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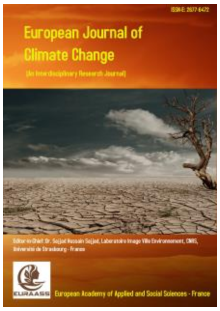

Research Article

Research and development of the moisture separation system to extract water to meet the needs of people living in drought area

Ly Cam Hung[a]*, Le Van Lu[a], Phan Dinh Tuan[a], Le Huu Quynh Anh[a]

[a] *Hochiminh City University of Natural Resources and Environment, Vietnam.*

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Abstract

In the context of global adaptation to climate change, the demand for water, especially drinking water, becomes a serious issue that needs to be studied to find feasible and economical solutions. Many available technologies have been applied to produce drinking water such as filtration of groundwater or seawater. However, the implementation of these technologies is feasible or not depending on specific nature as well as socio-economic conditions. For the drought regions where there is no seawater and lack of groundwater, moisture separation technology becomes a feasible solution. A system to extract the water from moisture has been designed, fabricated and installed to provide 10 liters of drinking water per day. As the system operates; it can produce around 2.1 liters of drinking water per hour; and consume 1.8 kW of electricity. The system has been designed to be able to use two types of power sources: one from solar energy (main source) and the other from the national grid (auxiliary source).

Keywords: Moisture separation technology, extract water from moisture, water resources, solar energy, Climate change.

1. Introduction

Water is one of the most important resources, which is an essential component of the environment representing the existence of life and the development of a country as well as the world. Currently, lack of water, especially drinking water, is a major threat to the survival of human and the life on earth.

Due to the impact of El Nino, about 7.6 million hectares of land in Vietnam are under the process of degeneration, leading to desertification (moitruong.net.vn). Desertification in Vietnam focuses on four regions: Northwest, Central Coast, Central Highlands and Long Xuyen Quadrangle. One of the most degraded regions is the central part of Vietnam such as Ninh Thuan and Binh Thuan provinces. Studies on moisture separation have been carried out by many research groups around the world (Wahlgren, 1993; Beysens et al., 1998; Gerard and Worzel, 1972). In the United States, this technology was researched, developed and registered for copyright in the early 1970s (Groth and Hussmann, 1979; Lund, 1973). Harrison (1996) developed a condensation technology to extract water from the air with a capacity of 9-18 liters per day. Poindexter (1994) combined a water cooling system with an air cooling system in his design

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* Corresponding author: Email: lchung@hcmunre.edu.vn (LC Hung)

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to produce 11 liters of water per day, and then the water has been treated with a UV lamp. At the same time, a pilot system with a capacity of 170 liters of water per day have been researched and developed by Hellstrom (1969). Depending on specific purpose and demand, the system can be designed as a small-scale to produce around 15-50 L/day for domestic use, or as a large-scale (up to 200,000 L/day) for providing water to support agricultural activities (Peter et al., 2013). So far, most of the system is operated by electricity provided from national grid which may not available in many drought areas where not only lack of water but also no electricity.

In this paper, a system to extract water from moisture has been developed with a capacity of 10 liters per day. The system is operated using two types of power sources: one from solar energy (main source) and the other from the national grid (auxiliary source).

2. Methodology

Based on the Mollier diagram (Rao, 2001), the air at different temperatures and humidities have been studied to find out an optimized operating condition from which the system to extract water from moisture has been designed and developed to ensure providing enough water as well as energy saving. Furthermore, a control system has been designed in which power inverter was used to convert direct current from solar energy to alternating current to supply the moisture separation system.

As an example of using a Mollier diagram in determining the amount of dry air used as an input of the system, we do the calculation as followings,

- The temperature and humidity of the air at the inlet (responding to the point A1 in Figure 1) are $T_1 = 27^oC$ and 75%, respectively.
- The vertical line in Mollier diagrams shows the moisture content $d_1 = 17$ g H_2O/kg dry air
- The temperature and humidity of the air at the outlet (responding to the point A2 in Figure 1) where the air is saturated are $T_2 = 20^oC$ and 100%; and the corresponding moisture content $d_2 = 14.8$ g H_2O/kg dry air.
- So, the extracted water will be 17 – 14.8 = 2.2 g H_2O/ kg dry air.
- The density of dry air depends on temperature as followings

$$\rho = \frac{1{,}293 \times P}{(1 + 0{,}00367 \times T) \times 760}\ , \mathrm{g/l}$$

where: T is the temperature (^oC)

P is pressure, (in this case P = 760 mmHg)

Thus, the density of dry air is 1.18 kg/m^3 responding to the point A_1 (27^oC, 760 mmHg). For example, we can calculate the amount of dry air of 3863.78 m^3 in order to extract 10 liters of water.

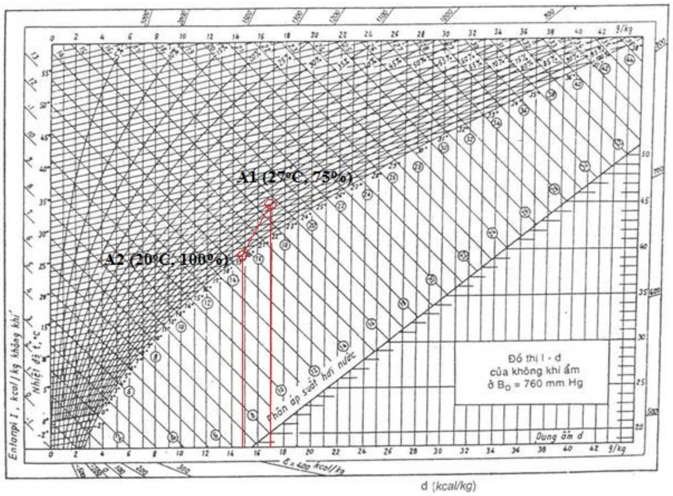

Figure 1: Mollier diagrams.

3. Results and discussion

3.1 Calculation of amount of dry air

To design the system producing 10 liters of water per day, the required amount of dry air has been calculated at different temperatures and humidities. The results are presented in Table 1 in which the inlet temperature T_1 vary from 20 - 40°C and the humidity is between 50-100%; whereas outlet humidities of the air are from 5 – 35°C.

Table 1: Amount of dry air (m^3).

Humidity	50%		75%			100%	
T_1 (°C) / **T_2(°C)**	20	40	20	27	40	20	40
35							661.89
30					1007.87		392.45
25		2771.66			547.49		295.64
20		1055.87		3863.78	414.45		251.97
15		698.37	13836.04	1307.74	345.11	1930.61	224.54
10		568.54	2371.89	904.29	310.12	1153.00	209.18
5	4150.81	492.74	1407.05	720.37	286.11	864.75	197.98

3.2 Design of moisture separation system with the capacity of 10 L/day.

The moisture separation system with a capacity of 10 L/day has been designed and presented in Figure 2. The system includes condenser, evaporator, compressor, water filter and solar system providing energy for the entire system.

Summary of the main steps in development of the moisture separation system is as follows:

a. Calculation of the condenser

- Determine the actual thermal cycle for the cooling process.
- Select the structure of the condenser: a cooling coil with tubes and fins, staggered tubes.
- Determine the inner and outer diameter of the tubes, spacing between the tube in different rows, thickness of the fins, heat rejection ratio.
- Calculate the heat transfer areas including the bare tube area, the area of the fins.
- Calculate and determine the number of tubes, number of fin, length and height of the fin, minimum flow area.
- Estimation of the heat transfer coefficient.
- Calculate and double check airflow through the condenser, the volume of air and total heat transfer areas.

b. Calculation of the evaporator

- Select the structure of the evaporator: copper tube, aluminum fin and forced convection.
- Determine the cooling load, inner and outer diameter of the tubes, spacing between the tube in different rows, thickness of the fins, heat rejection ratio.
- Determine the mean temperature difference of the air going through the evaporator.
- Determine the physical parameters of the air for the working conditions, thereby calculating the air flow needed to cool the condenser.
- Calculate the fin areas, spacing between the fins, total surface areas of the tubes, length of the tube, numbers of tube, inter and outer diameter of the evaporator.

c. Calculation of the solar system

- Estimate the daily power consumption of the system including the condenser, evaporator, and water filter.

- Determine the wattage of the panel, and then the number of panels needed for the solar system.

As a result, the main parameters are listed in Table 2 for the moisture separation system which may produce 10 L/day of water.

The detail moisture separation system is showed in Figure 3. The system has been developed as shown in Figure 4 while the solar panel has been installed as in Figure 5.

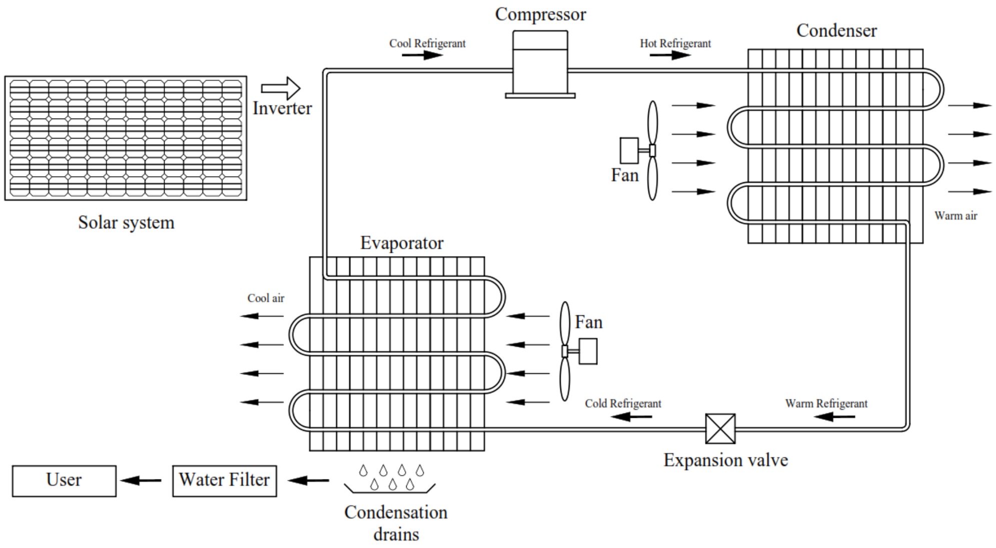

Figure 2: Diagram of moisture separation system with the capacity of 10 L/day.

Table 2: The parameters of 10-L/day moisture separation system.

Parameters	Value	Units
Condenser		
Total heat transfer areas	0.52	m^2
Mass flow rate of air	0.16	kg/s
Volumetric flow rate of air	0.14	m^3/s
Minimum flow area	0.03	m^2
Length of tubes	0.61	m
Number of row	6	-
Number of tube	5	-
Evaporator		
Volumetric flow rate of air	0.18	m^3/s
Total heat transfer areas	0.2	m^2
Total length of tubes	7.23	m
Number of tube	16	-
Solar system		
Power consumption of the system	1.976	kWh
Total watts-peak of the system	4.110	Wp
The wattage of the panel	170	Wp
Number of the panels	24	-
Dimension of the panel	1580 x 808 x 35	mm

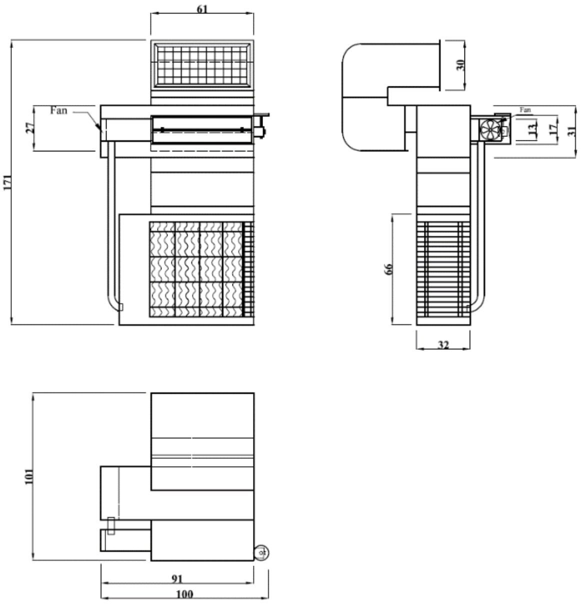

Figure 3: The design of the moisture separation system.

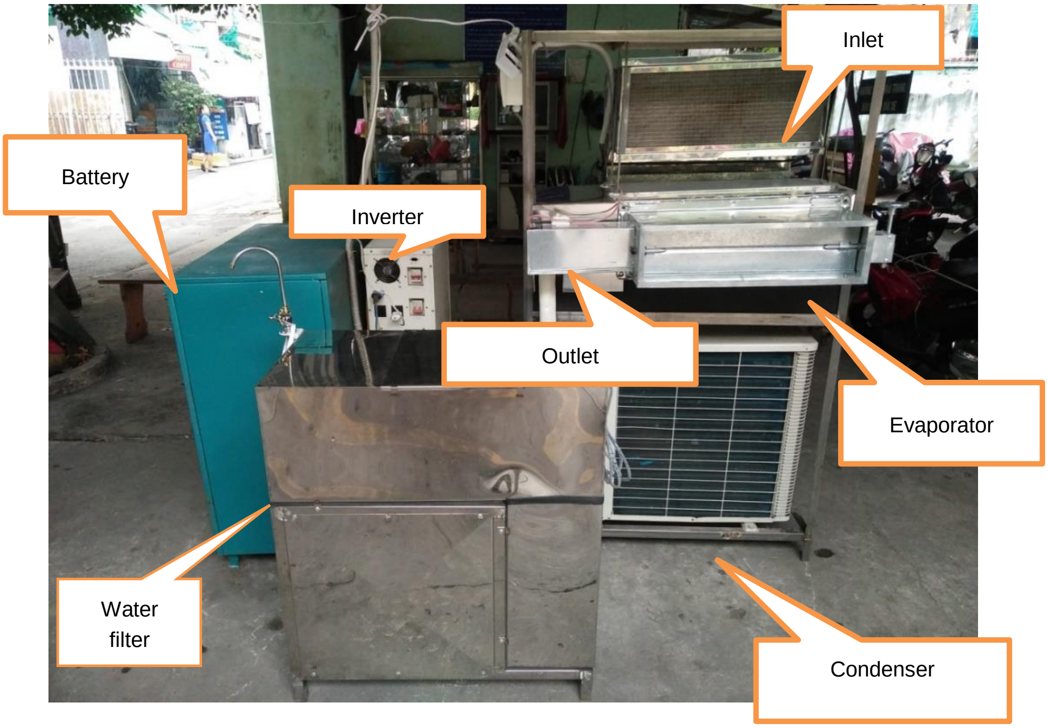

Figure 4: The development of 10-L/day moisture separation system.

Figure 5: Solar panel.

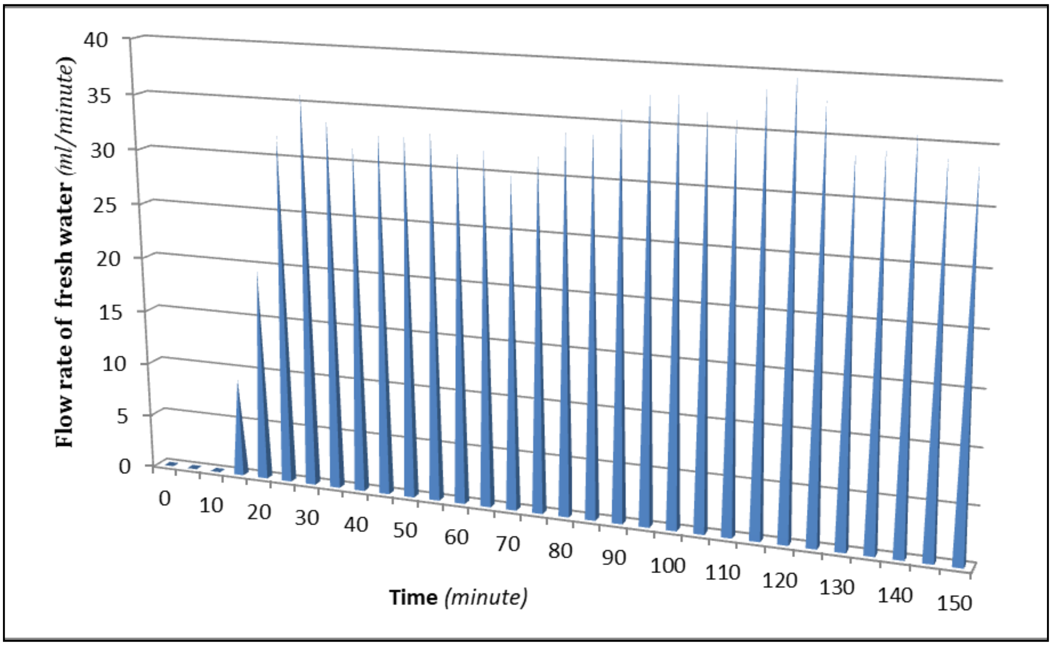

Figure 6: The flow rate of fresh water

The developed system has been operated under sunny condition with the temperature of 29˚C and the humidity of 54.5%. The amount of water collected from the system and power consumption of the system were measured under this operating condition.

Figure 6 shows the amount of water collected for every minute. As the system is turned on, it takes around 15 minutes to get the first droplet of water. It is easy to understand that it takes this time to low down the temperature in the system to the dew point. After 30 minutes, the flow rate of fresh water is almost stable at 35 ml/min. During the operation of 150 minutes, it can be seen from the figure that the water can be collected at the rate of 30-40 ml/min, i.e. 14-19 L/day as the system operates in 8 hours during the sunny day.

Thus, the system meets the required design of 10-L/day extracted water even operating within 8 hours. Furthermore, the data in term of energy consumption have been recorded and presented in Figure 7. The results show that the power consumption of the entire system is around 1.8 kWh.

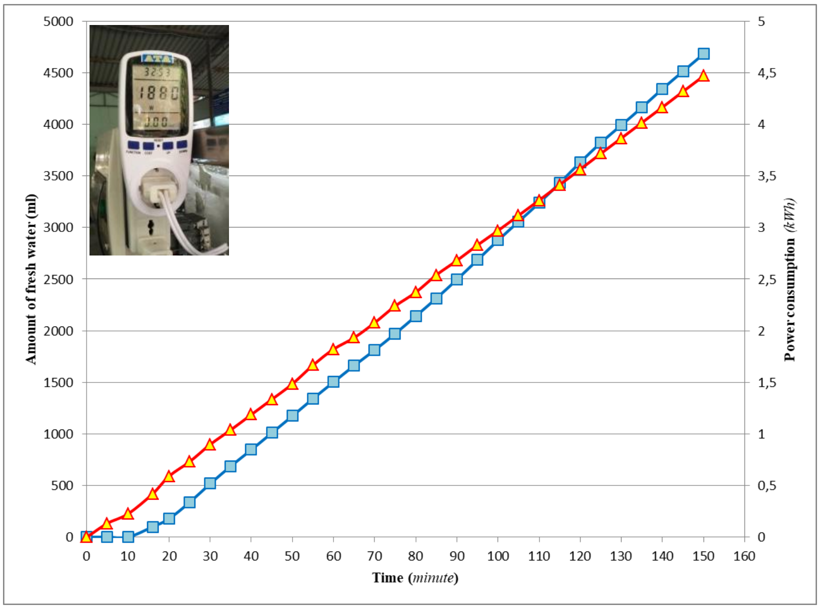

Figure 7: The operating condition.

4. Conclusions

A 10-L/day moisture separation system has been designed and developed including the condenser, evaporator, and water filter. Furthermore, the system is supplied by two types of power sources: one from solar energy (main source) and the other from the national grid (auxiliary source) in order to meet the use for people living in drought areas where lack of water as well as electricity, and the urban areas where electrical grid available. The solar system having 24 panels was developed to be able to generate 2-KWh electricity and convert to alternating current to supply the moisture separation system.

Under the condition of 29˚C and the humidity of 54.5%, the moisture separation system can produce 2.1 liters of water and consume 1.8 kW of electric per hour. Furthermore, the parameters of this system have been scaled up to develop a pilot system which was able to produce up to 200 litre of water per day. Both design as well as operating condition of the system needs to be optimized before taking part in commercialization.

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