A desalination plant with solar and wind energy

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Abstract. The shortage of freshwater resources has become a worldwide problem. China has a water shortage, although the total amount of water resources is the sixth in the world, the per capita water capacity is the 121th (a quarter of the world's per capita water capacity), and the United Nations considers China one of the poorest 13 countries in the world in terms of water. In order to increase the supply of fresh water, a realistic way is to make full use of China's long and narrow coastline for seawater desalination. This paper discusses a sea water desalination device, the device adopts distillation, uses the greenhouse effect principle and wind power heating principle, and the two-type start is used to solve the problem of vertical axis wind turbine self-starting. Thrust bearings are used to ensure the stability of the device, and to ensure absorption of wind energy and solar energy, and to collect evaporation of water to achieve desalination. The device can absorb solar and wind energy instead of input energy, so it can be used in ship, island and many kinds of environment. Due to the comprehensive utilization of wind power and solar power, the efficiency of the device is more than other passive sea water desalting plants, the initial investment and maintenance cost is lower than active sea water desalting plant. The main part of the device cannot only be used in offshore work, but can also be used in deep sea floating work, so the device can utilise deep sea energy. In order to prove the practicability of the device, the author has carried out theory of water production calculations. According to the principle of conservation of energy, the device is absorbing solar and wind power, except loose lost part which is used for water temperature rise and phase transition. Assume the inflow water temperature is 20°C, outflow water temperature is 70°C, the energy utilization is 60%, we can know that the water production quantity is 8 kg/m² per hour. Comparing with the disk solar distillation apparatus, of which water production quantity is only 3-4kg/m² per hour only in sunny day, but can’t be used at night, the water production quantity is highly increased. So the device should have a good application prospect.

1. Introduction

Water is one of the basic material of human survival and development. At present, about a third of the population live in water shortage areas around the world. By 2025, this figure will increase to two-thirds. The problem is also exist in our country. The resources of water in China is from 2.7 to 2.8 trillion m³, which is the 6th in the world, but as one of 13 water shortage countries which is listed by the United Nations, the per capita availability is only 2292 m³, the quarter of the world availability. The water resource in our country isn’t distribution in time, space and regional. the annual per capita water is about 1000 m³ in ten provinces(Liaoning, Shanxi, Jiangsu, Henan, Hebei, Shandong, Ningxia, Beijing, Shanghai and Tianjin), which is achieved the international water resource stress limit value. There is more than 300 cities of the total 640 cities in our country is shortage of the water, especially
in Beijing, which is only 7.8% of the world’s average level. By 2030, Chinese population will achieve to 1.6 billion, per capita availability of water will drop to 1760 m$^3$, then the water resources of our country will be scarce$^{[1-2]}$. Therefore, according to the actual situation in our country, make the best use of the long coastline for desalination, and make the brackish water in lakes and wells to fresh water, is a relatively feasible approach to remit the shortage of water situation in our country, even in the world.

1.1. The instruction of the basin-type solar desalination device
Solar desalination is the process of recombining the certain concentration of sea water by means of heat or electricity produced by the sun, and getting the fresh water at last. Basin-type solar desalination make the sea water phase change and separation by heat, and then carry out on the separation of water vapor condensation in order to produce the fresh water. Since without the external heating system, the device belongs to the passive solar distillation.

Passive water distillation system was built by a Swedish engineer Wilson$^{[3]}$ in the northern Chile in 1872, and it could produce 23 tons of fresh water every sunny day. This kind of system has many advantage: its design is simple; the comprehensive cost of it is low; and the professional maintenance isn’t needed. But its disadvantage is also clearly: it doesn’t work at night; the production is greatly influenced by the weather; and the low production of per lighting area.

Zhang Xiaoyan$^{[4]}$ studied on multi-stage stacked tray solar still by experiment, using the multi-stage stacked systems to recycle the latent heat of condensation, and by comparing with the different numbers of stacked trays, they found when the device operate in high temperature($>$ 70 ℃), the performance is good. V. Velmurugan$^{[5]}$ installed the fin in the traditional solar sea water distillation in order to increase the effective area of absorb the solar and speed up the water temperature, and even water production rate. Through the comparing with the theory and experiment, they found that the installation of finned makes the water production rate increasing by 45.5%. A.E. Kabee$^{[6]}$ designed the solar distillation bottom to hemispherical, and then laying the black cotton material in the bottom, to reduce the capacity of sea water by capillary effect and the water thermal inertia, and also increase the effective area of water evaporation. They designed the glass cover to pyramid, consisting of all Angle 45° glass cover ,increase the solar absorption capacity of the water, avoid the bad influenced of the sun shadows which caused by the moving of sun. Depending on the experience study, the water production rate of device is 4.1L/m$^2$ by average. The maximum instantaneous efficiency of the device is 45%.

1.2. Wind turbine heating device instruction
Wind energy technology has a rapid development in recent years. By Betz limit, the ideal of wind turbine efficiency is 59.3%, but the practical application of the efficiency of wind turbines are generally only 70% of the ideal efficiency$^{[7]}$. Generally speaking, the efficiency is only 16% when wind turbine is used to water lift, it is 30% when wind turbine is used to generate electricity.as we all know, wind turbine heating is convert the mechanical energy of high grade to the heat energy which is low grade, so the efficiency is higher, the highest of it will achieve to 45%, generally around 40%. Now, there are three methods to convert the wind energy to heat energy$^{[8]}$: the first is use wind turbine to generate electricity, and then put the electricity to heat. The second method is convert the wind energy to air pressure energy, and then achieve the heat. The last one is convert the wind energy to heat directly. Because of the higher adaptability and efficiency, wind power convert to heat directly is popular. There are four ways to wind turbine heating, Respectively is liquid mixing heating, liquid extrusion heating, solid friction heating and eddy current method heating. Because of easy to make, not use of wearing parts, without strict requirements of heat transfer medium, high performance and fixing to wind turbine output power characteristics, liquid mixing heating was widely used$^{[7]}$.

2. Design scheme
2.1. The instruction of the structure

Figure 1 is the structure diagram of the seawater desalination device. As it shown, the device is equipped with wind turbine which supply the electrical energy, converted the wind power to the electrical and storage into battery, the battery is used to provide the power to control system. The suction pump, the strong brine discharge pump and the water collecting pump which is shown by figure 1 is driven by it. The suction pump is connected with sea water, the Y-type filter is used to filter the impurities. Water collecting pump is connected with water collection tank to collect the fresh water. Strong brine discharge pump is used to discharge the strong brine. Vertical axis wind turbines pass through the still, and link with the mixing heater, making up the wind turbine liquid mixing heating. It should be pointed out that the device which change the position of mixing vane is installed to solve the vertical wind turbine self-starting. The top of the still is double deck glass. The outer is plastic, the inner is stainless steel with thermal insulation material outside. UCPC plastic should be used in all piping, inlet pipe wind around the inner 2~3 rounds before cross the tank.

![Figure 1. Desalination device schematic diagram.](image)

2.2. Operation instruction

The work of the desalination is shown in diagram 2, use wind turbine to charge the battery, and use the battery driving the small pumps, make the water entre the still as shown in figure 1 after pass through the Y-type strainer. The airtight greenhouse is still. According to the greenhouse effect, the solar radiation reaches the device upside, most through the glass cover plate, and others is absorb by it. Most the power which through the glass cover plate is absorbed by sea water, make the temperature of the water rise. At the same time, vertical axis wind turbine liquid heating will also convert the wind energy to heat energy to heat the sea water, accelerate the evaporation of sea water. Then, some of the water vapor will contact to the glass cover plate and condensation at the lower surface of it. So if the appropriate dip angle is existence, the condensate will flow along the roof down under the action of gravity, and flow into the interlayer at last. The other parts of the water vapor will meet the cold shell of the pipe, also release of latent heat of vaporization and coagulate, it doesn’t only collect the fresh water, but also preheat the import sea water. There are water level indicator in the interlayer. When the water accumulate to the certain right, the water collecting pump will work to collect the fresh water. There are salimeter in the tank, the strong brine discharge pump will work to discharge the strong brine when the salinity achieve to the certain value.
3. Estimates of the production yield

To estimate the yield of the device, we are on the following assumptions:

1) The quality and the temperature of the water doesn’t change before and after the distillation. The injection temperature \( T_i \) is 20°C.

2) the size of the still is \( 5m \times 2m \times 2m \), the windward area of wind turbine for heating is \( 2m \times 3m \).

3) the efficiency of wind power converted into the heat energy \( C_p \) is 35%, the solar radiation absorptivity is 80%, the flow velocity is 10m/s, the heat utilization of the still \( \eta \) is 60%

According to the principle of conservation of energy:

\[ Q_r + Q_w = Q_i + Q_0 \]  \hspace{1cm} (1)

Where \( Q_r \) is the heat generated by the solar energy, \( Q_w \) is the heat generated by the wind turbine, \( Q_i \) is the consumed heat of the sea water evaporation, \( Q_0 \) is the heat dissipation.

According to the 1981~2000 “China meteorological radiation data high-school year-book” which the national meteorological center issued, then use the method of calculating the monthly average solar radiation suggested by Klien and Theilacker as the internationally recognized method to achieve the Shanghai maximum of solar irradiation is \( 3.6kW \cdot h/(m^2 \cdot d) \), the energy which device can absorb is \( 1.04 \times 10^8 J / d \) \[^9\].

\[ Q_w = C_p \times \frac{1}{2} \rho V^3 \times A \times t \]  \hspace{1cm} (2)

We can use the formula (2) to calculate the heat which wind turbine generated. Where \( C_p \) is the efficiency of wind power converted into the heat energy, \( \rho \) is air density, \( V \) is flow velocity, \( A \) is windward.
d area, $t$ is time, so we can calculate the result is $1.17 \times 10^8 J / d$

The heat which 1kg evaporation need is

$$q = c(T_0 - T_e) + q_r = 4.32 \times 10^3 \times (100 - 20) + 2.26 \times 10^6 = 2.60 \times 10^8 J / kg$$

Where $c$ is specific heat capacity, $q_r$ is latent heat of vaporization.

Put these results into the formula (1), we know the average daily water yield $m$ is 85kg. Comparing with the same size of basin-type still, water yield is doubled.

4. Conclusion

This paper provide a sea water desalination device, the device can make full use of Chinese long coastline and northwest inland brackish water to desalination. Undoubtedly, it’s a feasible way to remit the shortage of water. Based on the above discussion, the device has the following advantages:

1. this device is used for solar energy and wind energy, which is known as the renewable energy, the device can be self-sufficient, not need the external energy input.
2. Since the device needed for solar and wind energy, which is universal existence, it can be used in various environments, for instance, it can be used in northwest for brackish water purification, or used in coastal area, even in the island. After the modification, it could be used in the deep sea for floating work, widely used in many kind of situation.
3. Generally, when sunny, wind is small, but when wind is high speed, the sunshine is weaker. The device realize the wind and solar, overcome the disadvantage of other solar desalination device that can’t work at night, and increase the water yield greatly.
4. The size of the device could choose by the actual requirement.
5. The cost of desalination mainly include energy consumption, assets depreciation and maintenance cost. Generally, the cost of energy consumption is about 55%, the depreciation is 24%\cite{10}. Because of lack of energy consumption and automatic production, it makes the cost reduced greatly.

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