Conception of a New Water Collection System Using LiBr Solution for Dry Area

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0616

The Asian Conference on Sustainability, Energy & the Environment 2013

Official Conference Proceedings 2013

Abstract

Nowadays the problem of water shortage and water pollution is very serious all over the world. Moreover, these limited water resources are faced with a very serious industrial and domestic pollution particularly in developing country like China. To solve the problem of water shortage, many methods have been proposed and studied. we designed a new water condensation system inspired by the principle of dehumidifier which can collect liquid water from humid air based on the water absorption nature of the concentrated lithium bromide solution (LiBr) coupled with the method of vacuum distillation. To verify the conception, we have built a small prototype of the system. Experiments with the prototype show that with a 2L (Liter) LiBr solution of 57% concentration, we can get 0.23g/s liquid water. The energy needed to get 1L liquid water is 7500 kJ which is relatively large. However, as most of the energy is used to heat the solution (4000kJ), we could easily applied solar energy into our system and energy efficiency optimization to reduce the consumption of energy. The proposed water collection system can work in a dryer and colder condition than traditional water condensation system. Preliminary results show the feasibility of this kind of system and open the water condensation technique to a larger scope of weather conditions. This proposed technical solution is a new alternative to climate change adaptation for dry land areas in particular. Improvement of the system is currently under investigation.

Keywords: water collection, LiBr solution, vaccum distillation, solar energy

Introduction

Water shortage is, now and even more in a near future, one of the most serious problem on which the humanity faces all over the world. In the total amount of water available in the world, seawater accounts for about 97%, the freshwater accounts for only 2.5%, and the water in lakes, rivers, and surface water which can be used by human accounts for only 1.3% of the total global freshwater [1]. Moreover, these limited water resources are faced with a very serious industrial and domestic pollution. Nowadays, more than 100 countries around the world have different degrees of water shortage, and 28 countries are classified as water-scarce countries or serious water-scarce countries.

To solve the problem of water shortage, many methods have been proposed and studied. Generally, there are 3 kinds of solutions.

- Seawater desalination:

The traditional process of seawater desalination is vacuum distillation which consumes a lot of energy and which is not very effective. An alternative way is to use reverse osmosis technology or electrodialysis, which are usually too expensive for widespread use. Moreover, this solution can only be used in coastal areas as desalting seawater requires a consistent and reliable source of feed water to operate and produce potable water effectively and efficiently [2].

- Water purification:

Water purification aims at reduce the concentration of particulate matter like suspended particles, parasites, bacteria and a range of dissolved and particulate material in the water. In general the methods used include physical processes such as filtration and sedimentation [3], biological processes such as slow sand filters or activated sludge [4], chemical processes such as flocculation and chlorination[5] . In most cases, all these processes are combined to form a whole water purification system. Water purification helps to recycle waste water to provide water for industrial or domestic uses. However, during the process of treatment, essentially during the chemical processes, the water can be polluted again by the chemicals and cause corrosion or toxicosis. Moreover, the process of distillation removes all minerals from water, which makes the water not ideal for drinking.

- Condensation:

For high humidity areas such as places close to the sea, water can be condensed from the air. This method also applies well in places which has a large day-night temperature difference. A relatively new method to cool warm air and condensate its contents of moisture is to use thermoelectric (TE) devices [6]. Nowadays, atmospheric water condensing products are available for residential and industrial uses. They mainly use sustainable energy such as solar, to achieve the purpose of energy control. However, all the existing products can only work in humid areas but not in a dry and cold condition. For example, in the Chinese city of Dulin, the traditional way of condensation can only function during 4 months (6,7,8,9) when the average vapor pressure is above 4.58mm/Hg as showed in table 1 (0 °C, the saturation vapor pressure is 4.58mm/Hg) [7].

In order to solve this problem of humidity limitation for water condensation systems, we designed a new water condensation system inspired by the principle of dehumidifier, [8] which can absorb the moisture in the air but cannot obtain liquid water.

Table 1: Average vapor pressure of Dulan, China

Station	Dulan, China
Month	Average vapor pressure (mm/Hg)
1	1.1
2	1.3
3	1.8
4	2.5
5	4
6	5.9
7	7.4
8	6.9
9	4.9
10	2.8
11	1.5
12	1.1

In this paper, we propose a water condensation system that can collect liquid water from humid air based on the water absorption nature of the concentrated lithium bromide solution with the method of vacuum distillation. Tests and validations have been made on a simple prototype of the system. The paper is organized as follow. The second section describes in detail the conception of the system and the process of water condensation. The third section presents the tests and results of the experiments. We discuss the performance of the system and present the water quality check in the fourth section and in the last section we give the conclusions.

1. Principle of the LiBr condensation system

We design the water collection system based on the water absorption nature of the concentrated lithium bromide (LiBr) solution coupled with the method of vacuum distillation. LiBr solution is colorless liquid with salty taste and it is non-poisonous. The concentrated LiBr solution has a great ability of hygroscopicity as its water vapor partial pressure is very low. The Pressure-Temperature-Concentration curve of LiBr solution is showed in Fig.1. Another important nature of LiBr solution is that it has a great corrosion to ferrous metals and red copper, which make us have to pay attention to the choice of materials of the equipment used in the experiments.

The machine consists of seven parts (Fig.2): aerator (1), LiBr absorber (2), heat exchanger (3), solar heating panels (4), reaction vessel (5), collection device (6) and vacuum pump (7).

We suppose that the temperature of the environment is T = 30°C, the humidity relative is HR = 15%, and in this condition the concentration of the saturated lithium bromide solution in the LiBr absorber is 56% which means that the solution contains a lot of water. It is the concentration of saturated LiBr at 30°C. Firstly, we use the vacuum pump to make the pressure in the reaction vessel to 0.1bar, and the pressure difference between the reaction vessel and the LiBr absorber will push the solution into reaction vessel. Then the solution will be heated to 110°C by the solar heating panels around the reaction. This is the process vacuum distillation. The water will turn to vapor and will be taken out of the reaction vessel by the vacuum pump. Next the vapor is cooled down in the copper tube of the condenser and then we can collect the liquid water in the collection device.

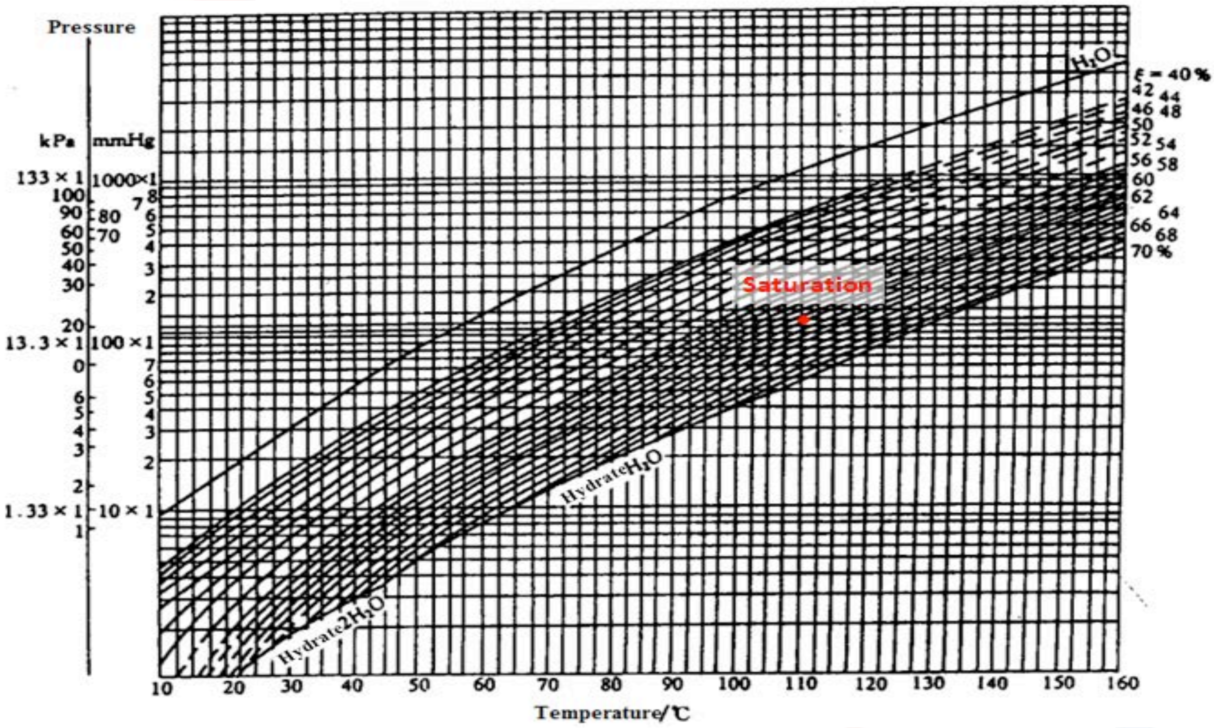

Fig.1: Saturated vapor pressure-Temperature-Concentration curve of LiBr solution [9]

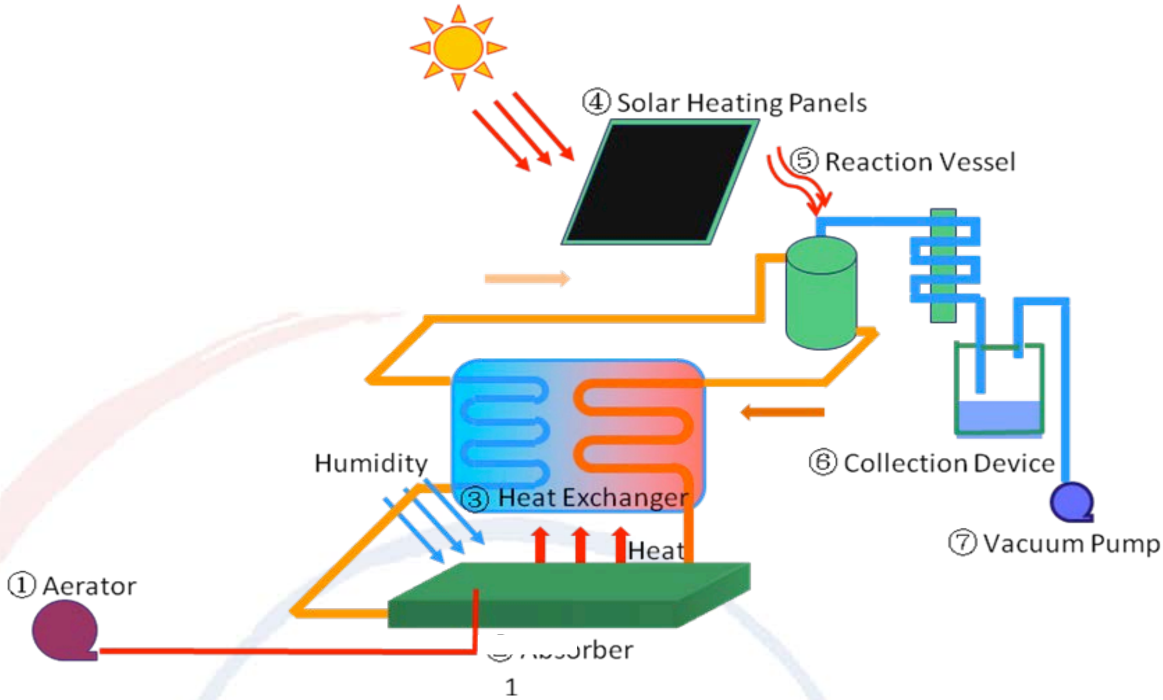

Fig.2: Sketch of the water collection system

When the solution in the reaction vessel reaches T = 110°C, we stop heating and in this condition the concentration of the LiBr solution is 64% (Fig.1 red point). There is less water inside the solution. Next, we shut down the passage of the vapor and open another opening on the vessel to balance the pressure between the reaction vessel and the environment. The gravity will make the solution flow out of the vessel and into the heat exchanger, cool down, and flow back to the LiBr absorber. After the solution of 64% mix with the solution in the absorber, it will absorb the humidity in the air. To accelerate the absorption needed time, we use an aerator. The concentration of the solution in the absorber will become 56% after a certain time and then the next cycle begins. The whole cycle of the system is showed in Fig.3.

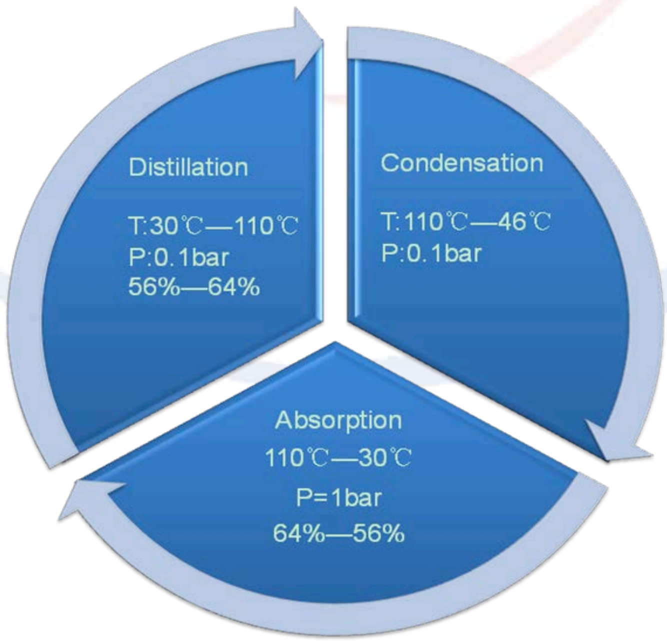

Fig.3: Cycle of the water collection system

2. Experimental verification of the proposed principle

To verify the conception, we have built a small prototype of the system. And we designed and conducted many experiments with the prototype to verify the conception of each section of the system and to evaluate the overall performance of the system.

A. Absorption section

The condition of the experiment is T = 20°C, RH = 40%. Equipment setup is showed in Fig.4.
We use densimeters to measure the density of the LiBr solution every 30 minutes with an air pump which blows maximum 300L air per minute into the absorption cell.

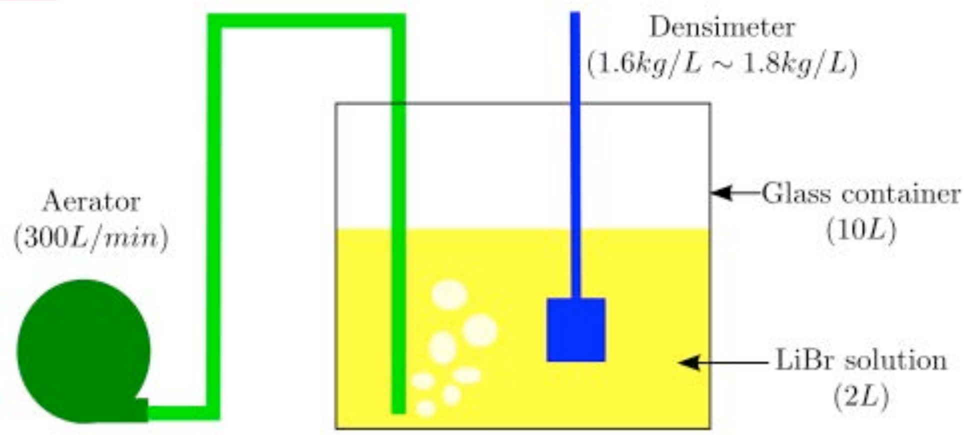

Fig.4: Equipment setup of experiments of absorption section

We can get the concentration of the LiBr solution in the absorption cell with the measured density based on the Condensation-Density table of LiBr solution [10] and the concentration-time curve is showed in the Fig.5. We can see that the concentration of the LiBr solution declines as it absorbs the humidity in the air. We can also notice that the absorption rate varies with the concentration and we would also like to observe the change of the absorption rate. First we calculate the initial mass of the solution m_0 given the initial volume V_0, initial density ρ_0 and the initial concentration of the solution w_0 by using the Eq.1.

$$m_0 = \rho_0 * V_0$$
(1)

The mass of the solution contains the masse of water plus the mass of LiBr. The mass of LiBr keep unchanged during the experiment. We can then get the mass of LiBr m_{LiBr} using Eq.2.

$$m_{LiBr} = m_0 * w_0$$
(2)

Then we can calculate the mass of the solution at any time t during the experiment with the concentration of the time t given by Eq.3.

$$m(t) = m_{LiBr} / w(t) = \rho_0 * V_0 * w_0 / w(t)$$
(3)

At last we can get the average absorption rate of time t by Eq.4.

$$\bar{v}(t) = (m(t) - m_0) / t$$
(4)

The average absorption rate-time curve is showed in the Fig.6. We can see that the average absorption rate declines quickly while the concentration declines. We can also see that 3 hours is a critical time after what the concentration is below 57 % and the average absorption rate becomes smaller than 0.01 kg/ h. In practice, we will consider that the LiBr solution riches saturation at 57% instead of 56% which needs a too long time of absorption for a little gain in amount of water from 57% to 56% concentration.

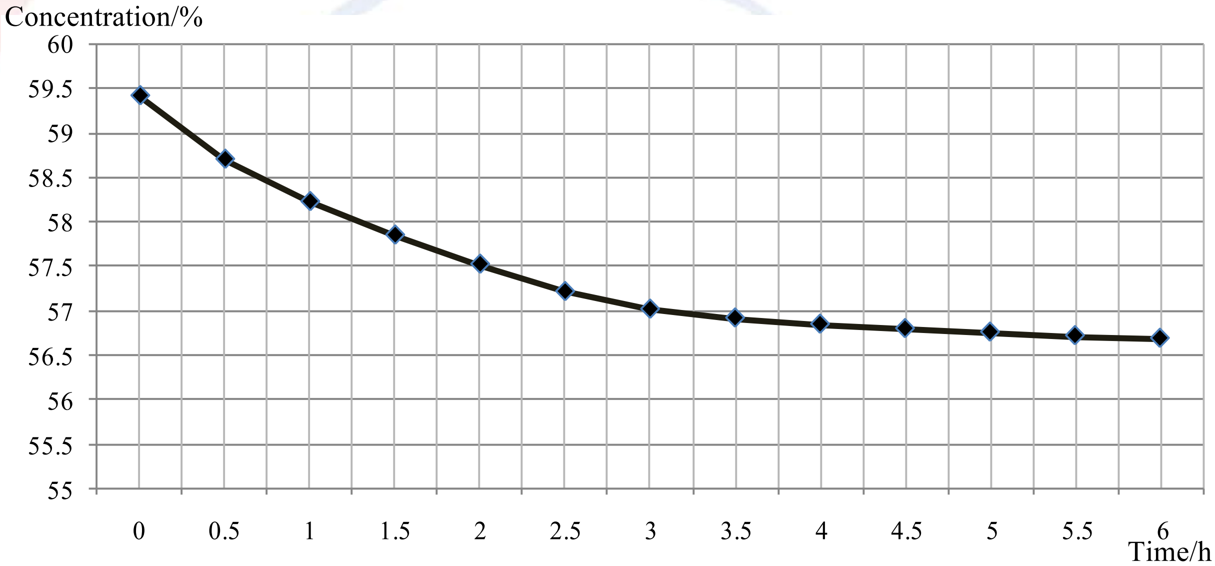

Fig.5: The concentration-time curve of LiBr solution in the Absorption cell

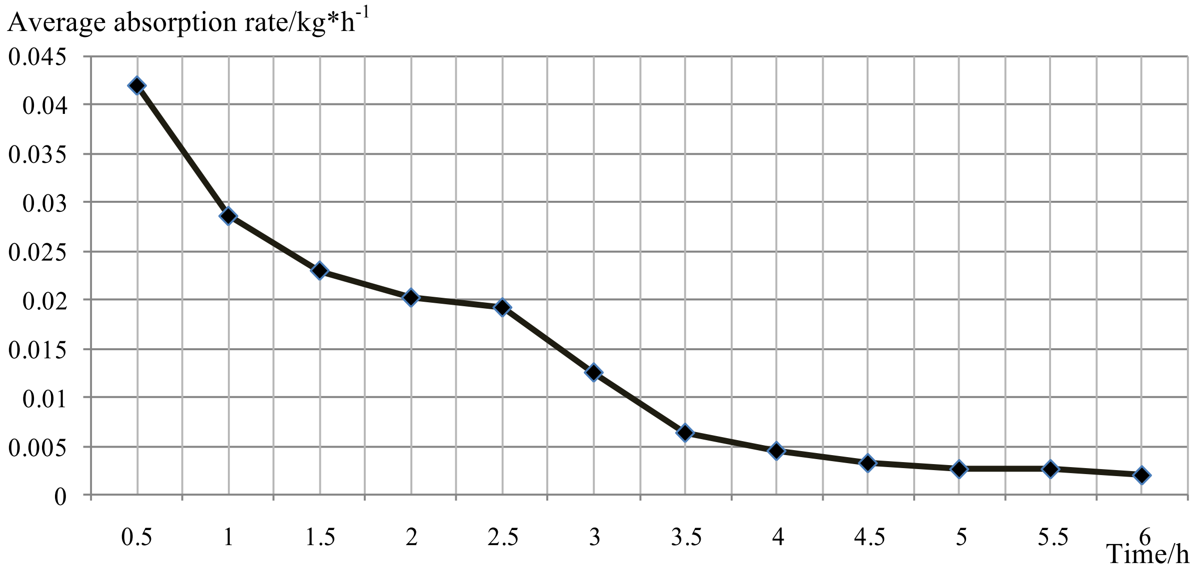

Fig.6: The absorption rate-time curve of LiBr solution in the Absorption cell

B. Distillation and condensation sections

To verify the conception of the distillation section and evaluate the performance of the system, we designed the experiments to calculate the energy needed and the quantity of water obtained theoretically in one cycle.

The experiment of the distillation section and the condensation section is unalienable. So we present the result of the experiments together in this part. The equipment setup is showed in Fig.7. In this preliminary work, we did not have solar energy equipment as we planned in the system design. So we used the electric heater instead. The effect of these two heaters is the same. The condition of the experiment is also T = 20°C, RH = 40%.

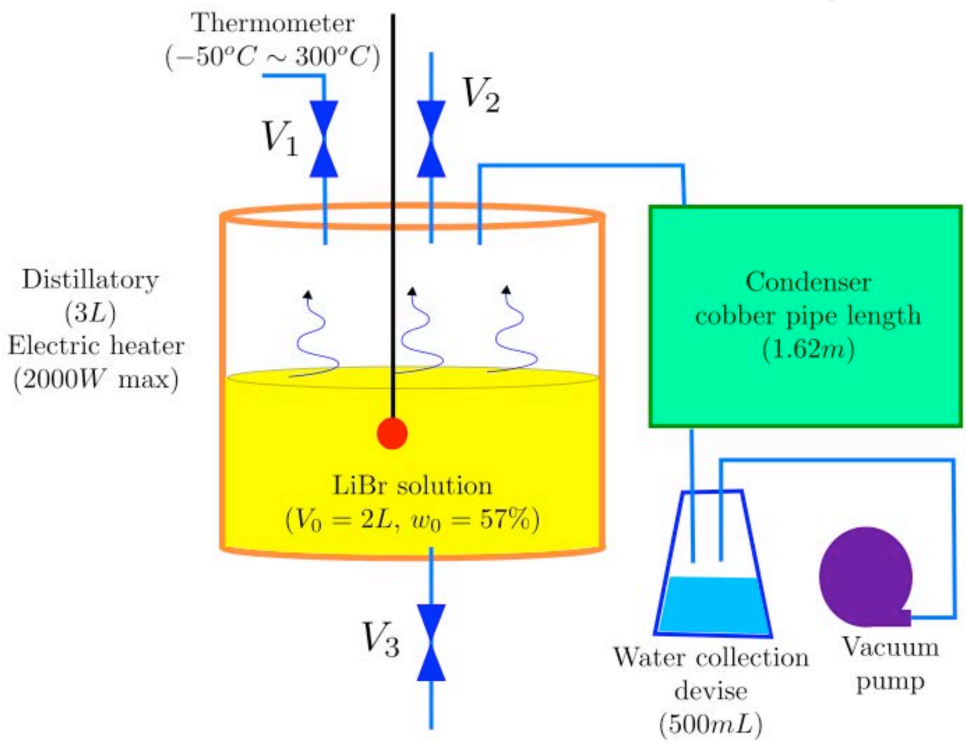

Fig.7: Equipment setup of experiments of distillation and condensation section

The main reaction vessel is made of glass and has a thickness of 3mm. It is cylindrical with an outer diameter of 130mm. When 2L solution is contained, the liquid level is about 165mm in the cylindrical reaction vessel. The reaction vessel is wrapped by electric heater of 2000W which automatically stops working when the temperature reaches at 300°C.

After a period of heating, the system reaches equilibrium. At the beginning of boiling, we swich the temperature controller to auto on/off mode and found that the heater works approximately 50% of working time, so the actual power of electrical heating can be regarded as $p = 1000W$.

The procedure of this experiment is complex as there is a change of the pressure and temperature. The whole steps are showed below:

1. Use the vacuum pump to make the pressure in the distillatory section to 0.1 bar.
2. Close the valves V2 V3, open V1. The LiBr solution then enter the distillatory section from V1. Close the valves V1. Heat the solution with the electric heater up to 110and then stop heating. During this process, we measure the temperature of the solution every 1 minute after boiling. The vapor flows out of the distillatory and into the condenser where it is condensed and then is collected in the collection device.
3. Shut down the vacuum pump and open V2 to balance the pressure between environment and inside of the distillatory section.
4. Turn on V3 to make the solution flow out of the distillatory section.
5. Measure the density of the solution flow out.

The density of the solution after the process of distillation equals a concentration of 64% and the temperature-time curve obtained is showed in Fig.8.

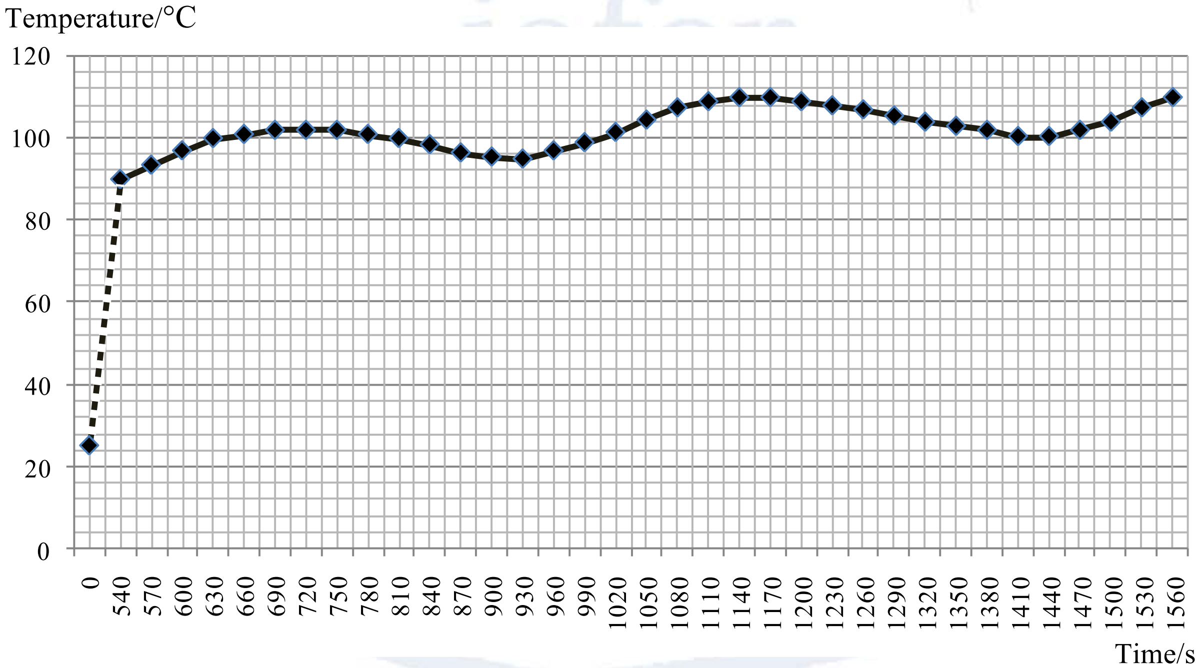

Fig.8: Temperature-Time curve of the LiBr solution in the experiment of distillation

The solution started to boil at 540s when the temperature reaches 90°C. Because of the low pressure (0.1 bar), the boiling point of the solution is lower than at the atmospheric pressure [11]. We stops the heating when the temperature reaches 110°C because if the temperature becomes higher than 110°C, the LiBr may crystallize in the distillatory. Now we can get the quantity of water collected during the experiment by Eq. 5.

$\Delta m_{water} = m_0 - m_t = m_{LiBr}(1 / w_0 \quad 1 / w_t)$.
(5)

We can get the mass of LiBr in the solution by the Eq. 2 and then we can calculate the quantity of water obtained per second by Eq. 6.

$q_e = \Delta m_{water} / \Delta \mathrm{t}$.
(6)

Given that $w_0 = 57\%$, $w_t = 64\%$, $V_0 = 2L$ and $\Delta t = 1560s$, we get that:

$q_e = 364.58g / 1560s \approx 0.234g / s$.

The energy needed for heating to get 1L of water can be calculated by the Eq. 7.

$W_{heater} = (1000 / q_e) * p = 4273kJ$.
(7)

The other energy needed is the energy used by the aerator and the vacuum pump. The vacuum pump works during the process of distillation.

$$W_{vacuum} = (1000 / q_e) * 180 = 770kJ \qquad (8)$$

The aerator works during the process of absorption and the time to absorb 1L water from air is calculated by the Eq. 9.

$T_{aerator} = 1000 / (\rho_0 * v_0 * w_0 * (1 / w_{3h} - 1 / w_0)) * 3 * 3600 \quad 73973s$
(9)

Then we can caculate the energy used by the aerator by the Eq. 10.

$W_{aerator} = T_{aerator} * 35 = 2589kJ$
(10)

And we can get the total energy needed to get 1L of water is:

$$W = W_{heater} + W_{aerator} + W_{vacuum} = 7632kJ \qquad (11)$$

Our system is quite energy consuming but it is reasonable as many improvement can be done on the energy efficiency of this preliminary experimental setup. With this setup, we can get nearly 0.234g water per second and it consumes 7632kJ energy to get 1L water.

3. Discussion

The new water collection system is based on the ability of hygroscopicity of the LiBr solution. So it depends little on the environment temperature. We compare our conception with the product “Dolphin1” from Air2Water Company [12]. The Dolphin 1 can only work when the temperature of the environment is about 30°C and the humidity is above 40%. While our system can work even when the temperature is about 0°C and the variation of temperature influence little our system. As long as the LiBr solution is in state of liquid, the system can function. The system demands that the water partial pressure of LiBr solution is smaller than the one of the air, so the LiBr solution can absorb the humidity in the air. The crystallization is also not preferred in the distillatory. So our system needs to work in the condition where the relative humidity is above

15%. When the humidity is below 15 %, the absorption rate becomes too small and a cycle may take a lot of time.

Meanwhile, our system consumes relatively a lot of energy compared to the Dolphin 1, which consumes 1565 kJ to get 1L water. However, as most of the energy is used to heat the solution (4273kJ), we could easily applied solar energy into our system to reduce the consumption of electrical energy. The main value of our system comes from the fact that we propose, in this work, a new water collection system which can work in a colder and drier condition than existing condensation system. Our system is more suitable for dry areas which have a lot of sunshine but a lack of water.

We have also examined the quality of water we had obtained to prove that there is no pollution of lithium bromide. We use the Silver nitrate solution to test lithium bromide because silver ions and bromide ions will produce silver bromide which is light yellow precipitate. We compare the water we obtained with the tap water and 5% lithium bromide solution. There is no visible precipitate in the water we obtained, proved that the concentration of bromide ion is lower than 7.43×10^{-7}mol/L, which is very low and harmless to human.

4. Conclusion

In this paper, we proposed a new water collection system based on the ability of hygroscopicity of LiBr solution coupled with the method of vacuum distillation. The new system can work in a drier and colder condition than the traditional water condensation system. The prototype we built verifies the feasibility of the system. It can collect about 0.23g water per second and consumes 7632kJ energy to get 1L of water. Water quality check confirms that the water we collected is not polluted by the LiBr. The bottleneck of the system is the absorption rate of the lithium bromide solution which reduces when the concentration of solution in the absorber is close to the saturation. The slow absorption rate prolonged the time of each cycle and thus reduces the efficiency. In order to improve our system, we are currently working on adding solar energy to the system to heat the solution and to provide the needed energy for the air bloomer and the vacuum pump. We are also working on a bigger absorption container maximizing the air/solution contact surface and on a better air bloomer to accelerate the humidity absorption rate of the LiBr solution. We would also like to set an automation system to control the valves based on the data obtained by sensors installed in the system. In this way the all cycle process will be autonomous.

5. Acknowledgements

We strongly thank the other students from the group who actively participated to the conception of the entire experiment. We would like to express our thankfulness to the laboratory of the Chemistry and Environment School of Beihang University who provide the laboratory to do the water quality check. We would also like to thank Greenwater project from Shin Development Association and Center of Condensed Matter and Materials Physics of Beihang University who supervise us and provide us the fund to do the research.

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