Research On Effective Utilization Of Thermal Energy In Vacuum Salt System

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Abstract This article puts forward the direction, technological ideas and measures of using thermal energy in vacuum salt system based on thermodynamic analysis.

Keywords Vacuum evaporation, Heat pump, Heat economy.

1 FOREWORD

In recent years, the tension of energy and environmental deterioration have become the world's hot spots and focus of attention. The Chinese government's 11th Five-Year Development Plan has defined the production consumption's targets. Under such a background, It is a wise choice for manufacturers to eliminate outdated production technology and equipment, and depend on independent innovation, technological advancement, adopt the way of less resources consumption , better economic returns and environmental friendly.

In the salt industry, the fuel and power consumption are the main components of the production costs (as shown in Chart 1), and the consumption of raw coal constitutes the main part of the fuel and power (as shown in Chart 2). The coal consumption of the vacuum salt is mainly reflected on the heat (steam) and power's consumption, it's very meaningful that to make effective use of heat (steam) and reduceg power consumption for production.

Chart 1 cost composition of salt

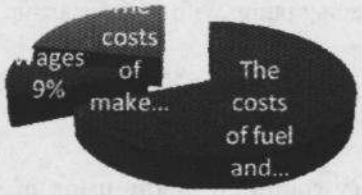
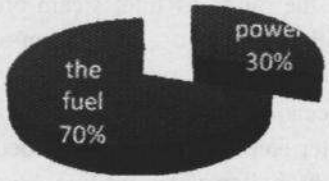


Chart 2 cost composition of fuel and power



2 ANALYSIS OF THE HEAT IN EVAPORATION PROCESS

2.1 The form of heat in evaporation process

Multi-times evaporation system relies on two conditions that is heating and decompressing. Saturated water steam is used as the heating sources, while decompressing is realized by vacuum equipment. In the Multi-times evaporation course, the steam's enthalpy has two forms, one is sensible heat, the other is latent heat. Heating and evaporation is

realized by the steam's latent heat and sensible heat alternatedly. The total heat of steam remains unchanged after depressing the temperature and reducing pressure, but its quality degrades with lower value.

2.1.1 Sensible heat of the evaporation

For solid, liquid or gaseous material, when being heated, as long as its state is not changed , its temperature will rise, the heat added can be indicated by temperature, such heat is called sensible heat.
In the multi-times vacuum evaporation system, Sensible heat is the enthalpy difference between brine into tank and condensated water. Sensible heat isn't the main part of total enthalpy, but it will directly affect the economic value of the thermal evaporation system.

2.1.2 Latent heat of the evaporation

For example, if the water temperature reaches boiling point when being heated, but the water temperature does not rise even more heat is being added continuously , the temperature will stay at boiling point, the heat only make water change into steam. such heat is (also known as phase-change) called the latent heat.
In the multi-times vacuum salt system, latent heat is the heat difference between the steam and the second steam. The steam and the second steam contain a large amount of heat which is the main part of the steam's enthalpy, it is the evaporation's power.

2.1.3 Relation between the two heat energy

Table 1 the relationship between the saturated steam's latent heat and sensible heat with the pressure

Saturated pressure MPa	0.1	0.2	0.3	0.4	0.5	0.6	1.0	1.5
Sensible heat of the total heat %	25.1	27.5	29.2	30.8	31.8	33.2	36.9	40.8
Latent heat of the total heat %	74.9	72.5	70.8	69.2	68.2	66.8	63.1	59.2

From Table 1 and Chart 3, we can know that: with the pressure of steam become lower, Sensible heat gradually reduces while the proportion of latent heat increases in total steam heat, therefore, in the high temperature and high pressure stage, we should pay attention to the latent heat as well as the sensible heat of the condensated water, while in the low temperature and low pressure stage, attention should be paid on the latent heat of the second steam.

2.2 Thermodynamics analysis of evaporation process

In order to analyze the thermodynamics of the evaporation process, we suppose the evaporation process to the brine as an adiabatic process. and make further simplify the heat transfer of multi-times evaporation process as the transformation of the same heat source.

Chart 3 Relation of the latent heat and sensible heat of the steam

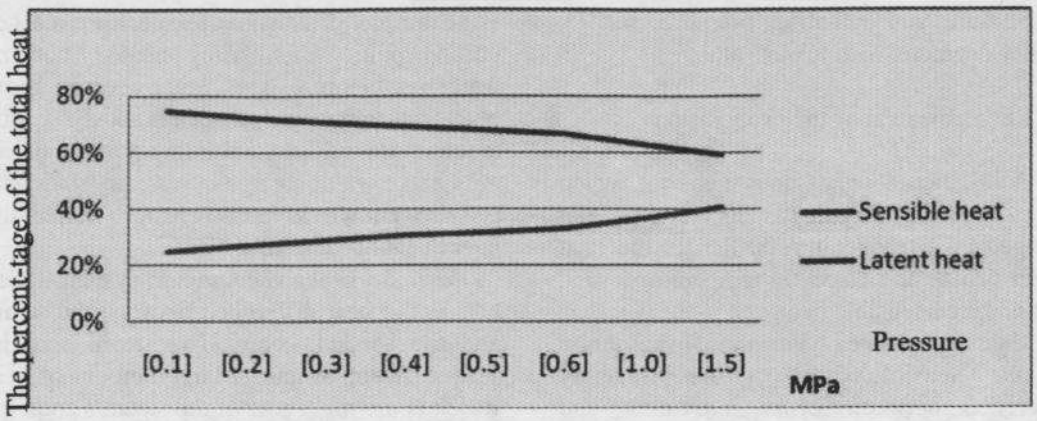


Chart 4 shows an one-effect evaporation process, the working substance is the superheated steam, the second steam is wet steam. From figure 4, we would see that working substance from the state 1 (p_1, t_1) along the dotted line to the state 2 (p_2, t_2), there are two processes. The first process is a heat losing process, the working substance along the isotherm to pressure line P_2, the working substance's temperature does not change, the latent heat is changed into the sensible heat, the steam is condensed into water. The second process is the unchanged pressure process, the working substance along this line to the state 2, the temperature of the working substance fall low, the form of the heat is changed back to the latent heat, this means the salt water is evaporated. In the evaporation process, the working substance's internal energy and enthalpy is changed low, but the working substance's entropy is increased, it shows that the evaporation process is irreversible, and the high heat is changed into the low the low heat.

Chart 5 is the multi-effectd evaporation process, the working substance and the second steam are the saturated steam. We can see that the entropy of the steam is changed high in every time, the working substance's temperature will be reduced, the heat substance 's heat is the conversion from various forms of heat, its heat state will be degraded. If the difference of temperature gets small enough between each effect in the evaporated system, that means the difference in temperature is supposed to e zero. The heat would be converted amid latent and sensible heat, so the heat economy will tend to be infinity.

In fact, $\triangle t$ cannot get a value of small enough to be similar to zero that means $dt \rightarrow 0$ is not achievable. There are many forms of heat loss in the evaporation process, e.g. flash, static pressure, overheating and tube stop etc. if the effective temperature difference is small enough ,the evaporation process cannot be operated, However, the study found in the evaporation system that the steam must have condition for entropy increase, the heat can be recycled more times with higher thermal economy of evaporation.

Chart 4 enthalpy-entropy diagram of one-effect system

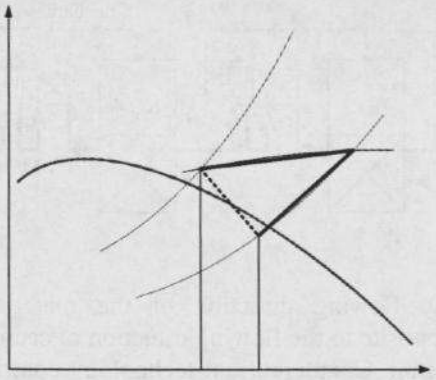
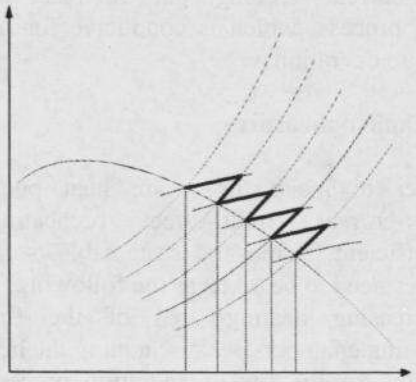


Chart 5 enthalpy-entropy diagram of multi-effect system



What need to be explained more, the irreversible evaporation process does not exist, the heat of the working substance can not pass the heat by a hundred percent the to next-effect evaporation, there always is some part of the heat being brought out from the evaporation system. Practical production can not live up to the infinite thermal economy, because each evaporation must cost the device's devotion and consumption of power. After analyzing the enthalpy-entropy diagram in evaporation, we can understand some theories of the heat transfer in the evaporation process, which can guide the effective and economical utilization of thermal energy.
In the multi-effects evaporation system,

1) the multi-times evaporation process is irreversible.
2) The water's evaporation is realized by the heat transformation of the latent heat and sensible heat many times.
3) Under conditions for entropy increase, the more the recycling times the better the heat economy
4) In the evaporated process, the total heat of the working substance will not change, but the energy efficiency degrade as effects increase.

2.3 Heat direction of the evaporation

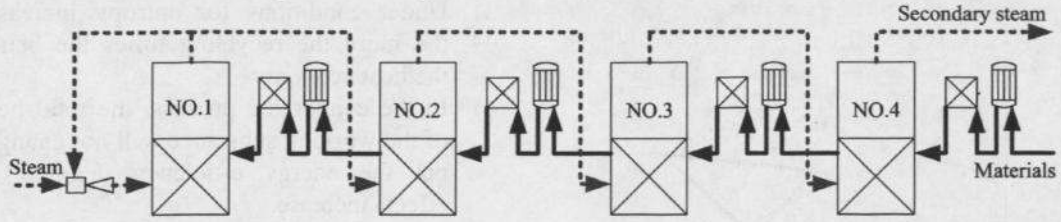
For multi-effects evaporation system, the more times of the enthalpy of steam being used, the better the heat efficiency, but it is subject to two restrictions. On the one hand, the effective temperature of the evaporation system determines that the effect of the evaporation effect can not be excessive; On the other hand, investment in equipment and power consumption limits the number of evaporation. Factors that affect the evaporation is very much, in this paper, we do not introduced them in details , The article expatiated only how to make use of latent heat of secondary steam and sensible heat of condensated water to obtain a higher efficiency.

1) Part of latent heat of second steam is used repeatedly by itself.
2) Enhancing the efficiency of flash operation to condensed water, and recycle some sensible heat of the condensed water.
3) Using condensed water warm brine up to get back more sensible heat.

3 PROPOSE ON EFFICIENT EVAPORATION PROCESS

According to the effective use of heat in multi-effect evaporation, and principles of controlling equipment investment and energy consumption, the efficient evaporation process adds a steam pump to the four-effects evaporation process, and recycle some steam of the first evaporator. The feed system will adopted the adverse current process, using the second steam and condensed to warm brine up. Envision of the efficient evaporation process is shown as follows.

Chart 6 Schematic diagram of the process



3.1 The steam heat pump

The steam heat pump is using the high temperature and high pressure steam to generate high-speed airflow for absorbing, compressing and heating the lower ones, and then used for heating materials. The principle is the same with mechanical steam compressor. In the whole process, the high temperature and high pressure steam does a small amount of compression work, the secondary steam can be recycled, thereby improve the energy efficiency.

Compared with the five-effect process, four-efficiency technology can make up for heat efficiency by the heat pump, But its investment in equipment is economic and with lower power consumption.

3.2 Boiling point feeding

As well known, progressive preheating is an effective way of energy saving in multi-effect evaporator system. This technology use the secondary steam and condensed water as sources of heat for preheated brine. So that the temperature tends to close to the temperature of evaporator, which will greatly improve evaporation efficiency. The reasons are as follows:

1) Preheating process uses the sensible heat of the secondary steam condensated water, which increases the times of heat being used.
2) In the course of feeding, the system has raised the temperature of brine, and the heat would be used in evaporation rather than be used to heat brine, which saves most of the heat for circulating, and the circulating force only was consumed by the heat transfer in evaporation.

3.3 Countercurrent feeding

The so-called counter-current process means the flowing direction of the materials is opposite to the flowing direction of secondary steam. Countercurrent technology contributes to the economy in that it will recycle part of the heat letter to the previous evaporator, which will increase the times of reuse of the thermal energy. On the other hand, counter-current feeding put forward the heating process ,which is conducive for the follow-up operation.

3.4 Technical measures

In order to make the steam heat pump (counter-current, multi-effect preheating) more efficient, stable and sustainable, some measures need to be taken as the following,

1) Increasing heating area of the first heating chamber. Because adding the heat pump for the first evaporation process, the heat chamber has more than energy than others, when the heat flux increase, the heating area is doomed to increase.
2) Technical concepts, lower temperature difference and larger heat exchange area. Compared to domestic and foreign concepts, foreign technical concept is more inclined to lower temperature difference and larger heat exchange area. The reason is that lower temperature difference can reduce to loss of energy in evaporation.
3) Brine purification. Because the brine contains Ca^{2+}, Mg^{2+}, SO_4^{2-} and other impurities, in the heating evaporation process, these impurities will precipitate on the surface of the heating pipe, it will lead to resistance, blocked tubes and corrosion etc. seriously affecting the heating of materials and stable and effective transportation. In addition, these impurities continuously enrich in evaporation, and will increase the boiling point of liquid, which is not conducive to efficient evaporation.

Countercurrent feeding technology is not suitable for materials with higher boiling point, therefore, it is necessary to carry out on the purification treatment of brine.

4 CONCLUSION REMARKS

In the multi-effect evaporation system, there are still more than 70% of the total enthalpy is discharged in the form of gas, which is of certain grade. when discharged directly to environment, it will not only cause thermal pollution, and also need to consume a large amount of cooling water. How to consume little energy, and to recycle a large amount of latent heat of the exhausted steam, I think this will be a very meaningful subject.

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