compactly under the same conditions, if using inorganic heat pipe exchanger to recover the residual heat of flue gas in desalination.

In this paper, a desalination process is designed, in which an inorganic pipe evaporator is used to recover the flue gas residual heat from a 4t/h boiler, and the residual heat is taken as the heat source of the process. The main operating parameters, the amount of saving energy, and the freshwater output of the system are calculated.

Manuscript received December 30, 2008.The work was supported by the Chinese foundation committee of nature and science, under the project No.50576078; and was supported by the natural science fundamental research project of shaanxi province, under the project No:2007E$_2$27

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Ⅱ. DESALINATION PROCESS

A. Process flow

The new desalination process, as shown in figure 1, is mainly consist of seawater preheater, seawater evaporator, freshwater condenser, seawater pump and other equipments. Seawater evaporator are separated into two parts by a division plate. It consists of flue gas heating chamber (the hot end of pipes in it) and seawater evaporating chamber (the cold end of pipes in it). In the evaporator, inorganic pipes are placed near horizon with 4^{o} gradient. The part of pipes fixed in the flue gas heating chamber are finned pipes in order to enhance the rate of heat transfer in the gas side, the other part of pipes in evaporating chamber are smooth pipes. When the process is operated, the hot flue gas discharged from the boiler flows into the flue gas chamber. The heat of flue gas is swiftly transferred by the pipes to the seawater in the evaporation chamber. Then the flue gas flows out the chamber and enters into the seawater preheater to recover heat by seawater further; finally it is discharged into air. The seawater sprays from up to down in the evaporating chamber and evaporates in the form of falling film when it is heated in the outside of the pipes. The generated vapor enters into the condenser through vapor pass and be condensed into freshwater.

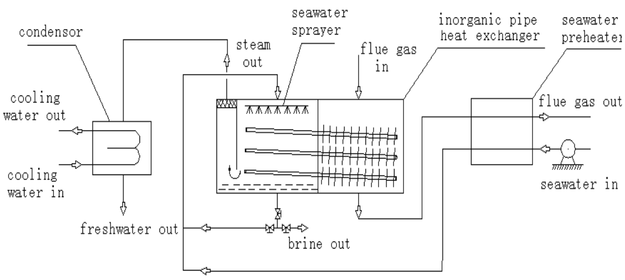

Fig.1 The desalination process flow recovering the residual heat of flue gas

B. The main parameters of process

Supposing the flow of spraying seawater in the evaporator is m, in which $1/7m$ is evaporated. The rest of $6/7m$ be heated to the saturation state and discharged off the evaporating chamber. When it flows out of the chamber, it is divided into two parts: one part containing $5/7m$ water is mixed with $2/7m$ seawater coming from the seawater preheater, and then enters to the sprayer; another part containing $1/7m$ water is discharged off the system to maintain the spraying seawater under the low brine concentration.

The temperature of flue gas at the inlet and outlet of the evaporator is 325℃ and 200℃, at the inlet and outlet of the preheater is 200℃and 180℃ respectively. The temperature of seawater entering to the preheater is 16℃.

According to the heat balance relationship, the calculated flow of seawater is *m* = 0.685kg/s; the temperature of seawater at the outlet of the preheater is 64.6℃, and which at the inlet of the evaporator is 90℃.

The volume flow of flue gas from a 4t/h boiler is V_f = 5000m^3/h (in standard state), corresponding to it, the mass flow is *M* =1.8 kg/s. The temperature of flue gas is 325℃.

Ⅲ. CALCULATION OF SEAWATER EVAPORATOR

To enhance the heat transfer coefficient in the seawater evaporator, the flue gas and seawater in two chambers of it all flow in vertical direction to cross the near horizon pipes.

A. Heat Transfer Calculation

1) The flue gas heat transfer coefficient

The finned pipes with circular stainless steel fin are used in the flue gas heating chamber. To prevent the dust in the flue gas occupying the pipes' surface, the fin pitch s_f is chosen wider, which is 5.0mm, the height of the fin L_f is 12.5mm, the thickness δ_f is 1.5mm, the amount of fin n_f is 154 pieces per meter, the outer diameter of the pipes d_o is 0.025 m, the length of it is *L* =2m, and its pitch S_T is 0.075m.

In the inorganic heat pipes exchanger, the velocity of the flue gas could not be too fast or too slow. For the flue gas including some dust, if it flows too fast, it can increase the wear of the pipes and the flow resistance, though it can improve the heat transfer coefficient; if it flows too slow, some dust can be accumulated on the surface of pipes and decrease the heat transfer coefficient.

The formula (1) can be used to calculate the heat transfer coefficient of flue gas

$$N_{uf} = 0.137 \times \mathrm{Re}_f^{0.6338} \times P_{rf}^{1/3} \quad (1)$$

The temperature scope of (1) is 240～380℃, Re_f is 6000～14000.

When the qualitative temperature of flue gas is 262℃, the heat conductivity coefficient can be looked-up in relative tables:

$$\lambda_f = 4.53 \times 10^{-2} W/(m \cdot ℃) .$$

By calculation, it is obtained:

Pr =0.66，Re_f =4745，

$$h_f = 0.137 \times \frac{\lambda_f}{d_0} \times \mathrm{Re}_f^{0.6338} \times p_{rf}^{1/3}$$

$$= 46.2 \text{ W/(m}^2\text{.K)}$$

The fin efficiency η_f is 0.93, the total area (A_H) of the outer surface of pipes are 0.55m^2, and the effective heat transfer coefficient h_{fe} is 43.32W/(m^{2}K).

2) Evaporating heat transfer coefficient of seawater

The Sernas' relation is used to calculate the falling film evaporating heat transfer coefficient on the outside surface of horizontal pipes:

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

Where λ_f is the heat conductivity coefficient of liquid，W/(m·k)； υ_f is liquid kinematics viscosity，m^2/s； μ_f is liquid dynamic viscosity，kg/(m·s)； a_f is liquid thermal diffusivity，m^2/s，$a_f = \frac{\lambda_f}{\rho c_P}$；$\Gamma$ is spraying density，kg/(m·s); *C* is constant, when the pipes' inner diameter d_o is 0.025m, *C* should be taken 0.01925.

The calculated values of the mass flow, temperature and pressure of spraying seawater are respectively 0.685kg/s，90 ℃ and 0.1MPa. By looking up the seawater performances in the ralative table, the thermal diffusivity a_f can be calculated, it is 0.166×10^{-6}m^2/s.

If it is assumed that the length ratio of heat pipes between the cold and hot end is $l_c : l_h$ =1:1, and taken $l_c = l_h$ =1m, therefore, it can be calculated that the spraying density Γ is 0.0428kg/(m · s)，α is 4158 W/(m^2 · K) .

3) The total heat transfer coefficient and the heat transfer capacity

The total heat transfer equation is

$$Q = K_H A_h \Delta t_m \quad (3)$$

Where Q is the total heat transfer capacity, K_H is total heat transfer coefficient, A_h is the heat transfer area in the hot end, Δt_m is the logarithm average temperature difference. If taking the outside surface of pipes in the hot end as reference one， K_H can be shown as follow[3]:

$$K_H = \frac{1}{\frac{A_h}{K_h A_h} + \frac{A_h}{K_c A_c}} = \frac{1}{\frac{1}{K_h} + \frac{A_h}{K_c A_c}} \quad (4)$$

Using above formulae, some parameters can be calculated

Δt_m =158℃

K_H=40.4 W/(m^2 K)

Q=$C_{pf}M$ (325-200)=249.75kW

$$A_h = \frac{Q}{K_H \times \Delta t_m} = \frac{249.75 \times 10^3}{40.4 \times 158} = 39 \text{ m}^2$$

B. Calculating results

The calculating results are: the rows of pipes are *n*= 9, the number of pipes is 76, the inner diameter of the pipe d_o is 25mm, the pipe pitch is 3d_o =75mm, the nearest distance between the edge of pipe sheet and the heat pipe is 1.5d_o.

The heat transfer area of the hot end is 0.55m^2, the cold end is 0.079m^2, the total heat transfer coefficient is 40.4W/(m^2 K), and the heat transfer capacity is 250 kW.

The diameter of the pipe sheet is 814mm. Considering the inorganic heat pipes are placed with 4°gradient relative to the horizontal plane, and the altitude difference between two ends is 70mm for 1m length pipe, so the diameter of exchanger's shell is taken 960mm.

Ⅳ. THE ANALYSIS OF ENERGY SAVING AND

ECONOMIC BENEFITS

Supposing the fuel used in the boiler is diesel, the combustion value of it is 46.04 MJ/kg. The recovering heat by seawater evaporator can be converted to the amount of diesel as follow:

$$\frac{Q\times 3600}{46.04\times 10^3} = \frac{250\times 3600}{46.04\times 10^3} = 19.55\text{kg/h}$$

If the boiler's working time is 7000 h/a, then the calculated freshwater output of the system is 2466t/a.

On the assumption that the efficiency of boiler is 80%, the recovering heat can be converted into the actual amount of fuel which is 24.4kg/h, with corresponds to the saving amount of diesel is about 170t/a. As the price of diesel is 5500 yuan(RMB)/t, it can be calculated that the cost of saving is 93.5×10^4 yuan(RMB)/a. If the cost of the desalination equipments is 30×10^4 yuan(RMB), the investing cost can be recovered in about four monthes.

Ⅴ. CONCLUSIONS

It introduces a new desalination process using the residual heat of flue gas. The calculation results show that using this process can save energy obviously and has better economic benefits.

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