STUDY ON THE APPLICATION OF HEAT CONDUCTIVE OIL TECHNOLOGY IN THE HEATING CIRCULATORY SYSTEM FOR VACUUM SALT PRODUCTION AND THE ENERGY SAVING MEASURE

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Abstract: As the salt industry develops, the consumption of the energy resource of coal and natural gas also increases. The issues of energy consumption reduction, the energy resource saving and the emission reduction have become an increasingly prominent issue. In this paper, the main reason of the low thermal efficiency of the heating circulatory system in the traditional vacuum salt production was analyzed. The development and application of the heat conductive oil was discussed. The heat conductive oil technology was applied in the heating circulatory system for the vacuum salt production and the solutions were provided for the difficult problems in the application of the conductive oil technology. At the end of this paper, the concept of the development of novel heating circulatory system for the vacuum salt production was raised.

Keywords: heat conductive oil technology, vacuum salt production, energy saving

1. INTRODUCTION

As the advanced technology from abroad was continuously introduced to our county, the vacuum salt production technology of our country has developed fast in the recent years. Especially, the utilization rate of the waste heat and pressure has been increased remarkably by using the multi-effect vaporization process for salt production. In the area of heat supply, as the medium and low pressure fluidized bed boiler develops, whether use the gas-fired boiler or the coal-fired boiler, the combustion efficiency is close to that of the advanced technology in abroad. Because our country is rich in coal resources, the coal-fired boiler is used in most of the salt production systems.

However, in the heating circulatory systems for vacuum salt production, water is used as the working fluid, whether the gas-fired boiler or the coal-fired boiler is used. Hence, there are three inherent disadvantages for the heat utilization: firstly, because the high pressure and temperature, the steam produced by the boiler can not be sent to the salt production tank to heat-exchange and this will cause heat and water loss; secondly, the steam after heat-exchanging in the salt production tank, the wet salt dryer or other heating equipment can not be sent directly back to the boiler and must be treated by a series of measures, including de-aeration, condensation, purification and etc. Even if the second heat energy is utilized, the problem of low efficiency also exists; thirdly, the method of vaporizing the water in the halogen is the least economical method. Because of the characteristics of the water vaporization at constant temperature, the average endothermic temperature of the circulatory system is low. Hence the temperature difference increases and the irreversible loss increases. In order to solve these problems, the concept of heat and power cogeneration for the salt production has been raised. Referring the heat and power cogeneration system for salt production, we have to know the status of the development of the steam powered cycle generation technology.

According to the engineering thermodynamics, for the steam powered cycle generation, the efficiency is high with steam of high initial pressure and temperature. Hence, supercritical pressure steam powered cycle generating units (pressure≥24.2 MPa, temperature≤580 ℃) are currently constructed vigorously in our country. Moreover, the large sized generating units and super-supercritical pressure units (pressure≥27 MPa, temperature≤600 ℃) develops rapidly. The efficiency of these generating units is 14% higher than that of the medium pressure backpressure turbine circulatory generating untits which are currently used in the salt industry. Furthermore, as can be seen from the characteristic of the current vacuum salt production system, the turbine generating units are the main body of the whole system. The salt production is merely the process of utilization of the waste heat. This kind of power generation is neither the main industry in the salt industry nor the predominant item. Though the people have used various measures to increase the heat efficiency, the problem of low efficiency is still unsolved. How to solve this problem is the important subject in the field of vacuum salt production industry.

Fortunately, as the heat conductive oil technology develops and especially as the heat conductive oil is used as working fluid in the gas-fired, the oil-fired, and the coal-fired boiler, new hope emerges for increasing the heat efficiency remarkably. The technology development and the application of the heat conductive oil provide technological support for the research and development of highly efficient heating circulatory system and equipment for salt production. In this paper, the application of the heat conductive oil technology in the heating circulatory system for vacuum salt production, as well as the energy saving of the application, was discussed.

2. THE CHARACTERISTIC OF THE HEATING CIRCULATORY SYSTEM FOR THE TRADITIONAL VACUUM SALT PRODUCTION AND THE ANALYSIS OF THE HEAT EFFICIENCY

Currently, water is used as the working fluid in the heating circulatory system for the vacuum salt production. The process is : (1) combustion of the fuel; (2) vaporization of the water; (3) after decompression, the vapor exchanges heat with the salt production system; (4) the condensed water is sent to the boiler after deaeration and purification.

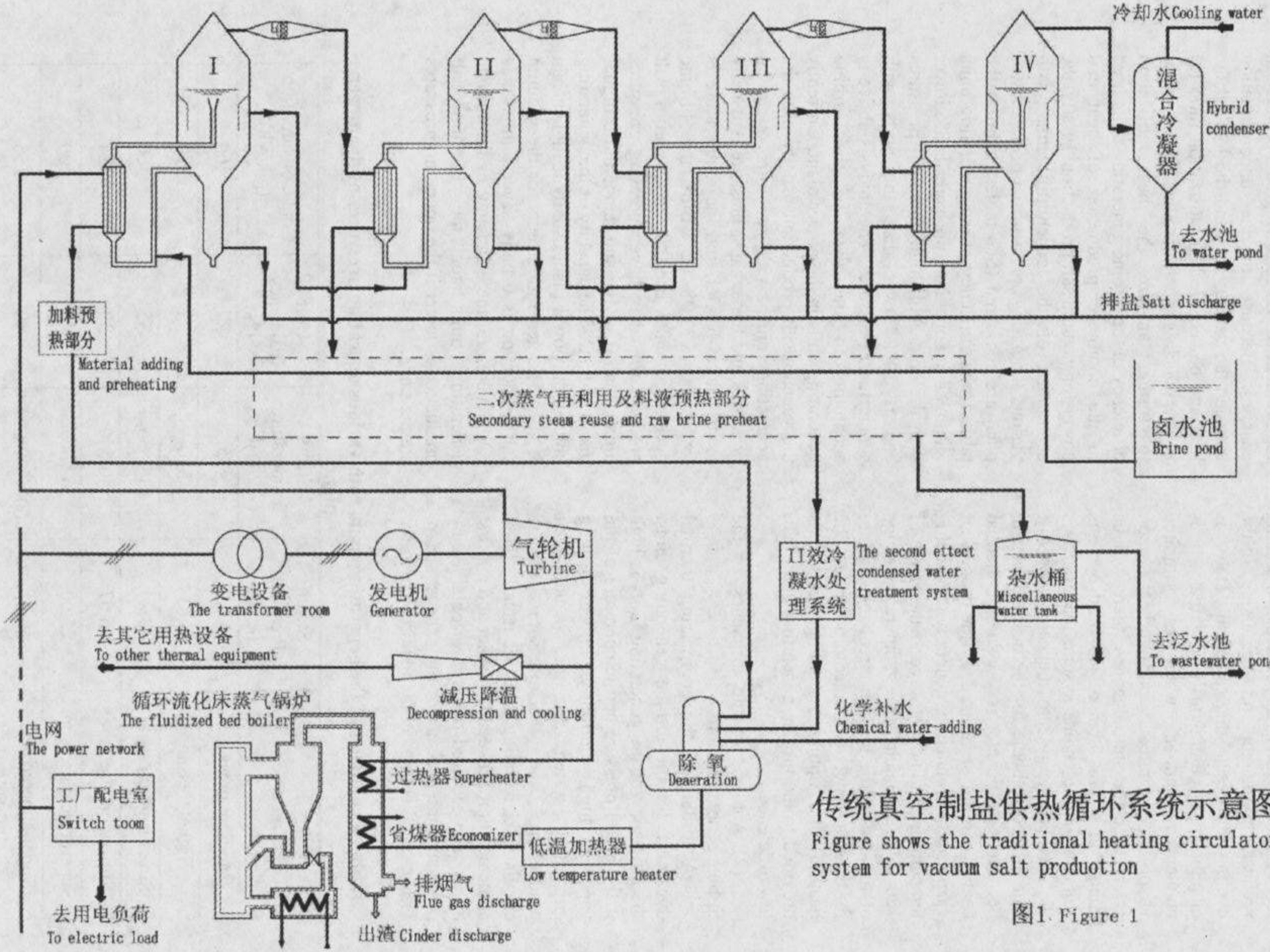
2.1 The characteristics of the heating circulatory system

As the development of the heating circulatory system for vacuum salt production, a series of heating circulatory systems with different constructive characteristic and operating parameters appeared. The heating circulatory system can generally be divided into four parts which are heat source (gas-fired, coal-fired boiler), decompression and cooling part (turbine generating units), heating part (heat-exchanger), water treatment part (deaeration, purification, and soft water treatment device). Figure 1 shows the traditional heating circulatory system for vacuum salt production.

Heat source: the equipment that can be used as the heat source can be divided into two types. The first one is the gas-fired boiler in which natural gas is used as the fuel. The characteristics of the gas-fired boiler includes high combustion efficiency, no pollution, wide range of the boiler capacity, small footprint; The second one is the coal-fired boiler. There many types of coal-fired boiler. Currently, the advanced circulating fluidized bed boiler is widely used. The characteristics of the circulating fluidized bed boiler includes high combustion efficiency, good adaptibility for various types of coal, and low pollution.

Decompression and cooling part: the typical equipment for decompression and cooling mainly include the backpressure turbine circulatory generating units and the direct decompression and cooling devices. The common characteristics is low heat efficiency. The cost of the turbine circulatory generating units is high, and the maintenance.

Water treatment part: for the properties of the steam, the water must be according to the Carnot cycle. This kind of exposed cycle consumes a lot of steam. In the cycle, the working fluid absorbs a great amount of oxygen. Hence, deaeration must be applied to the condensed water. The water used by the boiler should be softened if the running water is used. If the condensate from the effect after the second effect is used, the condensate should be purified.



传统真空制盐供热循环系统示意图

Figure shows the traditional heating circulatory system for vacuum salt produotion

图1 Figure 1

2.2 Analysis of the efficiency of the heating cycle using water as working fluid.

As the working fluid, cycle system can be completed after three steps, including preheat, vaporization and overheating. In the cycling process, the physical state is changing continuously, that is condensate-saturated water-wet saturated vapor-dry saturated vapor-overheat vapor. Every time the state changes, there will be energy loss. This kind of gas-fluid cycle is suitable for the engine system that transfers the thermal energy into mechanical energy. But it is not suitable for the heating system, because the efficiency is low and the thermal energy can not be utilized. In the process of vacuum salt production, generally the heating temperature should not beyond the range of 120-160 ℃, which is the temperature range of the end of the heating circulatory system for the heat-power combined production. The heat of the optimum heating section is provided to the turbine generating units with low efficiency.

(2) Analysis of the efficiency of the turbine generating units

According to the engineering thermal dynamics, for the turbine generating units, the efficiency of the generating units is high if the initial pressure and temperature of the vapor is high. Currently, in the heating circulatory system for the vacuum salt production, the backpressure turbine circulatory generating units are usually fixed at the position between the boiler and the first effect. The required pressure is obtained by increasing the pressure of the exhaust steam. This method is to meet the requirement at the cost of the efficiency of the turbine generating units. If the backpressure turbine circulatory generating units are used, the power production changes as the heat requirement of the following salt production changes. Because of the uncoordination between the various loss and the load of the heat and power, the heat utilization ratio (ξ) is low, which is usually around 70%. In order to further analyze the heat utilization efficiency of the turbine generating units used in the combined production of heat and power for vacuum salt production. Firstly, the economics of the generating units with various operating pressures in the power plant are compared (See table 1). From the table 1, the efficiency of the generating units with medium operating pressures is 8% lower than the units with high operating pressures and is 14% lower than the units with supercritical pressures. The analysis above is according to the data of the turbine generating units in the power plant. Currently, the vacuum salt production usually uses the generating units with medium operating pressures and the exhaust pressure is usually lower than 4-5 KPa, and the temperature is lower than 32.98 ℃. Burt the turbine generating units used in the vacuum salt production usually have operating pressures higher than 0.3 MPa and temperature higher than 133.56℃. The capacity of the generating units in the power plant usually is higher than 1 MW. The generating units for the vacuum salt production is usually several thousands KW. Therefore, the efficiency of the turbine generating units for the vacuum salt production is lower if the operating pressures are the same.

Table 1 Economics of the generating units with various operating pressures of the power plant

Unit type	Steam Pressure (MPa)	Steam Temperature (℃)	Unit Efficiency (%)	Coal Consumption (g/kWh)
Medium pressure	3.43	435	27	460
Highe pressure	8.83	510	33	390
Super-high pressure	13.24	535/535	35	360
Subcritical pressure	16.67	540/540	38	324
Supercritical pressure	25.00	567/567	41	300
Super-supercritical pressure	29.42	600/600/600	48	256

The above analysis is about the efficiency of the turbine generating units for vacuum salt production. The loss in the transport and transformation of the power is not considered. The power generated in the salt production process can not be directly utilized. The electricity should be sent into the transformer room, and the transformed electricity should be sent to the power network to be balanced. Finally, the electricity is sent back to the salt production factory. The cost of the transport and transformation is paid by the enterprise. Consequently, the cost of the power generation is always higher than that of the power plant. The figure shows detailedly the energy loss of the entire process of the power generation. The energy loss is the minimum value, but the actual value is higher than the data in the figure.

Results of the analysis of the entire process of the salt production indicates that only the heat utilization ratio is increased in the heating circulatory system of the turbine generating units, but the heat efficiency is very low. In addition, other costs should be considered, including the capital cost of the units, maintenance cost and etc. Therefore, It is not worthy to add turbine generating units in the heating circulatory system for salt production, but there is no other choice.

(3) Analysis of the energy loss of the water decompression and cooling.

In the traditional salt production system, the steam pressure from the boiler is usually higher than 3.82 MPa, and the temperature is around 450℃. Some processes use the direct decompression and cooling while others use the combination of turbine decompression and cooling and the partially direct decompression and cooling. Here we only discuss the thermal energy loss of the direct decompression and cooling. According to the requirement of the salt production process, the temperature of the steam sent to the heating room for the vaporization tank is usually not beyond the range of 120-160℃ and the corresponding pressure is abourt 0.4 MPa. In order to meet the requirement of the process, decompression must be carried out for the steam produced by the boiler. Meanwhile, it must be ensured that the cooled steam is in the form of saturated steam, so that the corrosion to the equipment will not be caused. Hence, multi-stage decompression and cooling is required. For the low capacity, this is easy to be realized. But for the large capacity, it is hard to realize. The process of decompression is actually irreversible. Although there is no large loss in the energy, but large friction loss is caused. And that is the reason why the turbine decompression is used. In the cooling process, a lot of water is consumed, and the water used in the cooling process should be softened and purified. In addition, the temperature of the supply water changes as the environmental temperature varies. Hence, the thermal energy loss of the direct decompression and cooling is higher than that of the turbine decompression and cooling.

(4) The effect of the temperature control accuracy on the heat efficiency.

After the design, installation and commissioning, the temperature of the first effect of vaporization salt production is defined. Because multi-effects vaporization is usually used in the salt production, there are many processes of the second utilization of the thermal energy. And the relationship between the processes is interactive thermal dynamical balanced. The vaporization temperature of the first effect will influence the condition of the whole system. If the temperature of the first effect is too low, the productivity will decrease and the thermal energy efficiency will decrease. If the vaporization temperature of the first effect is too high, the productivity will increase but the thermal energy efficiency will decrease or even interrupt the normal production.

For a convenient analysis, these factors are called as optimum working efficient, represented by K. The temperature is represented by T. Then, the simulation curve is shown as the figure. From the figure, there is an optimum point. The working efficient is high when the vaporization temperature is close to the optimum working temperature. Therefore, the degree of the temperature control accuracy will directly influence the thermal energy efficiency and the condition of the equipment. The traditional vacuum salt production can not provide high temperature control accuracy.

3. THE CHARACTERISTICS OF THE HEAT CONDUCTIVE OIL AND ITS APPLICATION

The heat conductive oil is a kind of excellent working fluid and it can be divided into two types: mineral oil or synthesized oil. The heat conductive oil can be used under high temperature and low pressure and it has the advantages of high thermal efficiency, high temperature accuracy, and notable energy saving effect. The heat conductive oil has been widely used in the light industry, textile industry, printing and dyeing, petrochemical industry, building materials, medicine, rubber and plastic industry.

The application of the heat conductive oil in our country is late. In the early 1980s, as the sets of equipment began to be introduced to our country after the Reform and Opening of China, the heat conductive oil began to be introduced into our country from the abroad. At the early stage, most of the heat conductive oil used in the production in our country is mineral oil, while the oil used in the developed countries is the synthesized oil. The efficiency of the synthesized oil is 31.8% higher than the mineral oil and the lifespan of the synthesized oil is 2-3 times longer than the mineral oil.

In the recent years, some chemical enterprises are able to produce the synthesized heat conductive oil. Before 1999, there was no standards for the heat conductive oil production. In 1999, the standard (SH/T0677-1999) for the production of the heat conductive oil was published by the government.

As working fluid, the heat conductive oil has the following characteristics:

(1) Excellent thermal stability, no degradation for longtime. The heat conductive oil usually has the lifespan of more than 6 years, or even more than 10 years for the oil with high quality and under suitable temperature and operating conditions.

(2) Can be used in high temperature heat-exchanging. The requirement for the operating pressure of the pipe is not strict.

(3) Can be circulated in the form of fluid in a wide temperature range.

(4) The condensing point is low, which is usually lower than -10 ℃ and the point can be as low as -70℃.

(5) The vapor pressure is low. Can be operated and transported under high pressures. The oil is hard to form steam bubbles, so the normal recycle of the oil will not be interrupted and it is safe.

(6) Low corrosion to the metal pipeline and heat-exchanger.

(7) Insoluble in water and can not react with the NaCl aqueous solution.

(8) Easy to wash. The heat conductive oil, heat-exchanger and pipeline can be washed online.

The most typical application of the heat conductive oil is the widely application in the boilers. The boilers that use the heat conductive oil as working fluid is called oil boiler. According to the different fuels used by the boilers, the boilers can be divided into three types: coal-fired boiler, oil-fired boiler, and the gas-fired boiler. The mechanism is the same with the steam boilers. The heating system of the oil boiler includes four steps: (1) combustion of the fuel; (2) heat-exchange between the flue gas and the oil; (3) heating the fluid oil; (4) heating by the high temperature oil and the low temperature oil is sent back to the boiler. The heating system using heat conductive oil uses fluid closed circulation. After heat exchanging, the high temperature oil from the boiler is sent to back to the boiler directly. The efficiency of the heat conductive oil is usually 35-55% higher than that of the steam. Consequently, the heat conductive oil is the best working fluid for the heating system, especially for the conditions of the vaporization salt production.

4. APPLICATION OF THE HEAT CONDUCTIVE OIL IN THE HEATING SYSTEM FOR VACUUM SALT PRODUCTION

From the discussion above, the traditional heating circulatory system for the vacuum salt production which uses water as the working fluid has low thermal energy utilization efficiency and complex structure. Water can be completely replaced by the heat conductive oil with excellent properties to develop novel efficient heating system for salt production. According to the situation of the current heating system for salt production, the heat conductive oil can be divided into two types: directly heating the oil by using the circulating fluidized bed boiler (details shown as figure 2). This method is not suitable for the enterprise with large size power plant. Using this method, the original turbine generating units with low efficiency can be replaced. The second type is using the exhaust of the turbine generating units to directly heat the oil (see the figure 3). This method is suitable for the salt enterprises with large power plant and it dose not influence the other heat used for other purposes of the power plant. Next, the structure and mechanism of the heat conductive oil boiler, taking the transformation of circulating fluidized bed boiler to oil boiler as an example.

4.1 Structure and mechanism of the highly efficient heating circulatory system for salt production

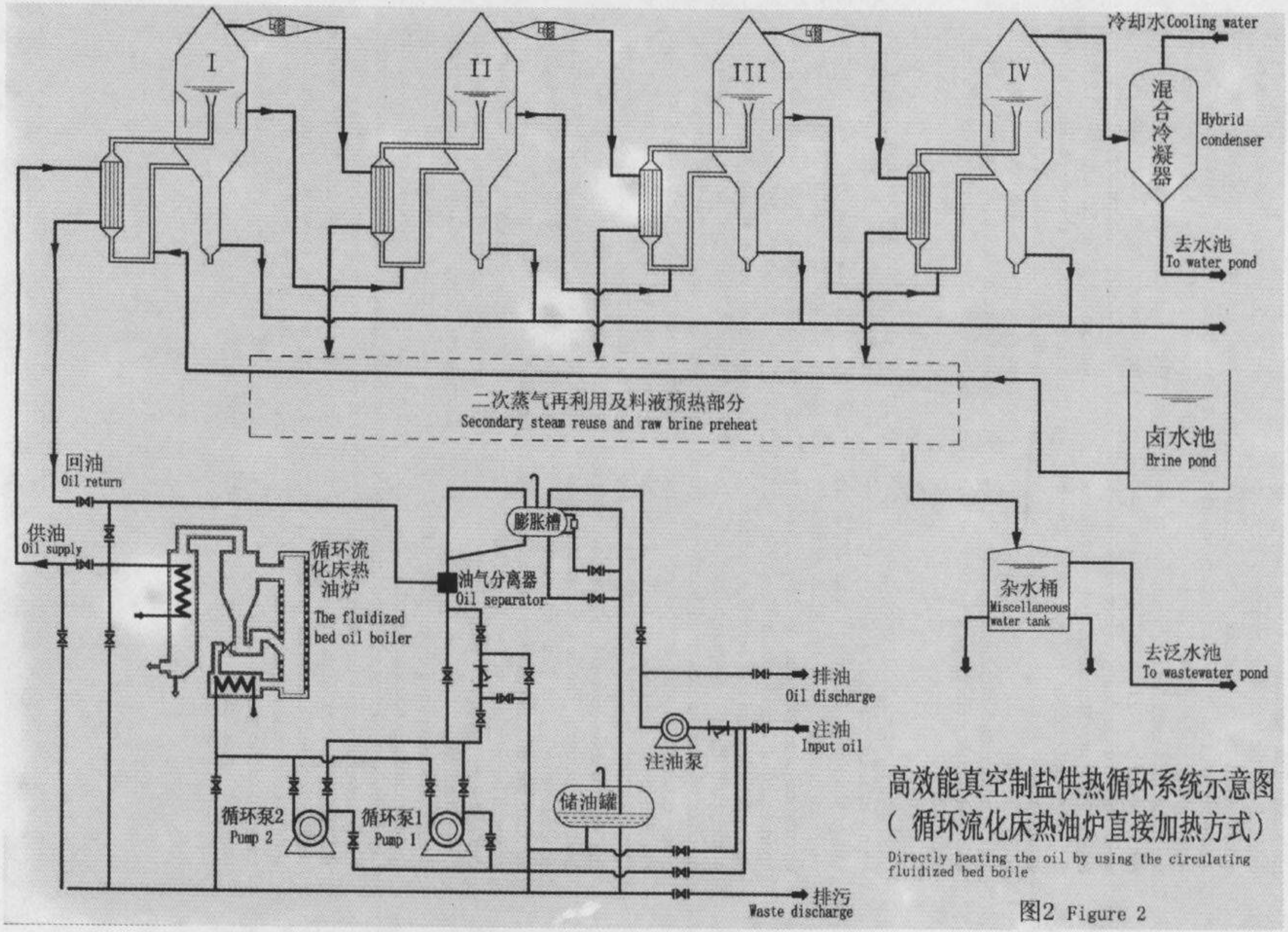
The structure and mechanism of the highly efficient heating circulatory system for salt production is shown in Figure 2. As can be seen in the figure, the system includes circulating fluidized bed oil boiler, heating apartment of vaporization tank for salt production, oil and gas separator, circulating pump, oil tank, oil pump and etc. Its mechanism can be described briefly as: the heat conductive oil is heated by the circulating fluidized bed oil boiler. Then the high temperature heat conductive oil is sent to the vaporization tank for salt production to heat the halogen. The low temperature heat conductive oil after heat exchanging goes through the oil gas separator and back to the boiler. The whole cycle is close fluid cycle driven by the circulating pump.

The main function of the oil/gas separator is to separate the oil gas produced in the circulating process and send the gas to the expansion slot. Meanwhile, separator controls the oil overflow and the supplementation of the oil. The amount of the oil gas produced in the heating and circulating process is quite little. At the operating temperature of 300 ℃, the ratio of the oil to the gas is about 70:1. If the heat conductive oil is used at the temperature lower than 160 ℃, there is almost no oil gas. Hence the heat conductive oil is very suitable for the heating process with operating temperature lower than 300 ℃.

The system usually has more than two pumps one of which is used and others are standbys. Because the flow rate must be in the range of 2-3 m/s, or the oil will tend to coke. The oil can be preserved statically only when the temperature is lower than 60 ℃. Hence, the reliability is significant.

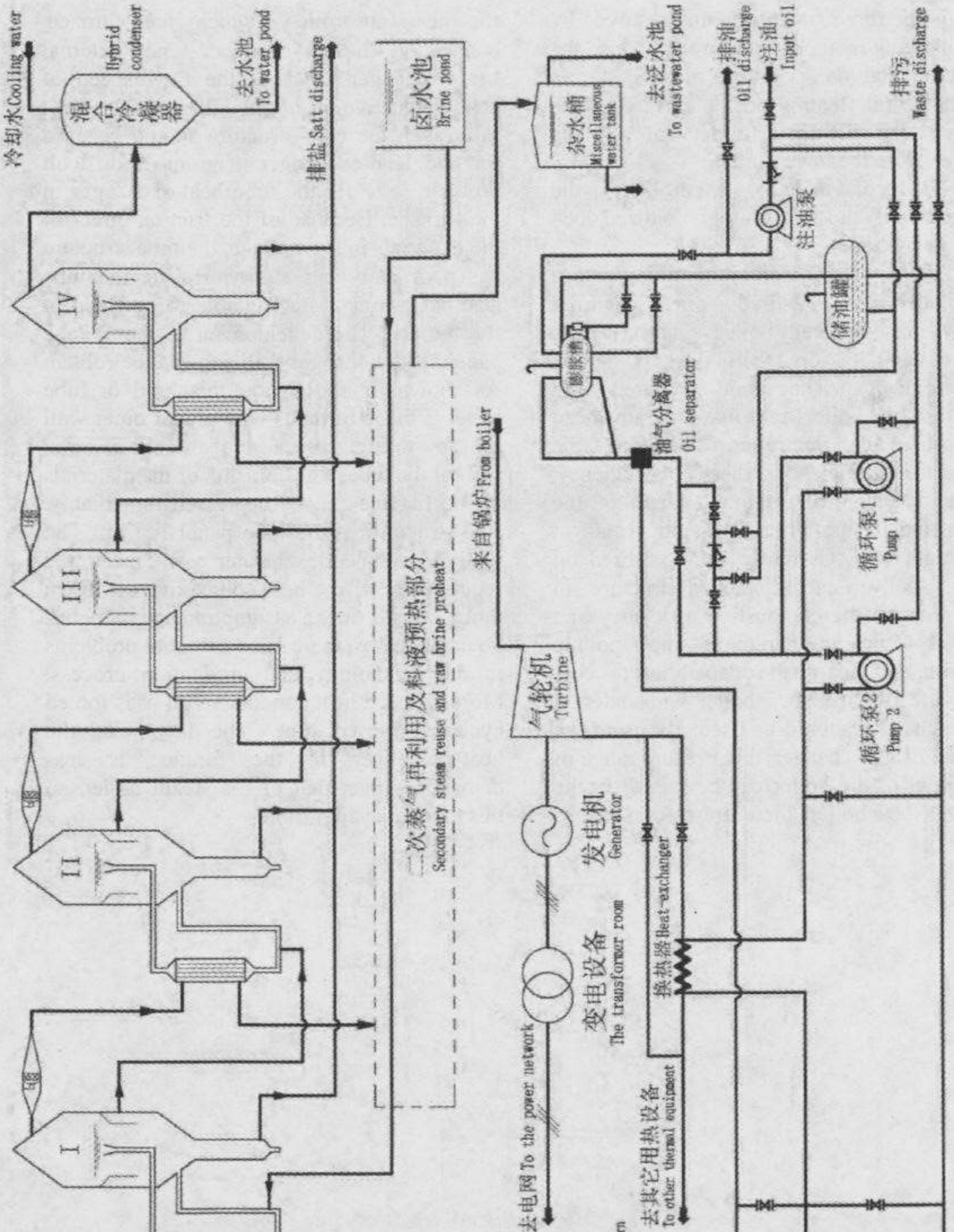
Because the fluidized bed boiler is used as the heat source, the two-stage temperature control should be used. The first stage regulates the output of the boiler to control the temperature of the oil at the outlet of the boiler. This stage has low controlling accuracy and slow response. This stage can also be called as previous stage. The second stage is using the temperature sensor to measure the temperature of the vaporization tank for salt production. According to the changes of the temperature in the tank, regulate the flow rate of the oil sent into the heating apartment by using the electromagnetic valve. Hence, the vaporizing temperature of halogen in the tank can be controlled precisely. The second stage has fast response and can be called as later stage control. The two-stage temperature control method is suitable for coal-fired circulating fluidized bed oil boiler. If the the gas-fired or oil-fired oil boiler is used as the heat source, only the single stage control will be enough to obtain high control accuracy.

If the oil is used under high temperature for longtime, the heat conductive oil will degrade and coke. The oil film forms on the pipe wall and the efficiency of the heat conductive oil decreases. In order to ensure that the heat conductive oil is at good status, the oil, heat-exchanger and pipeline should be washed every 1 or 2 years. The special detergent is used to wash online and the normal work of the system will not be influenced. The washing efficiency can be as high as 98%.



高效能真空制盐供热循环系统示意图
（循环流化床热油炉直接加热方式）
Directly heating the oil by using the circulating fluidized bed boile

图2 Figure 2



高效能真空制盐供热循环系统示意图(汽轮机乏气加热方式)

The exhzust of the turbine generating units to directly heat the oil

图3 Figure 3

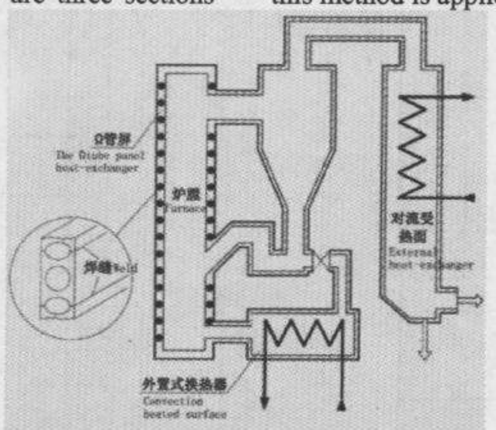
4.2. The difficult problem and the solutions.

The first difficult problem is the leakage of the oil in the vaporization tank.

Although the oil leakage rarely happens in the tank, it happens accidentally. The leakage can be divided into three situations: the first is the heat conductive oil leaks into the halogen water; the second is the halogen leaks into the oil; the last is the two situation coexists. Because the oil does not dissolves in the halogen, and the oil has higher boiling point than water, low condensing point, low density, the three situations can be solved by the following methods: the first is choose the non-toxic and non-pollutive oil; the last is decant the oil floating on the surface of the halogen from the upper outlet and vent the halogen from the lower outlet.

The second technological problem is the transform of the circulating fluidized bed boiler to oil boiler.

As mentioned before, the oil boiler can be divided into oil-fired boiler, gas-fired boiler and coal-fired boiler. Currently, the oil-fired and gas-fired oil boiler is mature technologically. The good oil-fired and gas-fired oil boilers all use the advanced combustor and controller. Therefore, the combustion efficiency, thermal efficiency, temperature control accuracy, range of the output and the pollution emission are all at very high level. Currently, the coal-fired oil boiler usually uses the chained structure. In order to raise the combustion efficiency and thermal efficiency, reduce the pollute emission, and enlarge the adaptability for coal types, the fluidized bed boiler with external heat-exchanger should be used. By using the external heat-exchanger, the pressure range of the output of the boiler can be raised. In the fluidized bed boiler, there are three sections for heat absorption, which are furnace, convection heated surface, and external heat-exchanger. Because the flow speed of heat conductive oil in the boiler must be kept at a level, the tube structure should be used for the heat-exchanger. The most difficult problem is to fix the tube heat-exchanger in the furnace. Because of the friction effect of the materials in the furnace, the tube structure has poor anti-wear ability. Hence, the tube heat-exchanger is not suitable to be fixed in the furnace. The development of the Ω tube panel heat-exchanger well solves the problem. As shown by the figure, this kind of tube panel is made of tubes with planar outer wall joint by welding. Because of the planar outer wall of the tubes, the abrasion of the materials in the furnace can be depressed remarkably. The structure of the tube panel is firm. The tube panel heat-exchanger can meet the requirement of the heat conductive oil. Even though this is only a assumption and there has no actual cases, there is no essential problems in the technology and production process. Moreover, the heat conductive oil uses forced cycle in closed pipe. The layout of the heat-exchanger in the furnace is less demanding than that of the steam boiler, so this method is applicable.



循环流化床热油炉示意图

Figure shows the fluidized bed oil boiler

5. ANALYSIS OF THE ADVANTAGES OF THE NOVEL HIGH EFFICIENCY HEATING CIRCULATORY SYSTEM FOR VACUUM SALT PRODUCTION

Compared with the traditional heating circulatory system for salt production which uses water as the working fluid, the advantages of the high efficiency heating circulatory system for salt production are as follows:

(1) high circulating efficiency

Because the heat conductive oil has the characteristic of transport heat under low pressures, the boiler and the heat consuming equipment simply use the single fluid closed cycle. This method does not cause other heat loss. On the contrary, the water uses the gas-liquid open cycle which has a series of complex water treatment and a large heat loss. Further more, the heat transfer efficiency of the heat conductive oil is 35-55% higher than that of water.

(2) high temperature control accuracy

The heat conductive oil is always in the form of fluid. It is easy to control the temperature of the heated equipment. The temperature control can be realized either by controlling the oil flow rate or by controlling the oil temperature. No matter which method is used, the heat efficiency will not be decreased. High temperature control accuracy and high response speed can be obtained.

(3) water saving

Water is not needed in the heating circulatory system in which the heat conductive oil is used. The lifespan of the heat conductive oil can be as long as 10 years if washed periodically. The heating system using water as the working fluid consumes a great amount of water. The condensed water and the supplied water need to be pretreated and this will add to the cost of the water treatment.

(4) fuel saving

Because there is no intermediate steps in the closed cycle of the high efficiency heating circulating system for salt production. The heating method is direct and the property of the heat transfer of the working fluid is excellent. Therefore, the heat efficiency of the system is very high and the fuel is saved remarkably. According to the inspection of the heating drying system in the factory of the artificial panel, the coal consumption is reduced 55% after the heat conductive oil technology has been applied.

(5) simple structure and low capital cost

High efficiency heating circulatory system for salt production has get rid of the low efficiency power generating system and the boiler water treatment system. The system works at low temperature and low pressure (pressure $\leq$ 0.3 MPa, temperature $\leq$ 160℃). Hence, the requirement of the pipelines and equipment for pressure and temperature tolerance is low. The structure of the system is simpler and the capital cost, maintenance cost and operating cost decreases remarkably.

(6) easy maintainance

The pipelines and equipment of the heating circulatory system can be washed online and the normal work is not influenced. The maintenance is convenient. The pipelines and equipment of the heating circulatory system for the salt production that uses water as the working fluid have to stop operation to carry out the maintenance (such as alkaline removal and etc).

In conclusion, the high efficiency heating circulatory system for vacuum salt production has remarkable advantages over the currently used traditional heating circulatory system for vacuum salt production.

6. OUTLOOK FOR THE HEATING CIRCULATORY SYSTEM FOR VACUUM SALT PRODUCTION

The development of the heating circulatory for salt production has close relationship with the increase of the heat efficiency and power generating efficiency. Therefore, when the trend of the development of the heating circulatory system for vacuum salt production is discussed, the status of the generating technology in our country and in the world should be known. The modern generating technology can be divided into two types which are the traditional rotating generating technology and the novel non-rotating generating technology.

The so-called rotating generating technology means the chemical energy of the fuel is transformed to the thermal energy of the working fluid. Then the thermal energy is transformed to the mechanic energy of the turbine. Finally, the energy is used to drive the generator and produces power. The rotating generating technology includes steam circulating turbine generation, gas-fired circulating turbine generation, steam and gas-fired combination circulating generation. Currently, the rotating generation technology used in the traditional vacuum salt production is the most undeveloped one. The disadvantages of the rotating generation technology includes: firstly, the chemical energy of the fuel can not be fully utilized; secondly, the energy loss is very high during the transform of the thermal energy to mechanical energy, and this is the main factor that limits the increase of the generating efficiency.

Since the 1970s, while every country continued to make efforts in the research of the rotating generation technology, great efforts have been made in the development of the non-rotating technology. This type of generation technology includes alkali metal thermoelectric converters, magnetohydrodynamic generator, fuel cell, and etc.. the alkali metal thermoelectric converters and the magnetohydrodynamic generator is the technology that converts thermal energy directly into electricity and has no intermediate step of mechanical energy in the circulating process. Fuel cell transforms the chemical energy directly into electrical energy. The theoretical efficiency can be as high as 80-95%. Even if the loss of the inner resistance is considered, the efficiency can still be as high as 40-60% which does not includes the waste heat recycling. The discussion above is only a brief introduction of the most advanced generation technology. And how to apply the technology to the salt production is the essential purpose of this paper.

In the previous sections of this paper, the high efficiency heating circulatory system for salt production that uses the heat conductive oil as working fluid is discussed. Compared to the traditional heating circulatory system for salt production, the thermal efficiency of the heating circulatory system using the heat conductive oil is much higher and the equipment is simplified. However, the heating system using the heat conductive oil still belongs to the traditional method that uses boiler as heat source. The boiler combustion temperature is higher than 850 ℃, while the operating temperature is only 120-160 ℃ which is much lower. This temperature difference increases the energy loss. Moreover, in the traditional vacuum salt production, the thermal energy is provided at the cost of decreasing the efficiency of the generating units. Hence, how to solve these problems using the advanced technologies is the key issue of the development of the heating system for salt production. The fast development of the fuel cell technology provides possibility for solving these problems.

The fuel cell has many advantages, including:

(1) The efficiency of the energy converting is high. It converts the chemical energy of the fuel directly into electric energy and has no combustion process. The actual efficiency can be as high as 40-60%.

(2) The pollution is minor. Because no large combustor and rotating equipment is used, the pollution of harmful gas and noise pollution are minor.

(3) Fast response and high quality operation. The power of the fuel cell can be changed to rated power from the lowest power in only several seconds. Furthermore, the power plant can be very close to the power consuming equipment, so the capital cost of the transmission and transformation lines, and the energy loss of the lines can be reduced.

(4) High adaptability for various fuels. Various types of fuels can be used, such as coal, natural gas, and the petroleum.

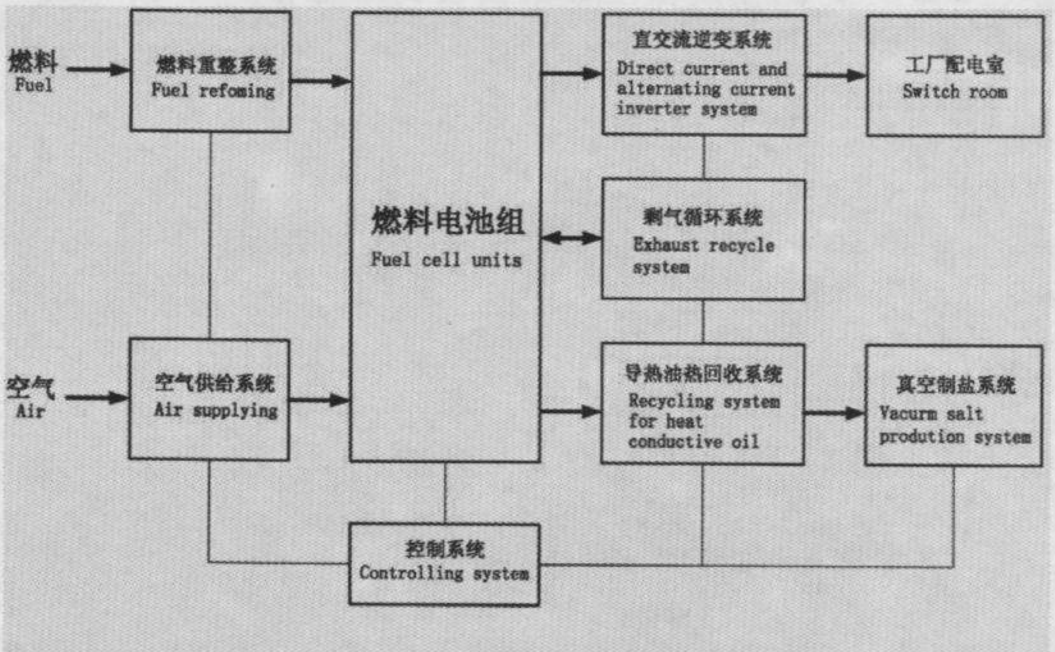
(5) The footprint of the fuel cell is small. The construction time is short. The fuel cells can be arranged either dispersedly or collectively.

Table 2 Economics of the generating units with various operating pressures of the power plant

Cell types	Alkali fuel cell (AFC)	Phosphorus acid fuel cel (PAFC)	Molten carbonate salt fuel cell (MCFC)	Proton exchange membrane fuel cell (PEFC)
Electrolyte	KOH	H_3PO_4	Li_2CO_3-K_2CO_3	Perfluoro sulfonated membrane
Anode catalyst	Ni or Pt/C	Pt/C	Ni (Cr, Al)	Pt/C
Cathode catalyst	Ag or Pt/C	Pt/C	NiO	Pt/C, Pt
Conductive ion	OH^-	H^+	CO_3^{2-}	H^+
Operating temperature	65-220 ℃	180-220 ℃	ca. 650 ℃	room temperature-80 ℃
Operating pressure	< 0.5 MPa	< 0.8 MPa	< 1 MPa	< 0.5 MPa
Fuel	refined H_2, byproduct H_2 of electrolysis	natural gas, methanol, light oil	natural gas, methanol	H_2, natural gas, methanol, gasoline
Electrode material	Ni	graphite	Ni, stainless steel	graphite, metal
Internal reforming	impossible	possible	very possible	impossible
Efficiency	50-60%	40-50%	50%	40-50%

There are many types of fuel cells. Four types of fuel cells are shown in table 2. As can be seen in the table, the phosphorus acid fuel cell (PAFC) is suitable for the salt production. The operating temperature is in the range of 180-220 ℃ which is close to the heating temperature of the salt production process. PAFC has excellent reliability for longtime. The cost of the electrolyte is low. PAFC has been commercialized.

If we combine the PAFC and the heat conductive oil technology, the high efficiency system of power-salt combined production. The system structure and the mechanism is shown as the following figure. As can be seen, the system includes fuel reforming system, air supplying system, fuel cell units, exhaust recycling system, direct-a current inverter, recycling system for heat conductive oil, vacuum salt production system, controlling system, and etc. The electricity of fuel cell is not needed to be sent to the public network to be balanced. The efficiency does not decrease as the power load fluctuates. The power generated by the system can be sent directly to the factories. the capital cost of the transmission and transformation lines decreases and the energy loss is reduced. In the fuel cell process, the 40% energy of the fuel cell is converted to power, while 60% energy is converted to thermal energy. The thermal energy can be recycled by heat conductive oil to provide energy for the vacuum salt production system. The system of combined production of power and salt does not need external electricity and does not consume water. The efficiency of the system can be as high as 95%. This system is the best salt production system.



高效电-盐联产系统方框图

High efficiency system for combined production of power-salt

7. CONCLUSION

In conclusion, there is no essential problem for the development of the heating circulatory system for salt production. As the fuel resource becomes deficient and the request for environment protection and energy saving increases, the development of high efficiency heating circulatory system for vacuum salt production has become the focus of the salt industry of our country. The most promising method is to develop the high efficiency heating circulatory system for salt production that uses heat conductive oil as the working fluid. By using this method, the capital cost is reduced and the energy is notably saved. Consequently, the cost of the salt production can be decreased, and becomes more competitive.

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