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Engineering Problems of a New Thermal Seawater Desalination Technology

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Abstract: A new thermal seawater desalination technology was introduced in this paper. The influencing law of temperature difference between fresh water and seawater on heat utilization was disclosed and a performance evaluation theory for the water-heat ratio-based thermal seawater desalination device was established. Engineering problems of the new thermal seawater desalination technology using fuel oil, natural gas, solar energy, nuclear energy and a variety of industrial waste heat sources were analyzed. A seawater desalination device design using waste heat of diesel engine which is applicable to islands and vessels was proposed. Finally, the technical route for comprehensive utilization of seawater resources and solving the water crisis was developed.

Key words: Seawater desalination, engineering, problems, applications.

1. New Thermal Seawater Desalination Technological System

Water shortage restricts human development increasingly and facilitates progress of seawater desalination technology continuously. In the past centuries, thermal seawater desalination technology matured gradually from the simple distillation method to nowadays multistage flash evaporation and multiple-effect distillation method. Membrane seawater desalination technology emerged and has occupied most market in the seawater desalination industry. Electrodialysis, capacitive adsorption, membrane distillation, positive permeation and freezing method are exploring [1]. All of these seawater desalination technologies separate seawater into fresh water and strong brine. Thermal seawater desalination technology is restricted by the condensation physical law of thermal transmission and water evaporation, while the membrane seawater desalination is restricted by the physical law of osmotic pressure. Other seawater desalination technologies are restricted by corresponding physical laws. Advanced degree of technologies is determined by reasonability of utilizing physical laws.

The new thermal seawater desalination technology is an advanced technology that uses thermal transmission and water evaporation most reasonably. The physical law of the temperature difference between fresh water and seawater approaches to 0 but is not 0 which indicates that the heat utilization is close to the theoretical limit. The new thermal seawater desalination technology has formed a seawater desalination technological system integrating positive pressure distillation, atmospheric distillation and reduced pressure distillation. Different from existing seawater desalination technologies, one outstanding feature of this new thermal seawater desalination technology is that it separates seawater into fresh water and solid salt.

The new thermal ogy was developed firstly for waste-heat utilization of Sterling generator [2, 3]. It uses the principle of air humidification and dehumidification into heat dissipation of seawater desalination technology the Sterling generator and seawater desalination. Therefore, a seawater

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desalination device based on multilevel hot-air heating was developed [4]. To use different waste heat sources effectively, heating channels are installed in different levels of seawater evaporation tanks [5] and sealed seawater evaporation tanks are used to prevent blow by Ref. [6], which perfects the humidification and dehumidification-based seawater desalination technology. It is characteristic of air involvement in seawater desalination, seawater evaporation on the interface of air bubbles and water surface as well as positive pressure evaporation of all seawater evaporation tanks. If heating surface and water surface of the first-level seawater evaporation tank are adequate to ensure heat exchange and evaporation of seawater under regulated temperatures, without the need of air humidification and dehumidification, seawater can evaporate under normal pressure and the seawater desalination device is under the most economical running state. Due to limited volume of the seawater desalination device, an exhaust fan could be installed in the exhausting channel to enhance evaporative capacity per unit water surface with negative pressure and form a combination of one or several negative-pressure seawater evaporation tanks and several atmospheric seawater evaporation tanks, thus constructing a seawater desalination device based on reduced pressure distillation [7].

Theoretically, the new thermal seawater desalination technology can make full use of heat compared to existing ones. Thermal transmission and water evaporation and condensation are physical laws that restrict the new thermal seawater desalination technology. Temperature difference between the fresh water and seawater is the key influencing factor of heat utilization of the new thermal seawater desalination device.

2. Engineering Problem of the New Thermal Seawater Desalination Technology

New technology shall benefit for human beings and engineering problems shall be well solved. Engineering problem of the new thermal seawater desalination technology is to search the balance among evaporation temperature, evaporation pressure, levels of seawater evaporation tanks, fresh water output and heat consumption. The new thermal seawater desalination is physical solid-liquid separation without chemical reaction heat. During continuous production and running of the device, there is heat conservation between the inflow and outflow in unit time and a material conservation between the inflow and outflow in unit time. Temperature of the n-level seawater evaporation tank is T_n. In other words, temperature of the first-level seawater evaporation tank is T_1, and so on. Suppose that the output fresh water temperature is T_0, seawater temperature is T, fresh water output in unit time is M, inflow heat in unit time is Q_1, heat loss for salt elimination in unit time is Q_2, and specific heat capacity of water is C_P. If neglecting other forms of heat loss, the heat conservation is:

$$\mathrm{Q}_1 - \mathrm{Q}_2 = C_P M(T_0 - T) \tag{1}$$

The ratio of fresh water output in unit time to inflow heat in unit time is K, which is called as the water-heat ratio. The mathematical expression of water-hat ratio is:

$$K = M/Q_1 \tag{2}$$

Eq. (1) is the theoretical calculation formula of the designed seawater desalination device, which reflects advancement of the new thermal seawater desalination technology comparing to existing ones. Existing multistage flash evaporation and multiple-effect distillation consume abundant heat for strong brine elimination. The new thermal seawater desalination technology uses all heat in strong brine for seawater desalination, and increases by at least 3 times when eliminating salt pollution and thermal pollution of strong brine.

Eq. (2) is an index to evaluate heat utilization of thermal seawater desalination device comprehensively, which is applicable to all thermal seawater desalination methods. Main influencing factors of

water-heat ratio include water difference between fresh water and seawater, heat loss in salt elimination, distillation method, device sealing and device thermal insulation. Higher water-heat ratio indicates higher fresh water output under same heat consumption and better performance of the seawater desalination device. The existing water output ratio could not evaluate heat utilization of the new thermal seawater desalination device.

Temperature decreases gradually from the first level of seawater evaporation tank to the last level of seawater evaporation tank, approaching to the seawater temperature. In other words, $T_1 > T_2 > T_3 > --> T_n > T$. However, the variation of temperature reduction is influenced by heating surface, evaporation surface and distillation method of different seawater evaporation tanks, which is extremely complicated and deserves further researches. The goal is to achieve the minimum fresh water-seawater temperature difference as much as possible with the least levels of seawater evaporation tanks.

The first level of seawater evaporation tank has the highest temperature and the highest salinity of seawater, which are easy to cause scaling. Appropriate temperature control and adding antisludging agent are two control measures of scaling.

Seawater desalination device based on positive pressure distillation uses positive pressure seawater evaporation tanks only and transmits water vapor by air. Seawater desalination device based on normal pressure distillation involves normal pressure seawater evaporation tanks only and realizes seawater desalination depending on natural evaporation and condensation completely. Although the device has the simplest structure, it owns the biggest volume. Seawater desalination device based on reduced pressure distillation generally comprises several negative pressure seawater evaporation tanks and several normal pressure seawater evaporation tanks. Negative pressure seawater evaporation tanks are before the air line of the exhaust fan, while normal pressure seawater evaporation tanks are after the discharge pipes of the exhaust fan. There are two extreme conditions: (1) it only has one negative pressure seawater evaporation tank and the rest are normal pressure seawater evaporation tanks; (2) it uses negative pressure seawater evaporation tanks only.

Distillation mode is chosen according to heat sources and environment. Normal pressure distillation device is often used under no space limitations and when heat source refers to industrial waste heat. Without the exhaust fan, the device is simpler and has more reliable running as well as lower electricity consumption. However, reduced pressure distillation device with both normal pressure and negative pressure seawater evaporation tanks is preferred in limited spaces (e.g., vessel) to reduce device volume. It generally applies a full-closed reduced pressure distillation device with negative pressure seawater evaporation tanks only for separation of toxic low-boiling solids and liquids, which can ensure operation security.

For gradient utilization of heat from two sources with temperature difference, heating pipes using low-temperature heat sources are installed at bottom of all seawater evaporation tanks and heaters using high-temperature heat sources are installed in the first level of seawater evaporation tanks, which can solve the engineering difficulty for industrial waste heat importing into the seawater desalination device [8]. This makes the new thermal seawater desalination device to make high-efficiency utilization of various industrial waste heat that is beyond the reach of multistage flash evaporation and multiple-effect distillation method.

Therefore, there is no problem that could not be solved in the engineering process of the new thermal seawater desalination technology. Future works shall focus on seeking the optimal technological parameters.

3. Application of the New Thermal Seawater Desalination Technology

The new thermal seawater desalination technology separates seawater into solid salts and fresh water, which not only increases the water-heat ratio, but also can extract elements in seawater concentrate and purify and use enriched rare elements, facilitating development of the marine chemical industry. Solid salt is just a by-product of seawater desalination. Modern salt extraction industry will lose the value of existence, thus saving tremendous land sources.

The new thermal seawater desalination technology can use fuel oil, natural gas, solar energy, nuclear energy and various industrial waste heat as the heat sources.

To use fuel oil or natural gas as the heat source, an oil gas boiler shall be equipped [9]. Steam is accessed to heaters in the first level of seawater evaporation tanks, and condensed water returns to the boiler and combustion emissions are accessed to heating pipes at bottom of all seawater evaporation tanks, which ensures that all heat from combustion of fuel oil or natural gas is used for seawater desalination.

To use solar energy as the heat source, a groove-type solar heating system is equipped to access heat-conducting medium into the heating pipes below the seawater desalination device, forming a circulation loop of heat-conducting medium and realizing seawater desalination based on solar energy.

It only has to set a circulation loop of heat-conducting medium for connecting the nuclear reactor and seawater desalination device in order to use nuclear energy as the heat source.

Steel industry, power generation industry, glass industry and cement industry all have tremendous industrial waste heat that will cause thermal pollution to surrounding environment. Using such heat to desalinate seawater can eliminate water crisis in coastal industrial cities completely. Seawater desalination technologies and equipment based on slag heat which is invented for the steel industry [8] also can be used in seawater desalination projects based on waste heat of power generation industry, glass industry and cement industry.

In islands of South China Sea with electricity and fresh water shortages, diesel generating set and seawater desalination plant accessories can access cooled water from the diesel engine to all heating pipes at bottom of seawater evaporation tanks and access combustion emissions to heaters in the first level of seawater evaporation tanks [8], thus enabling to realize hydropower generation and meet water and electricity demands of people on islands.

In large vessels, the new thermal seawater desalination device could be equipped on diesel engine or turbine for fresh water supply.

In a word, the new thermal seawater desalination technology can make extensive use of various heat sources and realize high-efficiency solid-liquid separation of seawater. It is a feasible technical route to comprehensive utilization of seawater resources and elimination of water crisis.

4. Conclusions

The heat utilization rate of the new thermal desalination technology reaches the theoretical limit. Compared with the existing method of seawater desalination technology, the cost and operating cost of the new type of seawater desalination technology are greatly decreased, and the economic efficiency increases exponentially. The new method of seawater desalination technology will replace the existing thermal seawater desalination technology.

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