Study on power generation performance of sea water evaporation steam

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Abstract. Seawater with softening pretreatment was used as the medium for experiment evaporation, and the influence of influent water, influent water temperature and flue gas flow on the steam flow and evaporation rate is discussed in this paper. The results show that with the increase of water inflow, the evaporation rate decreases at the beginning and then increases. Steam flow increases with the increasing water inflow; the increase of influent temperature has great influence on the evaporation rate and steam flow, however, the evaporation rate hardly changes when the influent temperature reaches a certain value; Steam flow and evaporation rate increases with increasing flue gas flow, and increases slightly with increasing before reaching 90m^3/h. The surface of the heating tube was analyzed by means of SEM and X-ray diffraction. These discussions and results has some guiding significance in designing evaporation equipment using softening pretreatment.

1. Introduction

Industrial water consumption is very large in China [1,2], among which the total amount of water used in power industry is 40%[3]. Cost allocation between power and water for a cogeneration plant has been a controversial issue, combining with the progress of seawater desalination technology in China and the existing problems, water-electricity cogeneration has been applied in many fields and has showed high efficiency[4].Gustavo et al. [5] proposed several methods to achieve the hydropower co-generation by using low-temperature heat sources such as waste heat from diesel generator, exhaust heat of back-pressure unit and extraction heat of condensing unit in multi-effect evaporation seawater desalination system. Neil [6] listed several methods for combined hydrogeneration of multi-stage flash desalination systems in the Middle East with back-pressure steam turbines, steam extraction steam turbines, gas turbines with heat recovery units, and combined cycle gas steam turbines. However, most of the current co-generation projects utilize the waste heat of power plants to desalinate freshwater from seawater production, and they still use large amounts of natural fresh water directly in the process of power generation [7]. Therefore, if the seawater can be treated as a substitute for fresh water for thermal power generation system, it will bring great social benefits, especially in cities with a shortage of fresh water resources in northern China.

In this paper the different operating conditions (such as water temperature, water inflow, etc.) of the treated water evaporation power generation, with a scanning electron microscope and X-ray spectrometer characterizing two different concentrations of calcium water heating pipe surface. The analysis provides an effective reference for the future seawater evaporation power generation.

2. Experimental part

2.1. Experimental water
In this experiment, the seawater was softened by a set of pretreatment process. The reaction was performed by adding Na_2CO_3 and NaOH to remove most of the Ca^{2+} and Mg^{2+}, nature and composition of water production as shown in Table 1.

Table 1. The product water quality

project parameters	numerical value
pH	7
TDS(mg/L)	25928
Conductivity(ms/cm)	36.3
FTU(NTU)	<0.1
Ca^{2+}(mg/L)	not detected
Mg^{2+}(mg/L)	not detected
SO_4^{2-}(mg/L)	120
Cl^-(mg/L)	15215
K^+(mg/L)	339

2.2 Experimental apparatus
Falling film evaporator evaporation chamber 316L is stainless steel processing, dimensions of 2422mm × 716mm × 866mm. The heat exchange tube adopts 316L stainless steel pipe, the specification is Φ20mm × 1.5mm, the effective length is L = 1350mm, and the heat exchange area is about 2.746m^2. A liquid spraying device is arranged above the pipe bundle.

2.3 Experimental method
The experimental process diagram as shown in figure 1, the raw water in the preheater (1) was pumped to the seawater evaporator (3) through a plunger metering pump (2). The preheated seawater entered the seawater evaporator and was uniformly distributed by the spraying device Sprayed onto the heating tube in the evaporator which was for falling film evaporation and separated to form concentrated seawater (8) and steam (5). Evaporation of steam was generated into the scrubber (6) and clean water diffusion occurred, and finally clean steam flowed into the generator (7) for power generation. In this experiment, the reflux valve is adjusted to control the water inflow. Data acquisition system, in order to ensure the experimental data is reliable, reasonable, accurate, used multiple measurement methods, multiple measurement points to minimize the error.
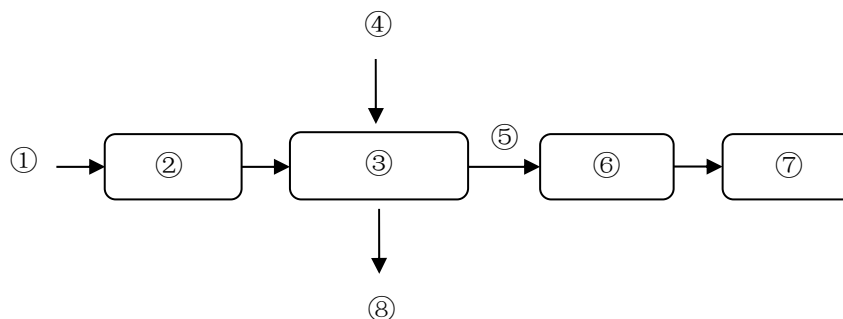
1. seawater preheater; 2. metering pumps; 3. evaporator; 4. liquefied petroleum gas; 5. steam; 6. washing tower; 7. generator; 8. concentrated seawater
Figure 1. Experimental process flow char

2.4. Analytical methods and apparatus

The thermocouple thermometer was used to measure the temperature of the system. The flow rate of the raw material liquid and the non-condensable gas were respectively measured by a liquid flowmeter and a gas flowmeter. The flow rate of steam condensate in each measuring water tank was measured at the same time using an electronic balance with an accuracy of 0.5g and a stopwatch. Surface morphology of the heating tube was conducted on s4800 cold-emission scanning electron microscopy (SEM) and X-ray spectrometry was for elemental composition analysis.

3. Results and discussion

3.1. Factors affecting the evaporation of seawater

3.1.1. Influent water on the amount of steam flow and evaporation rate. The effect of different water inflow (200L / h ~ 500L / h) on the evaporation rate and evaporation rate was compared with the same flue gas temperature, it can be seen from the figure 2 that the steam flow and evaporation rate increase as the water inflow increasing within a certain range (<450L / h). When influent exceeds 450 L / h, the steam flow continues increasing, but the evaporation rate does not increase obviously. 200L / h of water evaporation corresponding to the smallest amount of evaporation. This is because with the increase of water inflow, the liquid film gradually becomes stable, and the evaporation increases. Considering the evaporation effect, the amount of spray to ensure that the liquid film is not broken case as small as possible, so that the film will be thinning, shortening the preheating section, while the liquid in the heat pipe wall residence time long enough heat transfer, high evaporation rate.
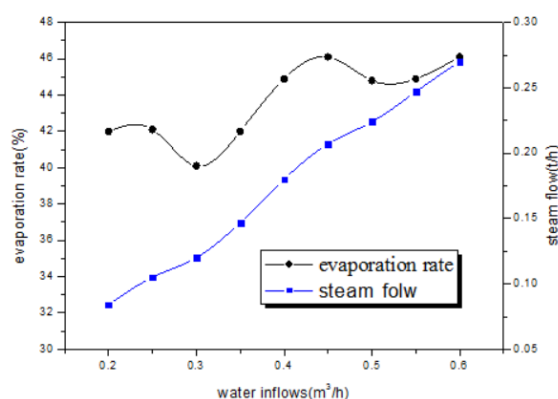

Figure 2. Effect of water inflow on steam flow and evaporation rate

3.1.2. Influent water temperature on the steam flow and evaporation rate. By adjusting the amount of water heat exchanger inside the heat or cold water into the amount of access, different feed temperatures are obtained. Which can be seen from the figure 3, the evaporation rate is only 33% when the inlet water temperature is only 15 ° C. When the feed temperature is in the range of 35 ℃ ~ 58 ℃, the steam flow and evaporation rate increase with the increase of feed water temperature; when the feeding temperature is 60 ℃, the corresponding seawater evaporation rate reaches 48%. With the further increase of feed temperature, seawater evaporation rate and steam flow did not increase anymore, showing a steady trend. This is because the seawater through the preheater, so water as close as possible to the bubble point, sea water temperature raise in the water evaporation chamber only part of the heat can reach boiling temperature, significantly increasing the evaporation chamber heat transfer efficiency, which can improve the system's processing power.
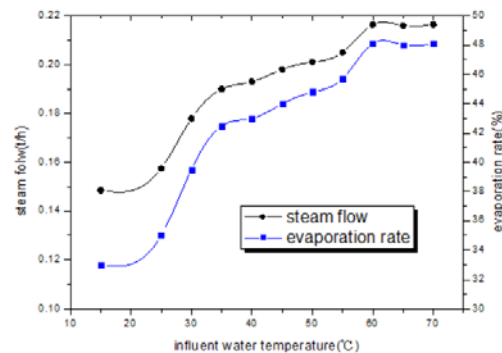
Figure 3. Influent water temperature on the steam flow and evaporation rate

3.1.3. Flue gas flow on the steam flow and evaporation rate. As can be seen from Figure 4, the flue gas flow rate is 50m^3/h, the steam flow and evaporation rate are only 112.5kg / h and 25% respectively. After that, the steam flow and evaporation rate gradually increased with the increasing of intake air flow rate. When the flue gas flow rate increased to 95m^3/h, the steam flow and evaporation rate were only 225kg/h and 50% respectively. Since then with the flue gas flow continues to increase, steam flow and evaporation rate increase is smaller This is due to the fact that the higher the temperature, the better the evaporation of water. However, in view of the test economy, the most suitable flue gas inlet flow is 95 m^3/h.

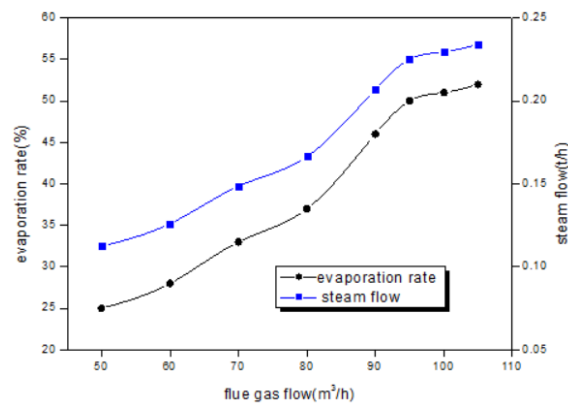**Figure 4.** Effect of flue gas flow on steam flow and evaporation rate

3.2. Characterization of contaminants

3.2.1. Heating pipe surface characterization. The surface morphology of the samples was observed by SEM. The heating tube in this experiment was a stainless steel structure with a rough surface. It can be seen from the figure 5 that the surface of the heating tube after the hard water evaporated is relatively rough and the shape is very irregular. Figure 6 is the surface of the heating pipe after the seawater evaporating, the original rough surface becomes dense and regular. This is mainly because of the formation of dirt Ca element, which attached to the surface of the heating tube. The heating tube is filled with aggregates, changing the shape of the heating tube.
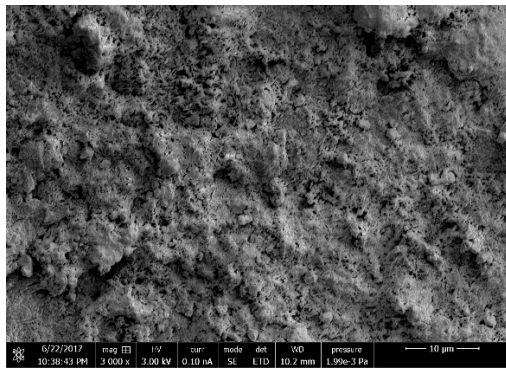
Figure 5. De-hard seawater
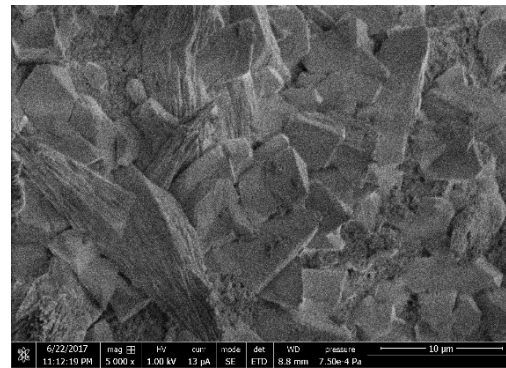
Figure 6. Untreated seawater

3.2.2. Spectrum Analysis (EDX). Energy Dispersive X-Ray Spectroscopy(EDX) was employed to determine the composition of pollutants. It can be seen from Table 2 and Figure 7 that after running the comparison of two heating tubes, it can be seen that the content of Ca in the hard seawater is very little, no fouling is formed, the heat transfer coefficient is reduced, and the normal operation of the evaporator is affected. The use of seawater evaporation, we can see the surface of the heating tube gathered a large number of pollutants which was formed by the Ca, these pollutants greatly reduced the heat transfer efficiency of the evaporator, impeded the transfer of heat, and affected the evaporation efficiency and device running.

Table 2. Results of line energy spectrum analysis

De-hard seawater heating pipe			Untreated seawater heating pipe		
element	Wt%	At%	element	Wt%	At%
Ca	1.043	0.55	Ca	59.44	56.87
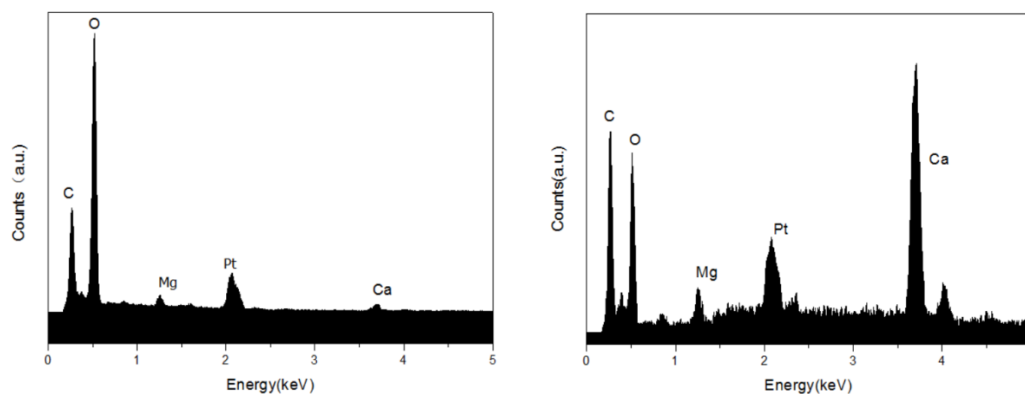
Figure 7. EDS spectra of two kinds of seawater

4. Conclusion

The result has shown that the steam flow and evaporation rate affected by many factors.，from the present evaporation tests we conclude:

(1) With the increase of water inflow, the evaporation rate decreases at the beginning and then increases. Steam flow increases with the increasing water inflow.

(2) The influence of influent temperature on the evaporation rate and steam flow is basically an increase. However, the evaporation rate hardly changes when the influent temperature reaches a certain values(60 ℃).

(3) Steam flow and evaporation rate increases with increasing flue gas flow, and increases slightly with increasing before reaching 90m^3/h.

(4) Cold-field SEM and Energy Dispersive X-Ray Spectroscopy were employed to determine the morphology and elemental analysis of the heating tube. Analysis found that the heating tube after the hard water was completely evaporated did not accumulate. However, the direct heating of the heating tube adhered to the surface of the heating tube of the pollutants, the evaporation efficiency is too low. Resulting in reduced evaporation affect the operation of the device. By energy spectrum analysis, this contaminant was identified as calcium salt, a common soil in desalination of seawater.

Acknowledgments

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