Characteristic study on heat-pump evaporation system for concentrating of waste solutions

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Abstract: The advantages of its energy conservation and environment protection are firstly stated when an industrial heat pump technology is applied for evaporation process of waste solution. Based on a concentrate need of zinc sulfate, a process design of heat-pump evaporation system is done, and a heat-pump prototype combined with water lubrication during compression stage is developed. Then, as far as the prototype machine, its characteristics of evaporating and concentrating zinc-sulfate solution are tested and analyzed by an experiment way when the heat pump runs according to the designed process. The study results shows that its concentration factor of zinc sulfate could be more than 3.0 by heat-pump evaporation process. And its energy-efficiency ratio (EER) could not be less than 4.6 as far as heat-pump evaporation prototype.

Background

In industry, a heat pump is thermo-technical equipment that could recycle some waste heat from exhaust fluids. It consumes some high grade energy to reuse lots of low grade one. Compared with conventional multiple-effect evaporation, heat pumps those are applied for evaporation process do not need original stream from boilers so as to avoid environment pollution from coal boilers[1][2]. Heat pumps could be adopted conveniently where there is only enough electric power. Consequently, the heat-pump technology is defined as energy conservation and environment protection. National policies of energy conservation and emission reduction carry out step by step, so heat-pump evaporation process will be applied widely in future industries.

At present, in overseas areas without plenty of water, the heat-pump evaporation is applied to desalination of seawater by researchers, and some perfect fruit has be gained [3~6]. In salt industry, this technology is forming its market and according to open references, some domestic big factories have installed the equipment [7] [8]. The heat pump evaporation systems of desalination or salt manufacturing are very complicated and their production capacity is quite large. It became a focus that process of waste solution is concentrated by heat-pump evaporation. The research fruits are helpful to meet the discharge standard of waste solution as far as chemical factories.

Based on the need of medium and small evaporation in industry, a heat-pump prototype with compact structure and simple manipulation is developed. It is designed to concentrate a solution of zinc sulfate. It provides data for optimization of latter systems by measuring and analyzing the performance parameters of this prototype unit.

Principle and process

As shown in figure 1, this heat-pump evaporation system is made of three main parts which are a compressor, an evaporator and a separator. Additionally, there are also some assistant parts such as pump and valve. External zinc sulfate that is collected into a tank defined as waste solution is preheated by the preheater firstly and then is given to the evaporator by the feed pump. The solution of zinc sulfate is heated in the evaporator where some concentrated solution remains after water is evaporated from the original solution. The zinc sulfate will be sent by the discharge pump to a tank called as concentrated solution when its concentration is content. On the other hand, the vapor mixture of some water and some zinc sulfate goes into the separator. Pure vapor separated from the mixture is compressed by a single-screw compressor, and then will step into the evaporator to heat the waste solution for both of its temperature and pressure are also high. The left separated part is sent to a cycle way to process again by the circulation pump. The vapor heating the original waste solution becomes high-temperature water which is then given to the preheater by the condensate pump. After it preheats the feed waste solution, it gathers together into a tank called as distilled water.

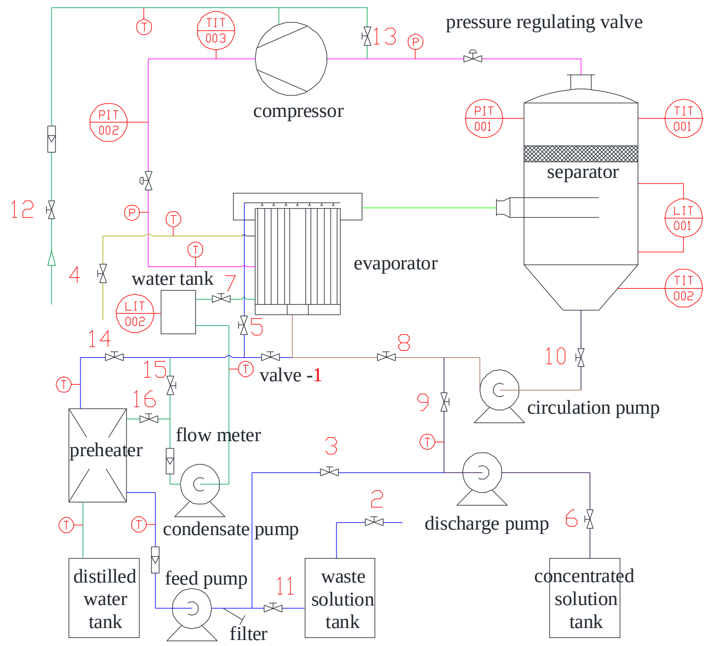


Fig.1 Principle and process of heat-pump evaporation on zinc sulfate

During the disposal, the evaporation pressure and temperature could be adjusted instantly according to evaporation process of zinc sulfate. Those condensing pressure and temperature of compressor are controlled by regulating valves. In order to adjust its function, there is an additional installation of electric heater in the heat-pump evaporation system. With the help, its thermal equilibrium will be stable and great running fluctuation will not appear.

Prototype and test installation

Fig.2 Heat pump prototype Fig.3 Test installation of heat pump

The heat-pump prototype for evaporation on zinc sulfate is shown in figure 2. Lots of operating parameters are recorded when zinc sulfate is concentrated, and they are done based on a test installation shown in figure 3.

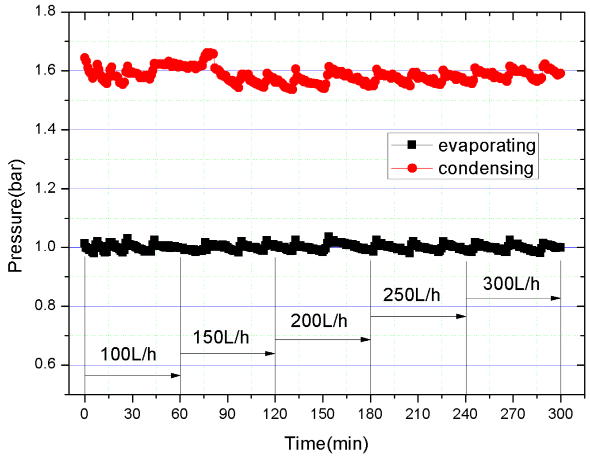
The installation for operating characteristic and function test of heat pump monitors and records on-line those parameters of each work stage. These parameters are such as pressure, temperature, position of solution, fluid flux, power, frequency and so on. Those sensors are pressure transducers, thermocouples, thermal resistance, electric heat adjuster, ammeter, flow meter with metal floater, and fluid-position measure with magnetic floater. All of these data are saved by an instrument called as agilent. The technical parameters of all measures are shown in table 1.

Table 1. Technical parameters of all measures for heat pump

Sensors	type	precision	range
Heat resistance	PT100	0.1	-50~400˚C
Thermocouple	T	0.1	-50~200˚C
Pressure transducer	Pressed resistance	0.5	0~0.5MPa
Fluid-position measure	with magnetic floater	±10mm	0~300mm
Flow meter	with metal floater	1.5	0~500L/h
	with glass floater	2.0	0~400L/h
Electric heat adjuster	Voltage adjusting	1.0	0~260V

Data disposal and analysis

When the experiment of concentrating zinc-sulfate solution is done by this heat-pump evaporation system, its evaporation pressure is set at 1.0 bar. In experiment, its operating characteristic of a single-screw compressor is tested with water lubrication firstly. During testing, the change of injected water is same manually every time. The range of injected water is 100~300L/h.



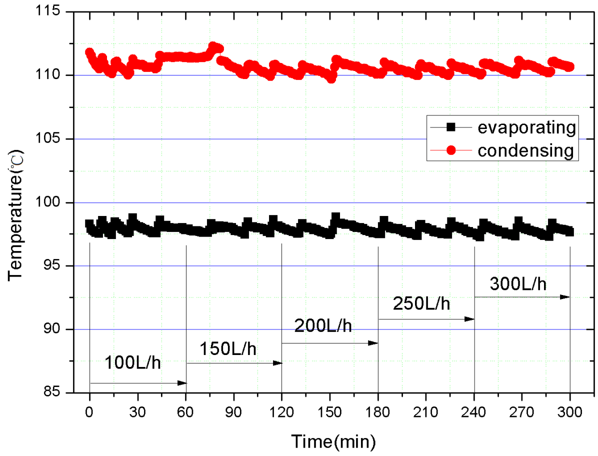
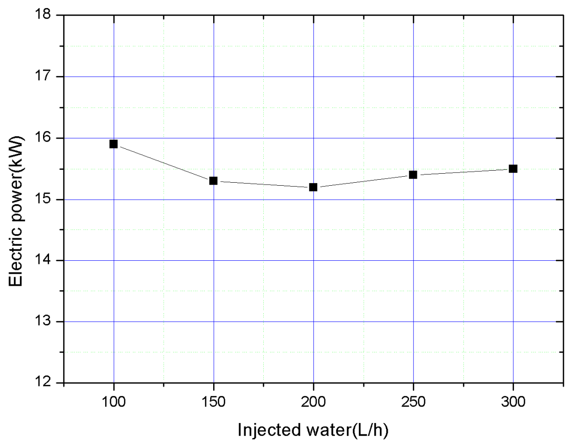


Fig.4 Pressure trend with injected water   Fig.5 Temperature trend with injected water

As shown in figure 4, the evaporating and condensing pressure of heat-pump prototype keeps constant with increase of injected water. During its stable run, compression ratio is about 1.6. Accordingly, operating pressure is not affected by the change of injected water. The time of each operating state is more than one hour for testing when its injected water goes up from 100L/h to 300L/h.

As shown in figure 5, the evaporating and condensing temperature of heat-pump prototype keeps constant with increase of injected water. It is related with the pressure of heat pump. Its condensing temperature is closed to that saturated temperature got from tested condensing pressure. However, its evaporating temperature is lower than that saturated temperature got from tested evaporating pressure. It is statics pressure difference that boil point of produced vapor goes up. What is more about its reason, it is because of the high fluid position in the evaporator.



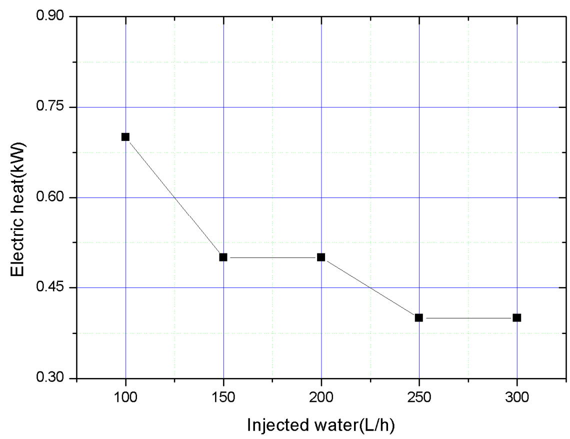


Fig.6 Trend of electric power with injected water   Fig.7 Trend of electric heat with injected water

As shown in figure 6, when the injected water increases from 100 L/h to 300 L/h, the input electric power decreases firstly. However, it goes up again while it gets lowest. The injected water is about 200 L/h as the input electric power is lowest. When the injected water decreases, the water going into heat circuit reduces. The injected water is hot condensing water and heats the solution of evaporation side. As a result, while the injected water goes down, there is much work transformed into heat to add up. That is to say, the input electric power goes up. While the injected water is excessive, the load of compressor increases, and so the input electric power goes up.

As shown in figure 7, while the injected water increases, the electric heat adding up reduces gradually. It goes down from 0.7kW at an injected water of 100 L/h to 0.4kW at 300 L/h. The more water is injected, the more water goes into heat circuit. It could add more heat up to heat loss of the whole system, and so the electric heat reduces more correspondingly. On the other hand, the supplementary heat goes down while the input electric power increases.

In figure 8, the trend of evaporating water is shown. At early stage of injected water 100L/h, its evaporating water is as much as 280 L/h. Afterwards, it reduces a little, and keeps about 272L/h. With increase of injected water from 150L/h to 300L/h, its evaporating water does not change nearly, being about 272 L/h. Accordingly, its evaporating water is affected a little when its injected water increases from 100 L/h to 300 L/h. If the system could run safely, the injected water may also be adjusted according to the range of 100~300 L/h.

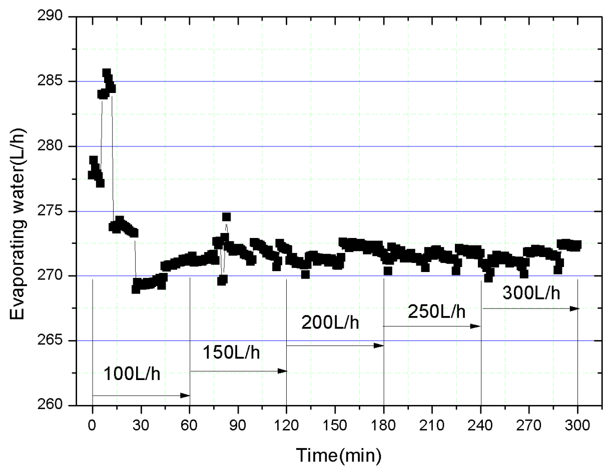
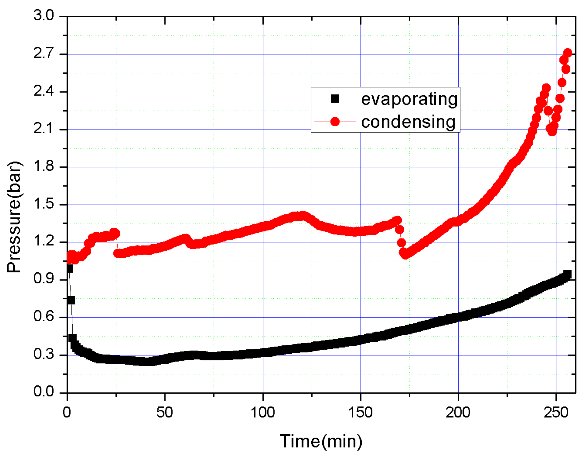


Fig.8 Evaporating water trend with injected water

Based on those experiments above, the concentrating of zinc sulfate by heat pump evaporation is done according to its solution characteristic. During its stable run, the evaporating temperature is 70~75˚C and the injected water is 200L/h at electric frequency of 50Hz.



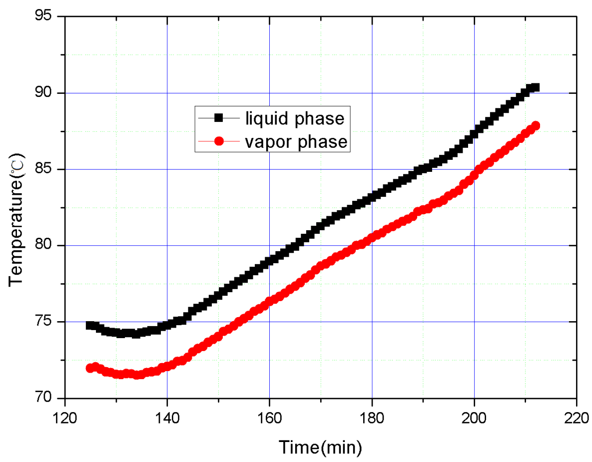


Fig.9 Pressure trend during evaporation Fig.10 Trend of fluid temperature during evaporation

The pressure trend of whole evaporation process concentrating zinc-sulfate solution is shown in figure 9. The system runs stably for about two hours at its early stage. During this stage, its evaporating pressure keeps being about 0.3bar. However, its condensing pressure goes up step by step. The compression ratio is about 4.0 though there is a little increase. With evaporation goes towards, zinc-sulfate solution reduces gradually. When its circulation pump shuts off, it evaporates at a different mode defined as spontaneous evaporation. At latter stage of evaporation, its evaporating pressure rises gradually and its increase of condensing pressure is more than that of early stage. Its condensing pressure is about 2.7bar while evaporating pressure goes up to be 0.9bar.

Here, its compression ratio is about 3.0. During the whole evaporation, there is reduction of condensing pressure because non-condensing gas discharges at some time.
During practical evaporation of some solutions, their temperature of saturated vapor is higher than their boiling temperature. It is because their concentration goes up and there is static pressure difference of solution. The trend of boiling temperature is shown in figure 10 as far as zinc-sulfate solution. At early stage of stable evaporation, the temperature of solution is about 2.5˚C higher than that of evaporating saturated vapor. At latter stage, its evaporation is not stable because its concentration of zinc sulfate becomes great and its evaporation mode changes. With its temperature increase of evaporation, saturated vapor temperature goes up. At the same time, the temperature of zinc-sulfate solution goes up and its increase is a little higher than saturated vapor.
The comparisons between initial and concentrated of zinc-sulfate solution are shown in table 2.

Table 2. Comparisons of zinc-sulfate solution parameters

Initial solution		Process parameters		Concentrated solution		EER	Concentration factor
mass(kg)	concentration	evaporating water (kg)	power (kWh)	mass (kg)	concentration	Evaporating water/power	Initial solution /concentrated
170	8%	115	24.9	55	20%	4.6	3.1
231.3	7%	165.8	32.7	65.5	18%	5.1	3.5

Conclusions

The process of concentrating zinc-sulfate solution is done successfully by heat-pump evaporation. It runs stably in practice and some expected results are got. The conclusions are shown following.

1）it is viable that the process of concentrating zinc-sulfate solution is done by heat pump evaporation driven by an single-screw compressor with water lubrication. The theoretical design of heat-pump prototype is accordant during its practical run.

2）During that process of concentrating zinc-sulfate solution done by heat pump evaporation with water lubrication, its boiling-point rise temperature caused by solute is about 2.5˚C.

3）As far as this heat-pump evaporation prototype concentrating zinc-sulfate solution, its concentration factor could be more than 3.0, and its energy-efficiency ratio (EER) could not be less than 4.6.

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