Air Water Collector based on Chimney effect

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Abstract. The main research content of this project is the water recovery efficiency of the hot-pressure-driven air water-taking device when the phase-change material is used for energy supply, and combined with the research process, an automatic water-taking device using desert temperature difference and phase-change material storage is designed. At a time when energy sustainability is of great concern, we must make the development of green energy a core goal. Among them, solar energy as a green non-polluting new energy, its development and utilization is an important research topic and direction. The desert areas have plenty of solar energy and enough temperature differences to take advantage of these two resources and combine the lack of fresh water in the area. The purpose of this project is to design a device that uses phase-change materials to store heat to provide heat pressure, guide air directional flow, and use high-efficiency coaxial water collection sails for air water collection, with less human and material input, to obtain the fresh water necessary for life. And from the theoretical and physical level to demonstrate its feasibility, explore the direction of marketing.

1. Introduction
The device is an air water-collecting device used in arid areas such as desert margins. In arid desert areas, freshwater resources are scarce. In the early hours of the morning in desert areas, the air humidity will also rise due to the large temperature difference between day and night. The device can use phase change energy storage materials under the influence of day and night temperature difference of suction, heat release characteristics, combined with chimney effect directional drainage humidity of the air, effectively extract moisture in the air. The overall unit shape is shown in the figure below:

2. Research background
The desert floor is completely covered with sand, plants are scarce, rain is scarce and air is dry. In fact, there is a lot of fresh water in the air. It is estimated that even in desert areas, it contains more than 10g/m3 of water. Desert areas are mostly sandy beaches or dunes, and rocks are often found under the sand. There are sometimes valuable deposits in the desert, and many oil reserves have been found in recent times. Desert has few residents, resource development is also difficult, in order to develop desert resources, the need for a habitable environment. Desert climate is dry, annual rainfall is very rare, but there is a lot of water vapor in the air. Especially in the early morning, due to the temperature difference between day and night, the moisture content in the air reaches a peak, how to get water from the air, not affected by wind and sand, is an important subject for the construction of a suitable human living environment.
3. Overall scenario

3.1. The overall scenario
The device is composed of a water collecting device, a temperature control device, a sand proof baffle, an air circulation pipe and a shell. The water collecting device is located in the center of the device and is tubular, taking into account the functions of water collection and air flow. The power of the directional flow of the air flow in the device comes from the pressure difference caused by the chimney effect. The phase change energy storage material releases heat outside the water collecting pipe and makes the air float continuously. A water collecting sail is placed in the center of the pipeline. After the water vapor condenses into water on the water collecting network, it can fall down along the drainage grid and be collected in a small diameter water collecting tank. At night, when the temperature is low, the PCM releases heat and heats the air in the water collecting pipe. The air in the pipe expands and expands when heated, and the pressure decreases. Under the action of atmospheric pressure, the cold air is forced to rise and contact with the water collecting sail, and most of the water vapor condenses into liquid water drops. Before leaving the installation, the heated air will touch the convex panel of the lower temperature secondary condensing device. The water vapor in the hotter air will liquefy here and drip into the pipeline, thus improving the efficiency.

Figure 1. Group 1 the overall scenario.

3.2. Water collecting device
The overall appearance of the water collecting device is an inverted funnel. The large opening at the lower end of the funnel is the air inlet, and the upper part is the air outlet. The lower part of the water collecting pipe is a collecting tank, and the opening of the water collecting tank is smaller to reduce the evaporation and dissipation of the collected water. The upper part is the secondary condensing device, where the heated air meets the colder convex surface secondary condensing device to further utilize the water vapor in the air. The outside of the funnel tube is wrapped with phase change energy storage material, which releases heat at night and in the morning when the air temperature is low, so as to heat the water vapor in the water collecting pipe, so as to provide the power of air flow.

Figure 2. Group 2 water collection pipeline.
3.3. Coaxial cylindrical sail

The device adopts the same spider web structure, uses hydrophobic material and water absorbing material to weave a water collecting sail, and obtains fresh water in the air under the semi closed condition. The bulge of the woven net is made of hydrophilic material, and the rest part is made of hydrophobic material. Polyester fiber is selected for the device, and its moisture regain is 0.4%. The main body of the network is made of hydrophilic material, and viscose fiber is used in the device, and its moisture regain is 13%. Compared with the "water catching net", the efficiency of the coaxial cylindrical surface water collecting sail of the device is higher. At the same time, under the semi closed condition, the water loss is reduced. The collected water is less polluted by wind sand and is relatively clean. At the same time, when collecting, all the water is collected in the water collecting tank under the device, with a high degree of automation. In this study, the bionic technology was applied to combine the characteristics of beetle back surface and the water absorption mechanism of spider silk with textile technology. The water collecting sail, the core part of the water collecting device in textile based fog, was mainly studied to improve the efficiency of water collection in fog.

Combining the characteristics of beetle back surface and the water absorption mechanism of spider silk with textile technology, the textile based water collecting device in fog (water collecting sail) was prepared by weaving technology, and the optimized water collecting device in fog was obtained by optimizing and improving it. The test results show that: the water collection capacity increases first and then decreases with the decrease of hydrophilic area ratio, and the water collection capacity reaches the maximum when the hydrophilic area ratio is 4:20; the water collecting effect of the water collecting sail with four corner rhombic hydrophilic area is better than that of the circular water collecting sail; the water collecting effect of the filament water collecting sail is better than that of the staple fiber yarn water collecting sail.

![Figure 3. Group 3 Collecting pipe and energy supply device of energy storage material.](image)

3.4. Hot pressing process

3.4.1. Application of chimney effect. The device uses the hydrate phase change heat storage material lithium nitrate trihydrate expanded graphite shaped material to store heat at high temperature, and starts to work after nightfall. When the temperature is the lowest, the water vapor in the air will condense into water mist, and the phase change energy storage material will release heat to heat the water collecting pipe. The air temperature in the water collecting pipe is higher than that of the outside world, the volume expands, the density decreases, and it rises under the action of atmospheric pressure, and the colder air below and outside enters to supplement and form airflow. The water vapor rich air continuously flows through the water supply pipeline with water collecting sail, contacts with the water collecting sail, accumulates gradually, and finally forms water drops.

3.4.2. Phase change energy storage materials. Lithium nitrate trihydrate expanded graphite, lithium nitrate trihydrate or lithium nitrate dihydrate are selected as phase change energy storage materials.
Taking lithium nitrate trihydrate expanded graphite as an example, the phase change temperature is 29.86 °C and the latent heat is 235.40 J / g. it is an ideal phase change material at room temperature. After 100 in-situ DSC cycles, the latent heat and temperature of phase change are relatively stable, and the cumulative latent heat attenuation is only 1.86%, which is one of the phase change materials with the highest latent heat in this temperature range. This paper takes it as the heat storage material of this project.

Phase change materials can absorb and store a large amount of heat at a suitable temperature above the phase change point, and release almost all the absorbed heat below the phase change temperature, so as to achieve the purpose of efficient utilization of energy.

3.4.3. Heat release control system. After sunset, the temperature in desert area drops rapidly. If not controlled, the heat energy stored in PCM will be released in a short time, but the air humidity has not reached the maximum value, that is, the maximum value of heat release rate and the maximum value of air humidity are not at the same time, and there is a large time difference. In order to solve this problem, there is a thermal insulation layer outside the phase change material, which is controlled by a mechanical temperature difference control mechanism, without external energy supply. When the temperature is high in the daytime and it needs to absorb heat, the insulation layer will be closed, and it will not play a role in heat insulation. When the temperature drops at night, it will start to work and slow down the heat release. When the difference between the external temperature and the internal temperature reaches the preset value, the insulation layer will be closed, and the phase change material will start to release heat, so as to increase the heat utilization rate and reduce the waste of heat in low efficiency work.

4. Difficulties analysis
The whole mechanism is mainly divided into two parts, one is the heat supply link with phase change material as the core, and the other is the water absorption system inside the pipeline. The heat released by the phase change material provides power for the air circulation in the pipe, so that the air in the pipe is continuously heated, forming a chimney effect, and rich in water vapor, which flows continuously near the water collecting sail. After collecting enough water vapor, the water collecting sail can form liquid water and fall into the water collecting tank. The device mainly uses the heat source capacity of phase change materials, the influence of chimney effect on air flow, and the water collection capacity of hydrophilic hydrophobic fiber of water collecting sail.

Therefore, it is of great significance to analyze the air flow in the device for the arrangement of water collection device. Phase change material (PCM) is a kind of green environmental protection and recyclable energy storage material. It has high latent heat of phase change and can absorb or release a lot of energy in the process of phase change. In this device, lithium nitrate trihydrate expanded graphite, lithium nitrate trihydrate, lithium nitrate dihydrate and other materials with suitable phase transition temperature and large latent heat are selected as phase change energy storage materials. The phase transition temperature is 29.86 °C and the latent heat is 235.40 J / g. it is an ideal phase change material at room temperature. After 100 in-situ DSC cycles, the latent heat and temperature of phase change are relatively stable, and the cumulative latent heat attenuation is only 1.86%, which is one of the phase change materials with the highest latent heat in this temperature range, and it is suitable to be used as a heat storage material for the project.

| Materials          | Melting point /°C | Latent heat /(J/g) |
|--------------------|-------------------|--------------------|
| CaCl·6H₂O          | 25.8              | 125.9              |
| H₃PO₄              | 26                | 147                |
| LiNO₃·2H₂O         | 30                | 296.8              |
| LiNO₃·3H₂O         | 30                | 189                |
| NaSO₄·10H₂O        | 32.4              | 257                |
| NaS₂O₃·5H₂O        | 48.5              | 210                |
5. **Benefit analysis**

The water collection capacity of the device is calculated and analyzed as follows:

The catchment sail of this device adopts multi-layer coaxial cylinder, and the power of air flow comes from the thermal pressure difference provided by phase change materials. The amount of water collected in a single cycle mainly depends on the amount of air flow, air humidity and the water absorption efficiency of the catchment sail in a catchment cycle.

There is a Bernoulli equation at the entrance and exit of the chimney:

\[
P_1 + \frac{1}{2} \rho_n V_1^2 + \rho_n g h_1 = P_2 + \frac{1}{2} \rho_n V_2^2 + \rho_n g h_2 + \Delta P_{sl}
\]

where:
- \(P_1\) — Absolute pressure at entrance (Pa);
- \(P_2\) — Absolute pressure at exit (Pa);
- \(\rho_n\) — Internal air density (kg/m³);
- \(V_1\) — Air velocity at entrance (m/s);
- \(V_2\) — Air velocity at outlet (Pa);
- \(h_1\) — Height at entrance (m);
- \(h_2\) — Height at exit (m);
- \(\Delta P_{sl}\) — Gas flow resistance between inlet and outlet sections (Pa);
- \(g\) — Gravity (m/s²).

The amount of hot pressing air exchange can be expressed as:

\[
Q_{heat} = A v = A \sqrt{\frac{2 \Delta P_{heat}}{\rho_w}} = A \sqrt{\frac{2g(h_2-h_1)(\rho_w-\rho_n)}{\rho_w}}
\]

where:
- \(Q_{heat}\) — Coefficient of thermal expansion (m³/s);
- \(A\) — Effective area (m²);
- \(V\) — Average velocity (m/s);
- \(\rho_w\) — External air density (kg/m³);
- \(P_d\) — Atmospheric pressure on the ground (Pa).

Data:
- \(\rho_w = 1.293\) kg/m³
- \(\rho_n = 1.153\) kg/m³
- The height difference is:
  - \(h_2 - h_1 = 0.5\) m
- \(T_w\) = 5°C
- \(T_n\) = 30°C
- \(\beta = 132.45\)
- \(G\) takes the g value of latitude 45° north, which is 9.807 kg/m·s²

The amount of hot pressing air exchange of single tube is calculated: \(Q_{heat} = 0.00809\) m³/s

Estimated time of single tube ventilation \(t = 6\) h = 21600 s

Single cycle single pipe ventilation \(V_{single} = Q_{heat} \times t = 174.744\) m³

Referring to the relevant literature, we know that the humidity in the desert area:

1. The average relative humidity of the oasis (taking Dariaboi Oasis as an example) is 40.2%. The highest monthly relative humidity of the year appears in December, which is 60.3%, and the lowest value appears in April, which is 25.6%.

2. Desert area (take Tengger Desert as an example): the humidity is the highest in October, more than 40%, the lowest in April, about 15%, and the driest in spring of the four seasons.

3. The shelterbelt is also between 15% and 40%. And more than 25% most of the time, calculated on the basis of 30%.

The saturated humidity (\(H_s\)) of air at 30°C is 30.4g.
The conversion formula from relative humidity (RH) to absolute humidity (H):

\[ RH = \frac{H}{H_s} \]  

(3)

It is calculated that the absolute humidity of the air is 9.12g/m³.

For the catchment sail composed of viscose fiber and polyester fiber, the catchment efficiency \( \eta \) can reach 15% in this humidity range. According to the above data, the whole water intake device is in one water intake cycle, that is, the amount of water taken in one day and night is \( W \):

\[ W = Q_{\text{heat}} \times H \times \eta \times n = 174.744m^3 \times 9.12g/m^3 \times 15\% \times 7 = 1,673.3485g \]  

(4)

6. Conclusions

The main research content of this project is the water recovery efficiency of the hot-pressure-driven air water-taking device when the phase-change material is used for energy supply, and combined with the research process, an automatic water-taking device using desert temperature difference and phase-change material storage is designed. At a time when energy sustainability is of great concern, we must make the development of green energy a core goal. Among them, solar energy as a green non-polluting new energy, its development and utilization is an important research topic and direction.

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