Air Water Intake Device Based on Peltier Effect

Zixuan Chen
Wuhan University of Technology, Hubei, Wuhan, 430070, China

Abstract. This paper designs an air intake device based on Peltier effect to solve the problems of insufficient per capita water use and difficult survival of living organisms in water-scarce areas in China. It uses semiconductor to refrigerate, takes water from the air in a cooling condensation way, uses wind power and solar energy to supply power for the refrigerator continuously. Through data analysis, the device can effectively collect air moisture and condense to produce liquid water, which has broad application prospects in arid areas in northwest China.

1. Introduction
In China, water resources are scarce and unevenly distributed, and freshwater resources are extremely scarce in islands and mountainous areas due to landform. Due to the lack of water resources, most organisms are difficult to survive, which will lead to extremely harsh living conditions. At present, there are condensation water intake, fog water intake, compression water intake and other methods, but there are problems of high energy consumption or low efficiency. The device aims at using solar energy and wind energy as energy output, using semiconductor cooling water vapor to collect water, and realizing the function of water intake with low energy consumption.

2. The research content of the project
2.1. Research content
This project has designed a zero energy consumption water intake device that uses both wind energy and solar energy to directly draw water from the air, in order to alleviate the problem of water shortage and difficult water intake in the areas where water resources are scarce. The device consists of a wind energy cooperation module, a regeneration runner module, a heating module and an electric refrigeration module. The device can convert water molecules in air into liquid water through three processes of adsorption concentration, evaporation and cold condensation dew, thus realizing the process of air water intake. The overall structure of the device is shown in Fig. 1.
3. The implementation plan of the project research and the research methods and technical routes to be adopted.

3.1. Overall structural design
The device is composed of wind energy coordination module, regeneration runner module, heating module and electric refrigeration module, which can convert the water molecules in the air into liquid water through three processes of adsorption concentration, evaporation and condensation, so as to achieve air water intake. The overall structure of the device is shown in Fig. 2.
3.1.1. Wind energy coordination module. As shown in Fig. 3 (a), the wind energy collaborative module is composed of spiral blades, supporting shafts and suction fans to achieve effective utilization of wind energy in multiple regions. The spiral wind generator rotates under the action of wind and changes the air flow direction, and cooperates with the lower suction fan to recover the kinetic energy of the wake air of the spiral fan and improve the air flow in the water intake device. And can generate electric energy under the condition of no illumination, form wind and light complementation with solar power generation, and enhance the environmental adaptability of the device.

The wind energy utilization rate of the spiral fan is 10-20% higher than that of the horizontal shaft fan, and the spiral fan can provide larger torque, which is favorable for driving the suction fan to rotate. The spiral fan does not need to be installed at high altitude, but can be directly placed at low altitude, which is convenient for installation and maintenance. The suction fan under the screw type fan is multi-wing centrifugal fan. Compared with the traditional axial-flow fan impeller, the extraction efficiency of multi-wing centrifugal fan can be increased by 20-30%. At the same time, it has the advantages of no noise, lightness and easy disassembly.

![Fig. 3 Wind energy synergy device](image)

When the spiral vertical fan rotates, it can be seen from the velocity vector diagram and pressure nephogram in Fig. 3(b) that when the air pushes the spiral blade to rotate, it flows downward along the blade, and at the same time, local low pressure will be generated in the central area. External atmospheric pressure will press air into the suction fan, increasing the air flow speed in the device. The suction fan is coaxially connected with the screw type vertical fan. By using the mechanical energy when the screw type vertical fan rotates, the cooperation with the suction fan is realized. At the same time, the suction fan will also generate low pressure in the central area, and once again improve the rate of air entering the device, so as to realize the multi-level utilization of spiral vertical axis fan energy and effectively improve the utilization rate of wind energy.

3.1.2. Regenerative wheel module. The regenerative runner module absorbs the moisture in the air to the inside of the material by using the porous material, and then evaporates the moisture in the material by the heating module. The condensing module refrigerates and collects the high-temperature humid air to realize the extraction of air moisture. At the same time, the ZSM-5 zeolite molecular sieve material selected has reproducibility under high temperature heating at 120 DEG C, has the capability of cyclic adsorption and desorption, and achieves the effects of energy conservation and environmental protection.

3.1.2.1 Device structure

The regenerative runner module is provided with perforated pipes to store materials. The specific device structure is shown in Fig. 4. The device consists of a metal isolation net, comb teeth, a porous bearing net, a partition plate, an internal gear and a bottom plate.
In the adsorption part, the metal isolation net is used to isolate multiple groups of molecular sieves, increase the contact area between the material and air, reduce the heating space and improve the heating efficiency. Comb and separation plate can effectively prevent air from entering desorption area and reduce heat loss. The porous bearing net is used for laying super absorbent materials and is convenient for air circulation. The internal gear is meshed with the bottom plate to drive the material to circularly move in the adsorption area and the desorption area, and the bottom plate is used for mounting and fixing the bearing device, the matching motor and other equipment.

Work flow: as shown in Fig. 5, the humid air enters the adsorption area through the centrifugal fan, the super absorbent material is relatively saturated after absorbing moisture, and the bearing plate is driven to rotate through the rotation of the internal gear. The saturated material is transferred from the adsorption area to the desorption area, and after entering the desorption area, the moisture in the material is evaporated by the heating module to generate high-temperature wet air. After a period of heating, the material becomes dry, re-enters the adsorption area under the continuous rotation of the rotating wheel, and adsorbs moisture in the air again, completing a cycle process and finally realizing regeneration.

3.1.3. Heating module. The heating module is in the form of electric heating. The electric energy is provided by solar energy and wind energy. It is used to heat molecular sieve with high water content in desorption area to separate water molecules from the inside of the material and generate high-temperature wet air, thus creating a good environment for condensation.
As shown in Fig. 6, the heating module is provided with heat energy by the heating patch, and the middle compartment part is a molecular sieve storage area. The heating power can be controlled by a feedback control system, and when the heating patch reaches a set temperature, the heating patch is converted into a low-power heat preservation mode. The outer side of the heating module is covered with thermal insulation materials to reduce heat loss and achieve energy saving effect.

3.1.4. Electric refrigeration module.

3.1.4.1 Overall structure
As shown in Fig. 7, the refrigeration module consists of condensation and collection. The condensing part is a semiconductor refrigerating plate, the hot end of which is provided with radiating fins, the cold end is in contact with refrigerating liquid, and the cold end can reach 0-5 DEG C at normal temperature to meet refrigerating requirements. The collecting part consists of an inclined metal guide plate with good thermal conductivity and a semi-cylindrical guide groove at the end of the inclined metal guide plate. The metal plate is installed above the desorption area and directly contacts with desorbed high-temperature wet air for refrigeration. The plate is provided with a certain slope, which is favorable for draining condensed water to the diversion groove. Finally, the collected water is guided to the lower storage area through the guide groove.

3.1.4.2 Work flow
As shown in Fig. 8, the cooling plate maintains a constant temperature difference between the hot end and the cold end under the energized state. Under good heat dissipation conditions, the cold end can be maintained at a lower temperature, meanwhile, the metal heat conductivity coefficient is high, the heat and cold transfer efficiency is high, and the metal drainage plate will also be maintained at a lower temperature. The high-temperature humid air generated by heating in the desorption area rises, contacts the low-temperature drainage plate to form condensed water, and the condensed water flows to the end diversion groove along with the inclined plane, and flows into the collection box after the condensed water is collected to complete collection.
4. Research Foundation and Feasibility Analysis of the Project

Let the initial ambient temperature be 0°C and the absolute humidity of air be ρ0, which is obtained from the saturated water vapor pressure and temperature:

\[ E_s = E \times 10\left( a \times t \right) \left( b + t \right) \]

Where: t: air temperature (°C); a, B fitting parameters, when \( t > 0 \) °C, \( a = 7.5, B = 237.3 \), when \( t \leq 0 \) °C, \( a = 9.5, B = 265.5 \);

\( E_s \): saturated water vapor pressure (HPA); when \( E_0 \): \( T = 0 \) °C, the saturated water vapor pressure is taken as \( E_0 = 6.11 \) hpa; the vapor pressure of water is:

\[ e = f \times E_s \]

Where, \( f \): relative humidity of air; \( e \): vapor pressure (PA)

Absolute humidity is:

\[ \rho_w = e / \left( R_w \times T \right) = m / V \]

Where: \( R_w \): gas constant of water \( = 461.52 \) j/(kg k); \( T \): temperature (k);

\( m \): mass of dissolved water in air (g);

\( V \): air volume (m³)

Therefore, the amount of water obtained is:

\[ \Delta \rho_w = \rho_{w0} + S - \rho_{w2} \]

Where \( S \) is the water volume (g) generated by the desorption of the adsorbent, and \( \rho W2 ' \) is the absolute humidity of the exhaust air (g/m³);

\( \rho W0 ' \) is the absolute humidity of the air entering the desorption zone.

---

**Fig. 8** Cooling module workflow

**Fig. 9** Relationship between saturation absolute humidity and temperature
As can be seen from the above Fig., condensation and water collection can be realized only by keeping the condensation temperature at C2.

4.1. Benefit Analysis of Water Collection

In this project, ZSM-5 zeolite was used as adsorbent for adsorption and desorption experiments. The working condition is set as 50% relative humidity and 40 °C ambient temperature. The definition of adsorption capacity X of material is as follows:

\[ X = \frac{m_t - m_0}{m_0} \times 100\% \]

Record the mass changes of the samples one by one under the constant temperature and humidity environment to obtain the X-t dynamic adsorption curve of the molecular sieve at different times, as shown in Fig. 10.

![Fig. 10 X-t dynamic adsorption curve](image)

The approximate function expression of adsorption X with temperature t is obtained by MATLAB simulation fitting data

\[ X = f(t) = p_1 \times t_5 + p_2 \times t_4 + p_3 \times t_3 + p_4 \times t_2 + p_5 \times t_1 + p_6 \]

Among them: \( p_1=2.365\times10^{-13} \); \( p_2=-2.714\times10^{-10} \); \( p_3=1.169\times10^{-7} \); \( p_4=-2.354\times10^{-5} \); \( p_5=0.002233 \); \( p_6=0.006774 \);

Similarly, the desorption experiment was conducted at an ambient temperature of 120°C. The ratio of desorption water vapor mass to adsorption water vapor mass is defined as desorption percentage, and the ideal state is 100%. The experimental results are shown in Fig. 11.
The approximate function expression of the percentage of desorption with temperature $t$ is obtained by fitting data through Matlab simulation:

$$Y = g(t) = p_1 \times t_5 + p_2 \times t_4 + p_3 \times t_3 + p_4 \times t_2 + p_5 \times t_1 + p_6$$

Among them: $p_1=1.108\times10^{-9}$; $p_2=-9.105\times10^{-7}$; $p_3=0.0002868$; $p_4=-0.04298$; $p_5=3.042$; $p_6=-3.069$.

In order to ensure the recycling, the desorption amount is equal to the adsorption amount and maintain the stability of the working efficiency of the device. That is, the state of the adsorbent remains unchanged after one cycle in the corresponding time. The following formula must be satisfied:

$$X_2 \times \left[1 - g(t_0)\right] = X_1$$

$$t_2 - t_1 = a \times t_0$$

$$X_2 = f(t_2)$$

$$X_1 = f(t_1)$$

In the above formula, $a$ is the ratio of adsorption area to regeneration area; $X_2 = 0.065$; $t_0=20\,\text{min}$ is the time required for desorption rate of 42.73% at $120\,\text{℃}$.

Obtain:

$$a=1.18$$

Assuming that the total mass of molecular sieve is $m=1\,\text{kg}$, the desorption rate in the regeneration zone is:

$$s = m \times X_2 \times \left[1 - g(t_0)\right]/t_0 \times (a+1) = 0.637\,\text{g}$$

Let the ambient temperature $C_0$ be $40\,\text{℃}$ and the relative humidity 50%. Taking the size of the condensation chamber as $15\times20\times30\,\text{mm}$, the absolute humidity of the air in the desorption zone is obtained as follows:

$$\rho_{w_0} = 25.52\,\text{g} / \text{m}^3$$

$$\rho_{w_0} = \rho_{w_0} / (a+1) = 11.71\,\text{g} / \text{m}$$

The cooling end temperature $C_2$ is $15\,\text{℃}$, so the absolute humidity of the discharged air is:

$$\rho_{w_2} = \rho_{w_2} / (a+1) = 5.88\,\text{g} / \text{m}^3$$

$$\Delta \rho_v = \left(\rho_{w_0} - \rho_{w_2}\right) \times V + S = 0.0524 + 0.637 = 0.6894\,\text{g} / \text{min}$$

Taking the use of 5kg molecular sieve as an example, the device can work at night and in the daytime, and only air is introduced at night to fully adsorb the molecular sieve to saturation. During the day, the device works continuously, first desorbing the molecular sieve saturated by adsorption at
night, and then performing continuous regeneration desorption. Take 10 hours of day and 14 hours of night, and the amount of water available in a day is:

\[ V = V_1 + V_2 = 3.35\text{kg} \]

According to the calculation, the device can collect 3.35kg of water from the air every day. Considering that the surplus energy during the day can still be used for desorption and collection at night, the actual water collection amount will be larger.

5. Summary
The device has the advantages of powerful function, convenient application, strong mobility, low power consumption and the like, and can be widely applied in many environments. This paper presents a method of taking water from the air based on solar energy and wind energy self-supply, and introduces its structural principle and its advantages. At present, large-scale production of semiconductor refrigeration chips, popularization of photovoltaic cells and mature development of high-precision semiconductor refrigeration temperature control system technology have provided favorable conditions for the production of energy-saving, environment-friendly and efficient air water intake devices.

References
[1] Wang Shuangcheng, Cheng Honglu. Calculation of water saturation and vapor pressure [J]. Henan chemical industry, 1999 (11): 29-30 + 34.
[2] Liu xinzan. Principle and application of thermoelectric refrigeration [J]. Hebei Industrial Science and technology, 2006 (06): 344-346.
[3] Zheng Yongming, Fang Fang, Xu Jianyi, Zheng Yanhong. Research on semiconductor refrigeration principle and application system design [J]. China test technology, 2006 (02): 49-51 + 88.
[4] Xin Feng, Yuan Zhongxian, Wang Wenchao. Adsorption and desorption characteristics of discolored silica gel and ZSM-5 zeolite molecular sieve [J]. Chemical progress, 2015,34 (06): 1730-1736.
[5] Yang Fan. Development and characteristics of adsorption air intake device [D]. Heating, gas supply, ventilation and air conditioning project of Southwest Jiaotong University, 2016.