Air water intake device based on heat slow-release system

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Abstract. In the arid desert regions of the northwest, fresh water is extremely scarce. But in the desert area's early morning, the day and night temperature are very different, and the air relative humidity will also reach the peak in the day at this time. In this paper, we plan to design an air water intake device in arid area. By using bionics, combining with the traditional water mist water intake method and chimney effect, we design a water intake device to direct the air with high humidity to extract water effectively. The heat release system is designed by using the heat absorption and exothermic characteristics of the phase change energy storage material under the influence of the temperature difference between day and night.

Keywords: air water intake, heat slow release, phase change material, drought, fresh water, Introduction.

1. Introduction
Northwest China is a continental region with a deep inland climate. Because it is blocked by mountains and its large temperature difference between day and night, it’s lack of fresh water resources and the average annual precipitation in Northwest China is only about one fourth of that in Southeast China. Much of the area is covered by a very dry desert with sparse vegetation and a lack of rainfall. However, in fact, there is plenty of fresh water in the air.

The average annual air moisture content in Northwest China is about 15mm. [1] Even at 35℃ and 20% relative humidity in the desert area, the water content of air per cubic meter is still above 10g/m³. [2] Especially in the early morning, because of transpiration of plants, the water vapor content in the air reaches its peak. How to draw water from the air without being affected by wind and sand is an important topic for building a habitable environment for human beings. In this paper, an air water intake device based on heat slow-release system is designed, and its overall structure and design of heat-controlled release system are introduced and analyzed in detail.

2. The traditional way of extracting water from air
1) Using the temperature difference between underground and surface, the underground is used as the cold source to extracting water from air [3]. This scheme requires external power to push air into the ground, and to achieve significant efficiency requires digging deep and heavy construction tasks.
2) Air cooling condensation method. The scheme uses refrigerators and compression pumps to cool the air. Although the efficiency is high, the cost is also high, so it is not suitable for popularization.

3) Adsorption and desorption method. In this scheme, solid adsorbent is used to adsorb water in the air, and the adsorbent is heated to desorb the adsorbed water \(^4\). But many of them have problems such as inconvenient operation, long time of adsorption and desorption, and poor effect of adsorbents.

4) A method of drawing water from water mist. It uses a fine stainless-steel mesh exposed to air to collect water. The cost of this scheme is low, and it is widely used, but its structure is simple, and it is greatly affected by weather. In addition, there is strong convection in desert areas and large windblown sand, so the water collected by this scheme has so much sand particles. what’s more, it is easy to evaporate, and the efficiency is low.

Combined with the above information, this paper designs an air water intake device based on heat slow-release system, which stores heat when the ambient temperature is high and releases heat in the morning when the ambient temperature is low and humidity is high to condense water vapor. This device has the advantages of simple manufacture, low cost and high efficiency. If widely used, it can promote the process of air water intake in desert areas, so as to meet the water demand in desert areas.

3. The design of the device

The device is composed of a water collecting device, a temperature control device, a heat slow-release system, a sandproof baffle and a shell, as shown in Figure 1 below. The water collecting device comprises a ventilation pipe, a hydrophilic and hydrophobic water collecting sail, a water collecting tank and a stainless-steel water collecting surface. When air flows through, ventilation pipe and hydrophilic and hydrophobic water collecting sails are used for the first intake of water, and stainless-steel water collecting surface is used for the second intake.

![Figure 1. Overall structure of the device.](image)

The power of airflow directional flow in this device comes from the pressure difference, which caused by the chimney effect. The phase change energy storage material is located in the heat insulation layer. When needed, it releases heat outside the ventilation pipe to make the air float continuously. Collecting sails are placed in the center of the ventilation pipe. After the water vapor condenses into water on the collecting network of the collecting sail, it can fall along the hydrophobic grid of the collecting sail and be collected in the small-diameter collecting tank.
At night, when the temperature is low, the phase-change energy storage material releases heat to heat the air in the collecting pipe, then the air in the pipe expands and rises. When it contacts the collecting sail, most of the water vapor condenses into liquid water and drops. Before leaving the container, the heated air will touch the stainless-steel water collecting surface used as a secondary water catchment at a lower temperature. The water vapor in the hot air will be liquefied here again and will also drop into the pipeline. The secondary water collecting improves the water collection efficiency.

3.1. Water collecting device

In desert areas where water is scarce, the desert beetle Stenocara uses a special structure on its back surface to draw water from the air to solving its drinking problem. The desert beetle Stenocara has irregular projections on its dorsal surface, which have smooth, hydrophilic surface. The lateral bevels and depressions between the protrusions are covered with hydrophobic waxy materials with micro and nano structures. Water is captured through the hydrophilic protrusions of the beetle and transported to the beetle's mouth through the hydrophobic basement to meet its water needs. [5]

Inspired by the desert beetle and the traditional water mist, we have developed a new method to obtain fresh water, which can solve the problem of getting fresh water in some environments.

The water collecting device comprises ventilating pipes, hydrophilic and hydrophobic water collecting sail, a water collecting tank and a stainless-steel water collecting surface.

The ventilation pipe is evenly distributed in the device, which is tubular and has the function of air circulation. The lower end is the air inlet and the upper part is the air outlet, and the air can circulate rapidly from the bottom to the top based on chimney effect.

The hydrophilic and hydrophobic water collecting sail is located inside the ventilation pipe. It is designed by bionics and is jointly woven by hydrophilic and hydrophobic materials to obtain fresh water from the air under semi-closed conditions [6]. The protrusions of the sail are made of hydrophilic material and the rest of the sail is hydrophobic. The hydrophilic material absorbs the water vapor in the air and converges it into water droplets. Then the water droplets transported by hydrophobic materials in other parts and fall into the collecting tank. Under semi-closed conditions, the water loss is reduced, the collected water is less polluted by sand, and is relatively clean.

After heating in the water collecting pipes, there’s still some hot air, which contains water vapor to escape from the pipes. The secondary catchment is at the top of the whole installation, located directly above the outlet of the catchment pipe. The surface of it is cambered, made of stainless steel, and the lower part is close to the air outlet of the collecting pipe to ensure that the air can fully contact the cambered surface when leaving the device. Outside the contact surface is a large area of stainless-steel net, to keep that there is a higher efficiency of heat exchange with the outside world, and to ensure the low temperature of the secondary water collection device. The warmer escaping air condenses into liquid water when it hits the cooler secondary catchment, after that, it drips down to the catchment pipe below, and finally it collects in the water collection tank.

Below the ventilation pipe is a water collecting tank, which had small opening to reduce the evaporation loss of collected water.

3.2. heat slow-release system

3.2.1. Design Principles of Heat Slow-Release System. In the heat slow-release system, lithium nitrate trihydrate - expanded graphite shaping material is used as heat storage material and placed in the heat insulation layer [7]. The heat insulation layer conducts heat when the ambient temperature is high in the daytime, absorbing heat from the environment, and the phase change material stores heat energy. When the ambient temperature is low at night, the phase-change heat storage material releases heat and heats the air, which makes the gas in the ventilation pipe circulate rapidly. The air rich in water vapor flows continuously through the ventilation pipe with the internal collecting sail, contacts with the collecting sail, accumulates gradually, and finally forms water droplets falling down. Among them, the change of the relative humidity of air in a day is shown in Fig. 2 [8]. As can be seen from the figure, the highest
relative humidity in a day appears about 4 am. At this time, the efficiency of water extraction has also reached the highest. It is necessary to control the heat release of PCM, to release a small amount of heat in the early night, and to release more heat in the morning when the humidity reaches the highest in the day, so as to improve the water intake efficiency.

Figure 2. Changes in the relative humidity of the air during a day.

In this paper, through the study of slow release of heat from the vacuum cup [9], the principle that the thermal conductivity of the thermal insulation layer changes should change the thermal insulation effect is used to design the thermal insulation layer that can change the thermal conductivity with the change of temperature and humidity, so that the role of phase-change materials in the water intake device can be maximized.

In order to realize the required function, air is used as the heat conduction medium, and the heat insulation/heat conduction switch is realized by the air thinning/air thickening switch in the ventilation sandwich. Finally, when the temperature of heat insulation layer is high, heat insulation layer becomes heat conduction. Low temperature, low humidity heat insulation; When the temperature is low and humidity is high, heat conduction.

3.2.2. Structural design of heat slow-release system. The heat release system includes temperature and humidity sensor, external gas box, heating system, ventilation line, ventilation interlayer, and phase change material wrapped outside the ventilation interlayer, as shown in Figure 3 below. The ventilation interlayer and phase change material are in the heat insulation layer, and the heating system is attached to the outer gas box.

Figure 3. Structural design of heat slow-release system.
During the day, when the temperature sensor receives a signal of high external temperature, the one-way valve that controls whether the vented interlayer communicates with the outside and the external air box is closed to ensure that the vented interlayer is sealed, and the gas is in a dense heat conduction state.

Transition from day to night time, when the temperature is high, the temperature sensor controls to open the one-way valve between the interlayer gas and the outside (only the gas can be discharged), due to the difference of air pressure, air interlayer gas expelled, eventually reach equilibrium with the outside world. In time for the signal, close the check valve between the gas and the outside world, at this time, the high-temperature rare gas is stored in the ventilated interlayer. Then the temperature gradually decreases, the molecular weight and volume of the air in the ventilation interlayer remain unchanged, and the pressure decreases. This moment, the temperature and humidity sensor feedback information, the temperature is low, the humidity is low, the air in the ventilated interlayer is thin and in a state of thin heat insulation.

In the early morning, the temperature is low and the humidity is high. The feedback information of the temperature and humidity sensor is used to control the heating system for short-term heating of the external gas tank. Open the one-way valve between the interlayer and the gas chamber (it can only make the gas from the gas chamber to the interlayer), the gas in the gas chamber is affected by heating, the temperature rises, the pressure increases, and the gas molecules are squeezed towards the interlayer. A large number of gas molecules pour into the interlayer, causing the interlayer air to return to the thick heat insulation state. At this time, on the one hand, the ventilation interlayer between the phase change material and the outside world conducts heat conduction, which enables the phase change material to feel the external temperature change and carry out heat release. On the other hand, the ventilation interlayer between the phase change material and the ventilation pipe in the water collecting device also conducts heat, so that the phase change material can heat the air in the pipe, promote the flow of high humidity air and increase the water collecting efficiency.

After the short-time heating of the external gas tank, the molecular weight of the gas in the gas tank decreases and the pressure in the gas tank becomes smaller. At this time, the one-way valve between the gas tank and the external environment is controlled to open. Under the action of pressure difference, the outside air molecules are added to the gas tank. Also take time as the signal, after enough time, control to close the one-way valve between the gas box and the outside environment (only can make the gas enter the gas box from the outside world).

From day to night to morning, the heat slow-release system goes through a complete cycle, and the ventilation interlayer realizes the transition from thick heat conduction to thin heat insulation and then to thick heat conduction.

4. Conclusion
The air water intake device based on heat slow-release system designed in this paper, combined with bionics, improves the traditional water mist water intake method, retains the characteristics of good water intake effect and less energy consumption, and solves the problems of impure water quality and easy evaporation. The heat release system is designed to limit the heat utilization time and improve the energy utilization rate and the working efficiency of the device. It provides a new solution to solve the problem of fresh water shortage in arid area.

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