Research on the realization of air intake device based on zero energy consumption complementary to wind energy and solar energy

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Abstract. The device studied in this paper is to solve the problem of water shortage in islands and mountainous areas. The area is developed by using traditional water abstraction technologies, such as seawater desalination and direct air condensation, which have the advantages of large investment, high energy consumption and low efficiency. With new technology, the project has developed a device that uses wind and solar energy to draw water directly from the air. The content of this product is mainly reflected in: 1) The device can synergistically utilize wind power to realize wind power generation and automatic inhalation of humid air, and then utilize high-efficiency water-absorbing material, and can collect moisture in the air, and then use the energy generated by wind energy and solar power generation device, and finally The water-absorbing material is heated to evaporate water vapor, and finally the semiconductor refrigeration technology is used to condense the water vapor to collect and obtain liquid water. 2) The device adopts aerodynamic simulation analysis and experimental verification, and this paper proposes a spiral vertical fan and an induced draught flow path. The structural design realizes the integration of wind power generation and humid air collection functions; 3) The design of the circulating suction mechanism of the suction and dewatering module of the device enables the device to realize the process of regeneration and recycling of the water absorbing material.

1. Introduction

1.1. Project Background
The water resources of China are scarce and the distribution is seriously uneven. In mountainous areas, islands and other places, fresh water resources are extremely scarce due to topography, but the air in these areas is rich in fresh water resources. Taking Guizhou's mountainous areas and China's largest archipelago as examples, according to statistics, in 2016, China's annual per capita water consumption was 438 m³, while Guizhou's annual per capita water consumption was 32.08 m³, and Zhoushan Islands' annual per capita water consumption was 79.38 m³, which is less than the national average of three points. One of them, the form of water shortage is severe, and the annual relative humidity of the mountainous areas in Guizhou is as high as 82%, and the changes in different seasons are small; the
Zhoushan Islands are subtropical monsoon maritime climate, with an average annual relative humidity of about 80%, higher than the national average. Has a good water vapor resource.

At present, the remote islands use traditional seawater desalination technology. The 100,000 t/d seawater desalination project consumes about 350,000 kWh of electricity per day, and the annual electricity consumption is close to 128 million kWh. The islands often have insufficient power supply and are difficult to meet the power demand. The manual water intake is adopted, but the altitude is high and the terrain is complex, which requires a lot of manpower and material resources and low water intake efficiency; the multi-stage automatic water intake method has high technical requirements and high cost. In response, the State Council put forward the "Opinions on Accelerating the Construction of Ecological Civilization" in 2015, developing green industries, and strengthening resource conservation. It is required to actively develop and utilize unconventional water sources such as reclaimed water, mine water, air cloud water, and sea water. Therefore, the development of new water sources to solve the problem of severe water shortage in islands and mountainous areas and difficulty in water intake has become a very significant issue.

However, the conventional air collection methods such as mist collection, air condensation, and dehydration take water are too low in efficiency or energy consumption, and effective large-scale air intake cannot be achieved. Therefore, the search for a new air intake method that is more efficient, convenient, and green and energy-saving has become an urgent problem to be solved.

Based on the above background, the project designed and produced a small, portable device that can utilize wind energy and solar energy to efficiently take liquid water directly from the air. It effectively solves the problem of water shortage and water intake in islands and mountainous areas, and realizes the mode of recirculating reclaimed air. The device can also be installed on mobile tools to provide flexible and convenient water sources for grassland nomads, oil fields, warships and other activities. The application prospects can achieve good energy saving and emission reduction effects and achieve significant social benefits.

![Figure 1. Overall workflow](image-url)
2. Project design

2.1. Integrated design of vertical axis fan and air duct

The natural wind blows through the vertical axis fan to rotate it directionally and form a downward air wake, entering the inner pipe of the Venturi duct, achieving the first draft effect; using the Venturi principle, the inner pipe cross-sectional area is reduced, the air flow rate increases, the flow velocity difference forms a vacuum environment at the pipe mouth, generates suction force at the air inlet, and inhales the surrounding air to achieve further air induction effect. Figure 2 is a simulation diagram of the fan wake and pipeline pressure.

![Simulation diagram](image)

**Figure 2.** Venturi wind channel data simulation diagram
The wind turbine generates air wake and uses wind power to generate electricity. The Venturi principle air duct generates a vacuum environment and uses the flow channel structure to organize the air flow, which improves the air flow and water vapor absorption efficiency in the device.

2.2. Workflow of the water abstraction model
The water intake model consists of a suction and dewatering zone, a condensation zone and a drainage pipe. First, the humid air is introduced into the suction and dewatering zone. The suction and dewatering zone collects and concentrates the moisture in the air by using the dehydration material, transfers, and evaporates by heating to form water vapor; The condensate plate is quickly liquefied to form condensed water; at the same time, the dry air leaves the suction and dewatering zone and then reaches the condensation zone through the drainage pipe to accelerate the heat dissipation of the heat dissipation fins, thereby finally realizing water concentration, efficient collection, condensation and efficient heat dissipation function integration.

The suction and dewatering zone is composed of a water absorption chamber, a buffer chamber, a dehydration chamber and a suction and dehydration unit. The condensation zone is composed of a condensation plate, a cooling fin and a heat dissipating fin, and is located above the desorption chamber of the suction and desorption zone.

The partitioning door is designed in the suction and dewatering zone so that the chambers are relatively independent. When the device performs the suction and desorption work, all the partition doors are closed, and after the adsorption material of the adsorption zone is absorbed, it slides to the buffer chamber, pushes the partition door, and the partition door passes the spring hinge. It is automatically closed immediately and enters the dehydration chamber; the water absorbing material is heated and evaporated in the dehydration chamber to release water; after the water absorbing material is desorbed, it is returned to the suction chamber through the transmission to complete the cycle regeneration. During the working period, under the action of the buffer chamber, the adsorption chamber and the desorption chamber are always separated to ensure the stability of the heating and condensation environment of the dehydration chamber. On this basis, multiple suction and desorption units can be set according to the actual situation, and multiple tracks can be independently staggered and slid.

The suction and desorption unit is composed of a plurality of groups of suction and desorption elements, and the adsorption and desorption elements include a porous metal compartment, a molecular sieve adsorption material and a PI heating sheet. During the adsorption process, the 5A molecular sieve adsorbs the moisture in the flowing humid air to the inside of the material to realize the concentration of water vapor. During the desorption process, the PI heating sheet is heated to 120 °C, and the water in the molecular sieve is distilled off to realize the water vapor. Desorption, lowering the dew point while regenerating the molecular sieve.

The condensation zone consists of a condensing plate, a cooling fin and fins. The high-temperature water vapor in the desorption chamber rises to the condensation plate and condenses into liquid water, which is collected and stored after passing through the water tank; the refrigeration sheet and the heat-dissipating fins constitute an electric semiconductor refrigeration module, which absorbs heat of the condensation plate and has dry cold air from the air outlet. Blowing through the fins, further cooling the air to improve heat dissipation efficiency.

2.3. Power Analysis
The device is mainly generated by a wind power generator and a solar panel, and the power consumption part is a heating sheet, a motor, and a semiconductor refrigeration module, as shown in the figure. The 12V vertical axis wind turbine and 12V, 150W solar panels are used to collect wind and solar energy respectively to generate electricity and store it to the battery; the device is self-powered and long-term battery life.
(1) Fan power generation calculation

The 12V vertical axis wind turbine used in the finished product, the natural wind blows the fan to make it directional rotation and connects the fan controller to stabilize the output voltage, and the battery is stably charged, and the battery is discharged when the device is working.

| Table 1. Fan power generation performance parameter table |
|----------------|----------------|----------------|
| Wind energy conversion rate $C_p$ | generator efficiency $\eta$ | fan blade gradient Radius R/mm |
| 1.293 | 59% | 90% |

When the wind speed $v=5.6\text{m/s}$, the air density $\rho=1.293\text{g/L}$, the wind energy conversion rate $C_p=59\%$, the generator efficiency $\eta=90\%$, the fan blade gradient radius $R=168\sim262\text{mm}$, the fan is hit within 1 hour. The air quality of the leaves and the energy obtained by the blades are as shown in equations (1) and (2).

$$m = \rho \pi (R^2) vt$$

$$E = \int_{R_1}^{R_2} \frac{1}{2} \rho \pi (R^2)(v^3)t C_p \eta dR$$

As a result, the hourly fan can emit about 0.15 kWh of electricity, the power is about 150w, and the power generation per day is about 1.8kWh.

(2) Solar power generation calculation

In the case of sufficient sunlight, the power generation and size corresponding to the solar panels of different powers are as shown in the following table. The power consumption is 2.85kwh and the power generation of the wind turbine is 3kwh. The solar panel with a power of 150W is selected.

| Table 2. Solar panel power generation performance parameter table |
|----------------|----------------|----------------|
| Rated power $W$ | solar conversion $C_p$ | power generation |
| 1.293 | 59% | 90% |

According to the data of the Hubei Provincial Meteorological Bureau, taking the Zhoushan Islands as an example, the average sunshine duration is $t_1=8\text{h}$, the rated power is $P=150\text{W}$, and the power generation is:

(3) Power consumption calculation

The power consumption part is the heating sheet, the motor, and the semiconductor refrigeration module. The device keeps working every day. The working hours and power of each power consumption module are shown in the following table:

| Table 3. Power consumption parameter table |
|----------------|----------------|----------------|
| Name            | Power /W | Working hour/h | Total/kWh |
| Motor drive     | 40(4x10) | 0.2            |           |
| Heater heating  | 140(5x10) | 16             | 2.85      |
| Semiconductor refrigeration | 60(2x30) | 10             |           |
In summary, under normal working conditions, the average power generation of the device is about 3kWh in one day, and the power consumption is 2.85kWh, which can ultimately achieve energy self-sufficiency.

3. Experimental analysis

3.1. Zero energy performance test
The equipment in this project uses vertical axis fans and solar panels to generate electricity, providing power for each module of the water intake, and finally achieving a zero energy consumption mode. In the test experiment, the whole device was placed in the mountains, and the amount of power generation and power consumption were recorded in real time, and experiments were conducted. The wind speed was 5.6m/s on the day and the total duration of illumination was 8 hours. The experiment time was 8:30-18:30, and it was tested every 9 minutes. The lithium battery was used to display the power generation and power consumption. There were 40 sets of data. The power consumption data is shown in Figure 3:

![Figure 3. Statistics of power consumption](image)

It can be seen from the figure that in the normal working environment, the power generation capacity meets the power consumption requirement; while in the actual island environment, the wind speed is higher and stable, the sunshine duration is longer, the actual power generation effect will be better, and the device achieves zero energy consumption design requirements.

3.2. Air intake module performance test
The device in this project adopts the integrated structure of spiral vertical fan and induced draft runner. The wind turbine generates electricity while recovering the airflow energy of the fan, uses the Venturi effect to generate vacuum suction, and uses special runner structure to design the airflow. At an external average wind speed of 2 m/s, the wind speed of the horizontal blown fan and the wind speed of the Venturi principle runner outlet are measured and compared using a wind gauge.
When the wind speed of the horizontal blown fan increases, the wind speed of the air outlet of the air intake module also increases, and the wind speed of the air outlet is always greater than the wind speed of the air blown into the air, thereby indicating that the air intake module has an introduction to accelerate the ambient wind speed. The role of the overall device.

3.3. Water intake performance test

In this project, the wind-solar complementary zero-energy air intake device is placed in Yujiashan, and the water collecting effect of the device is tested in the field. Select 24 hours a day for uninterrupted experiments, using 1 hour as a measurement period, using anemometer, thermometer and hygrometer, and measuring cylinder to measure the wind speed, temperature, humidity, and water collection at different times, the total working time of the device is for 1 week, the measured data is recorded in a table.

![Leading module air induction effect experimental data](image)

**Figure 4.** Comparison of the wind effect

![Water output per ml](image)

**Figure 5.** Shows the daily water withdrawal statistics
Analysis of the data obtained from the field test in the past 7 days shows that the water intake of the device has a certain relationship with the air humidity. The humidity at different times on the same day will have a greater impact on the water intake. The water intake of the device for 24 hours can reach 2.8L when the humidity is close to 80%, and the deviation from the theoretical calculation data is small, within the allowable error range, so the device can obtain 2.8 L of water from the air under normal conditions.

4. Benefit analysis

4.1. Product energy saving advantages
At present, the air intake products on the market consume electricity, realize the process of air introduction, compression and direct condensing and liquefaction. The simple and direct water intake method consumes a large amount of energy, has low energy utilization rate and low cost performance. The finished product provides a zero-energy water intake scheme. The main energy-saving features can be summarized as follows: A) complementary scenery and full use of natural energy; B) design of Venturi air duct, automatic introduction of air; C) use of water-absorbing materials, adsorption and concentration Water vapor, lowering the dew point temperature.

4.2. Analysis of energy saving benefits
After the finished product in the project is completed, the water intake experiment is carried out outdoors. According to the data obtained by the experiment: the experiment was carried out for one week in an environment with a relative humidity of 65% and a sunshine duration of about 8 hours. The average daily power generation was about 3 kWh, the power consumption was 2.85 kWh, and the final average daily water intake was 2.8 L.

The existing air condensing water intake device requires 385W (refrigerator + induced draft fan), according to the standard conditions, the water output is 820mL / h, the water can be made up to 2129.9mL per kWh, and the energy consumption for taking water is 0.47kWh / L;

| Performance parameters | Existing air water | This device |
|------------------------|--------------------|-------------|
| Water production power | 385W               | 120W        |
| Water output           | 820mL/h            | 116.7mL/h   |
| Water consumption energy consumption | 0.47kWh/L | 0 |
The device does not consume electricity. According to the mountain or island power generation cost is three times the normal power generation as the standard, the device can save electricity every day:

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3 \times 2.8 \times 0.47 = 3.9 kWh
\] (3)

Take the Zhoushan Islands in Zhejiang Province as an example. Among the 148 permanent islands, the population is 1.492 million, which is a family of three. If each unit is used, water can be taken daily:

\[
2.8 \times 14.92 \div 3 \times 10^4 = 1.39 \times 10^6 L = 1390
\] (4)

Save electricity every day:

The device can also be installed on mobile tools to provide flexible and convenient water sources for grassland nomads, oil fields, warships and other activities.

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1.39 \times 10^6 \times 0.47 \times 3=1.9599 \times 10^6 Kwh
\] (5)

5. Conclusion

5.1. Innovation points

(1) Synergistic use of wind power to realize the integration of wind power generation and wet air collection functions. The fan is used to generate electricity while recovering the air flow energy of the fan, and the Venturi principle flow channel is designed to realize the automatic inhalation of the humid air;

(2) Through the complementary of wind and light, realize the use of renewable energy all-weather zero-energy air intake;

(3) Automating the process of regeneration and recycling of water absorbing materials through the mechanism design of the suction and dehydration cycle working module.

5.2. Product application prospects

The device converts the hidden water resources in the air into the explicit and usable water resources, and realizes the effective extraction and collection of the moisture in the air, and can be widely applied to areas such as islands, mountains, deserts and the like where fresh water resources are scarce and water intake is difficult; It can also be installed on mobile devices to provide water sources for grassland nomadic, oil fields, warships and other mobile sites, with good energy saving and emission reduction benefits.

The device uses solar energy and wind energy to complement each other to stabilize the power supply. It is in line with the "13th Five-Year Plan for Renewable Energy Development" and actively uses the requirements of clean energy to provide new ideas for promoting green energy air abstraction technology. Compared with the traditional air water intake device, the device is clean, easy to operate, low in cost and high in efficiency. It has not only received the attention of Wuhan Polytechnic Group and Qingdao New Energy Co., Ltd., but also received the Yixingren Education Group of Wuhan University of Technology. It is favored by many social enterprises and public welfare organizations such as China Water University's Yishui Organization. Energy network, Hanwang and other news media have reported on it and achieved wide social recognition, which has broad application prospects.

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