Cooling adsorption type desert air water extractor based on STM32

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Abstract. With dry climate and scarce rainfall, the annual precipitation of desert areas is below 250 mm. The daily temperature difference of desert climate is very significant, the near surface temperature can reach 60 °C to 80 °C in summer and autumn noon, but it can be reduced to below 10 °C at night. If the climate characteristics of the desert can be reasonably used for low-cost water intake, it will provide great convenience to the aborigines and migrants in the desert. Some existing air water intake devices cannot produce good water intake effect due to the low air humidity in the desert. The device uses semiconductor refrigeration to improve the relative humidity of air, so that the adsorption efficiency is significantly improved. Using the low specific heat characteristics of sand to optimize the convection and condensation device, greatly reducing the energy consumption and mechanical failure rate. By using the P, N type semiconductor's Peltier effect, STM32 controls the switching circuit and then controls the voltage direction of the two ends of the semiconductor to realize the switching of refrigeration and heating modes. In this way, low-cost and high-efficiency water intake can be realized in the desert.

1. Introduction
In order to solve the problem of insufficient adaptability of the existing adsorption water extractor in desert area, the device is based on the adsorption method combined with refrigeration to improve the air humidity so as to improve the water intake rate. Using the characteristics of large temperature difference between day and night on the desert surface to improve the convection and condensation part, replace the existing device of the fan and condenser, reduce energy consumption and cost, and designs a cooling adsorption desert air water intake device based on STM32 control.

2. Research background
Desertification is a severe and expanding situation worldwide. Severe desertification has greatly occupied human living space. Residents in desert areas have difficulty using water. Effective water supply for desert residents is a prerequisite for ensuring their basic life.

The earth's atmosphere contains abundant water resources (cloud, water vapor and fog), even in arid desert areas, atmospheric humidity can exceed 10 g/m3. According to the principle of conservation of mass, when the air temperature increases, the surface water will evaporate, resulting in a decrease in water, and the absolute humidity of the air will increase. Therefore, air can be regarded as a huge, clean
and renewable water resource. Air water intake technology is a very promising and flexible way of water supply, which can alleviate the water demand of people in desert areas.

At present, air water extraction technologies in China and abroad can be divided into three categories: surface cooling method, membrane separation method and adsorption method. Among them, the surface cooling method is to condense water vapor into liquid water by passing wet air through the cooling surface. This method is limited by climatic conditions and is difficult to be popularized and applied. Membrane separation method uses osmotic pressure as a driving force to capture water vapor from the air, which is a new air water extraction technology and is still in the research stage.

Adsorption method uses liquid or solid desiccant to absorb water vapor in wet air, and then obtains the required fresh water through the regeneration of desiccant. Among them, the chemical reagents of liquid absorption method are not safe enough, so the fresh water obtained by this method is not suitable for drinking. Compared with the refrigeration condensation method, the adsorption air water extraction technology has the advantages of small footprint, simple structure and low cost. Due to the low air humidity and high average temperature in the desert, the water intake rate of the existing adsorption water sampler is reduced and the condensation energy consumption is increased when it is applied in the desert area.

3. Technical route

3.1. Overall device design

The overall device is shown in Figure 1, which is mainly composed of surface heat conduction module, semiconductor temperature control and water vapor adsorption module and guide pipe.

![Figure 1. Overall device.](image1)

3.1.1. Surface Heat Conduction Module. The surface heat conduction module is shown in Figure 1, which is mainly composed of heat conduction floor, heat conduction fin, water tank, fixed bracket and heat preservation shell.

![Figure 2. Surface Heat Conduction Module.](image2)
Aluminum with good thermal conductivity is used as the material for the thermal conductive floor and fins. The thermally conductive floor is 80 cm in diameter and 2 cm in thickness, directly contacting the desert ground, with a small number of holes connected to the catchment. The diameter and height of the thermally conductive fin are 30 cm and 70 cm, respectively, which are connected with the thermally conductive floor to accelerate the heat exchange between the gas inside the device and the ground. The water tank is used to collect the liquid water from the condensation of the heat-conducting floor and the heat-conducting fin at night. The fixing bracket is installed at the lower end of the heat conduction floor and inserted into the sand layer to fix the device. The thermal insulation shell uses XPS extrusion plate as the material, and the shell is clothed with a small amount of air holes, which can make air flow and reduce internal and external heat exchange.

3.1.2. Semiconductor Temperature Control and Steam Adsorption Module. The semiconductor temperature control and steam adsorption module are shown in Figure 3, which is mainly composed of thermoelectric sheet, adsorbent, adsorbent changer, stepper motor, fixed bracket and thermal insulation shell.

![Figure 3. Semiconductor Temperature Control and Water Vapor Adsorption Module (Right figure is internal structure).](image)

Among them, the fixed bracket and thermal insulation shell are the same. The heat preservation shell is designed as a cylinder with a rectangular opening. Two parallel TEC-12715 thermoelectric chips are installed outside the rectangular opening. An adsorbent exchanger with six grid containers is installed inside the container filled with composite adsorbent SiO2·xH2O·yCaCl2.

Due to the capacity of the adsorbent in the container is certain, when the adsorbent absorbs a certain mass of water, the adsorption rate decreases significantly, so the stepper motor is needed to drive the converter to rotate 60°, and the adsorbent in the next container is used for adsorption. The changer has six adsorption containers, HX711 pressure sensor is installed below, the measuring range is 50kg, used to detect the change of adsorbent quality; Composite adsorbent is filled with metal mesh and fully contact with air.

3.2. Circuit and control program design

The desert sunshine is sufficient and the power of the whole device is supplied by 270W solar panels. At present, the power supply of the device is thermoelectric, single chip microcomputer and stepper motor. The power obtained by the solar panels in the daytime is stored in the power supply for the operation of the device. The surplus power stored in the daytime can be used for the desorption process at night.

The device uses STM32 to control the work. According to the time conditions, the switching circuit is used to adjust the voltage of the two ends of the thermoelectric chip to adjust the working mode of the thermoelectric chip. The temperature value of the thermoelectric chip is obtained according to the signal returned by the temperature sensor. The power of the thermoelectric chip is adjusted in real time to stabilize the temperature in the adsorption vessel. The mass of absorbed water is calculated according
to the pressure change value returned by the pressure sensor, and the stepper motor is controlled to drive
the converter to rotate according to the set critical conditions.

Figure 4. Single-chip microcomputer control schematic.

3.3. Workflow design

3.3.1. Daytime adsorption mode. When the device works in the daytime, the single chip microcomputer
controls the switch circuit to make the inside cooling and outside heating of the thermoelectric sheet,
the temperature in the adsorbent container is lower, the gas density increases and flows downward. The
surface heat conduction module imports a large amount of heat from the ground. The temperature around
the heat conduction fin is high, the air density decreases, and the high-temperature gas flows upward.
The external air enters from the surface heat conduction module and flows through the heat insulation
pipe into the semiconductor temperature control and water vapor adsorption module. The composite
adsorbent adsors the water vapor. The treated gas is discharged from the outlet below. When the mass
of adsorbent increases by 0.38 kg, the stepper motor drives the adsorbent changer to rotate 60°, and the
new adsorbent is used to continue the adsorption.

3.3.2. Night desorption model. When the device works at night, by changing the switch circuit, the
positive and negative voltages of the two ends of the thermoelectric plate are adjusted, and the
thermoelectric plate is heated inside and cooled outside. The temperature in the adsorbent container was
high, the air density was small, and the adsorbent flowed upward. After reaching 80 °C, the composite
adsorbent desorbed and released the water vapor adsorbed in the daytime. The surface heat conduction
module is connected to the low temperature ground, where the temperature is low, the air density is
large, and the device is discharged. The external air enters from the outlet below the adsorption module,
carries the water vapor desorbed by the composite adsorbent, and enters the air intake module. After
high temperature and high humidity air cooling, the temperature reaches the dew point, and the water
vapor is liquefied into liquid water, which is attached to the thermally conductive fin and the thermally
conductive floor. Under the action of gravity, it flows into the water tank through the holes on the
thermally conductive floor to complete the water intake process. When the adsorbent mass is reduced
by 0.38 kg, the step motor drives the adsorbent changer to rotate 60°, so that the device can heat and
desorb the un desorbed adsorbent.

4. Feasibility analysis
The natural environment was set as July in the hinterland of the Taklimakan Desert. According to the
relevant literature, the average daytime surface temperature is 324 K, and the average nighttime surface
temperature is 298 K. The average daytime temperature is 30 °C, and the specific humidity of the atmosphere was 4.5 g/kg. According to the enthalpy surface, the air humidity was about 17%. When the temperature was reduced to 25 °C, the humidity could be increased to 40%.

4.1. Fluid analysis
From the Bernoulli equation

\[ P + \frac{1}{2} \rho v^2 + \rho gh = C \]  

Ideal gas-state equation

\[ P = nkT \]  

Density formula

\[ \rho = n \frac{M_{mol}}{N_A} \]  

Gas flow formula

\[ Q = Sv \]  

Where \( v \) is gas flow rate, m/s, \( Q \) is gas flow rate, m³/h; \( C \) is constant; \( k \) is the Boltzmann constant, \( k = 1.38 \times 10^{-23} \text{J/K} \); \( g \) is the gravitational acceleration, \( g = 9.8 \text{m/s}^2 \); \( M_{mol} \) is the molar mass of air, \( M_{mol} = 29 \); \( N_A \) is the Avogadro constant, \( N_A = 6.022 \times 10^{23} \); \( P \) is gas pressure, Pa; \( n \) is the number of gas molecules per unit volume; \( T \) is the thermodynamic temperature of gas, K; \( \rho \) is the gas density, kg/m³; \( h \) is the height of the calculation point, m; \( S \) is the cross-sectional area of the airway, m².

Substituting \( S = 1 \text{m}^2 \), \( \rho_1 = 1.093 \text{kg/m}^3 \), \( \rho_2 = 1.093 \text{kg/m}^3 \) into, the diurnal gas flow \( Q_D \) and nighttime gas flow \( Q_N \) can be solved.

\[ Q_D = 271 \text{m}^3 \cdot \text{h}^{-1} \]
\[ Q_N = 228 \text{m}^3 \cdot \text{h}^{-1} \]  

4.2. Energy consumption analysis
From the electric power calculation formula

\[ W_e = (P_o - P_i)t_D \]  

In the formula, \( W_e \) is the power stored in the daytime, kw·h; \( P_o \) is the solar panel power, \( P_o = 270 \text{W} \); \( P_i \) is the rated power of thermoelectric chip, \( P_i = 138 \text{W} \); \( t_D \) is day time, \( t_D = 8 \text{h} \)

Achieved

\[ W_e = 1.056 \text{kw·h} \]  

4.3. Adsorbent performance analysis
Formula for calculating mass

\[ M = \rho V_{max} \]
In the formula, $M$ is the maximum mass of adsorbent that can be filled in each adsorption container, kg; $\rho$ is the relative density of composite adsorbent $\rho = 780\text{kg/m}^3$; $V_{\text{max}}$ is the maximum volume of adsorbent that can be filled in each adsorption vessel, $V_{\text{max}} = 2.74\text{ L}$.

Achieved

$$M = 2.14\text{ kg}$$

(9)

4.4. Effectiveness analysis

According to the relevant experiments, the air flow $Q_a = 76.5\text{ m}^3/\text{h}$ for the adsorption of adsorbent and the air flow $Q_d = 54.5\text{ m}^3/\text{h}$ for the desorption can be obtained as $Q_D > Q_a$, $Q_N > Q_d$, and the flow of the device meets the requirements of adsorption and desorption. The desorption time of 80% composite adsorbent was about 70 min, and the desorption time of 6 times at night was 7 h. The energy stored in the daytime of the device can be heated for 7.7 h at night to meet the energy consumption demand. According to the adsorption performance of the adsorbent obtained in the literature, 1 kg adsorbent can absorb 0.38 L water. The filling mass of each adsorbent container was 2.14 kg, a total of six containers, and the total filling mass was 12.84 kg. The daily adsorbed water is 4.88 kg, which can alleviate the water supply demand of residents in desert areas.

5. Conclusions

Since the device uses the temperature difference between the surface and the thermoelectric sheet to form convection, and uses the surface low temperature to condense water, the condenser tube and fan are reduced compared with the traditional device, the device cost is reduced, and the mechanical failure rate is reduced. The working mode of day-to-day adsorption and night-time desorption is adopted to reduce the loss caused by frequent refrigeration and heating switching between semiconductor and adsorbent, and reduce the maintenance cost. And in the process of adsorption, the air is cooled to improve the air humidity, so that the composite adsorbent can give full play to the adsorption performance and improve the water yield. It is therefore suitable for use by residents in desert areas.

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