Faculty of Engineering

EXTRACTING WATER FROM AIR AS AN ALTERNATIVE WATER SOURCE IN SARAWAK, MALAYSIA

Chang Sze Ying

Bachelor of Engineering with Honours

(Chemical Engineering)

2022

UNIVERSITI MALAYSIA SARAWAK

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WATER EXTRACTION FROM AIR AS AN ALTERNATIVE WATER SOURCE IN SARAWAK, MALAYSIA

CHANG SZE YING

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Chemical Engineering)

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Dedicated to my beloved family and friends who have supported me unconditionally throughout this project.

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ABSTRACT

Atmospheric water has high potential to be implemented in Malaysia because of the relatively high average humidity. In this project, passive desiccant method and active condensation method were studied. The passive desiccant method was done by using a flat plate collector with calcium chloride desiccant, while the active condensation method was tested using a solar powered split air conditioning system. Results obtained show that the passive desiccant water extraction is affected by sunlight intensity, desiccant concentration, bed temperature, cover temperature and orientation of the collector. The water productivity of the collector is directly proportional to sunlight intensity, desiccant concentration, and bed temperature. When the cover temperature is higher than the dewpoint, the water production rate drops as the condensation rate is affected. The water productivity is also higher when the collector faces towards the sun. The experiments show the potential of the passive desiccant method as the high relative humidity in Malaysia allows more atmospheric water to be absorbed. The water productivity of the active condensation method is higher and more stable compared to the passive method. For the active method, the water productivity of the system is not affected by the surrounding condition, like sunlight intensity and temperature. The effect of the relative humidity in the room to the water yield is only significant when the relative humidity is between 10% to 40%. The solar powered air conditioning system achieved an average water production rate of 2.142L/h in the experiment when the relative humidity was higher than 75%. Hence, the active condensation method is more feasible than the passive desiccant method to extract and supply atmospheric water as an alternative water source in Malaysia.

Keywords: Atmospheric water extraction, desiccant, adsorption-desorption process, condensation.

ABSTRAK

Air atmosfera berpotensi tinggi untuk digunakan di Malaysia kerana purata kelembapan Malaysia yang agak tinggi. Untuk mengekstrak air dari udara, dua kaedah utama adalah menyejukkan udara lembap ke titik embunnya supaya air di udara terkondensasi, dan menyerap lembapan menggunakan bahan pengering, yang kemudiannya dipanaskan untuk menguap dan memekatkan air yang diserap. Dalam projek ini, kaedah pengering pasif dan kaedah pemeluwapan aktif telah dikaji. Kaedah pengering pasif dilakukan dengan menggunakan pengumpul plat rata dengan bahan pengering kalsium klorida, manakala kaedah pemeluwapan aktif dilakukan menggunakan sistem penghawa dingin berkuasa solar. Berdasarkan daripada keputusan eksperimen, pengekstrakan air pasif dengan bahan pengering dipengaruhi oleh keamatan cahaya matahari, kepekatan bahan pengering, suhu kain, suhu penutup dan orientasi pengumpul. Penghasilan air pengumpul adalah berkadar terus dengan keamatan cahaya matahari, kepekatan bahan pengering, dan suhu katil. Apabila suhu penutup lebih tinggi daripada titik embun, kadar pengeluaran air menurun kerana kadar pemeluwapan terjejas. Produktiviti air juga menjadi lebih tinggi apabila pengumpul menghadap ke arah matahari. Eksperimen menunjukkan potensi kaedah pengering pasif kerana kelembapan relatif yang tinggi di Malaysia membolehkan lebih banyak air atmosfera diserap. Bagaimanapun, produktiviti air kaedah pemeluwapan aktif adalah lebih tinggi dan lebih stabil berbanding dengan kaedah pasif. Produktiviti air sistem tidak terjejas oleh keadaan sekeliling, seperti keamatan cahaya matahari dan suhu. Kesan kelembapan relatif di dalam bilik terhadap hasil air hanya ketara apabila kelembapan relatifnya antara 10% hingga 40%. Sistem penghawa dingin berkuasa solar mencapai kadar pengeluaran air purata 2.142L/j dalam eksperimen apabila kelembapan relatif lebih tinggi daripada 75%. Oleh itu, kaedah pemeluwapan aktif adalah lebih sesuai daripada kaedah pengering pasif untuk mengekstrak dan membekalkan air atmosfera sebagai sumber air alternatif di Malaysia.

Kata kunci: Pengekstrakan air atmosfera, bahan pengering, proses penjerapan-desorpsi, pemeluwapan.

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ABBREVIATIONS

ACC	Absorption cooling cycle
AWG	Atmospheric water generator
CPV/T	Photovoltaic thermal
LFC	Large fog collector
LiBr/H_2O	Lithium bromide/Water
MOF	Metal organic framework
P4VP	Poly-4-vinylpyridine
POSS-PEMA	Polyhedral Oligomeric Silsesquioxane-Poly(ethyl methacrylate)
SFC	Standard fog collector

NOMENCLATURE

%	Percentage
°	Degree
°C	Degree Celsius
CFU	Colony-forming unit
cm/s	Centimetre per second
g	Gram
hp	Horsepower
kg/m^2	Kilogram per meter square
km^2	Kilometre square
km^3	Kilometre cube
kW/m^2	Kilowatt per meter square
L/day	Litre per day
L/h	Litre per hour
L/kg	Litre per kilogram
L/m^2	Litre per meter square
L/m^3	Litre per meter cube
m	Meter
m^2	Meter square
m^3	Meter cube
ml	Millilitre
ml/day	Millilitre per day
ml/h	Millilitre per hour
ml/kg/day	Millilitre per kilogram per day
mm	Millimetre
Wh/L	Watt hour per litre
Wt%	Weight percent

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia receives heavy rainfall of approximately 990 billion m^3 per year because of the monsoons. Out of the 990 billion m^3 rainfall, more than half of it ends up as surface runoff (The Malaysia Water Partnership, 2001). The surface runoff then eventually flows into rivers. Therefore, in Malaysia, the main water source is surface water, particularly rivers. There are a total of 189 river basins in Malaysia. Due to the abundantly available surface water resources, almost 99% of Malaysia's domestic water supply comes from rivers and only 1% of it is from groundwater (Azrina et al., 2011). Agricultural activities in Malaysia use 70% of the available water resources. To ensure the surface water supply is secured, reservoirs are built to store river water, which then becomes 90% of Malaysia's water supply (Huang et al., 2015).

The most important water source in Sarawak is the Sarawak River. The Sarawak River has two tributaries, namely Sarawak River Kiri and Sarawak River Kanan. The confluence of the two tributaries at Batu Kitang forms the Sarawak River that has a total length of 120 km. The area that catches rainfall and collects it into a river is known as catchment area. The main river of the Sarawak River has a catchment area of 1500km^2. When combining with the two tributaries, the total catchment area is 2459km^2 (Kuok et al., 2011). The Sarawak River provides 98% of water to the capital of Sarawak, Kuching, and the area surrounding it (Kuok et al., 2011). In addition of providing raw water, the Sarawak River also plays essential role in local transportation and tourism activities.

Atmospheric water exists in different forms, including clouds, fogs, and vapours. Different from the other alternative water resources, where water is obtained and treated directly, atmospheric water requires a particular process, known as water extraction from air, before it is treated as water. Water extraction can be referred as a wide variety of processes in different fields. In general, water extraction is defined as any process that draws water temporarily or permanently from any source or place to get water supply or to control flood. Water extraction from air is a type of water extraction process carried out specifically to convert moisture in the atmospheric air into water. Atmospheric water takes up 0.001% of total water on the Earth, which is 10 times higher than rivers that only takes up 0.0001% of total water (Mullen, 2021). The average water content in 1 km^2 of air is approximately 10000 m^3 to 30000 m^3 at most places on the Earth (Bar, 2004). In total, the volume of water exists in the air with different forms at any point in time is about 12900 km^3, which takes up 0.04% of freshwater on the Earth (Gleick, 1996). It also constitutes one tenth of the existing surface water as shown in **Figure 1.1** (Peeters et al., 2020).Without a doubt, atmospheric water has great potential to be used widely as an alternative water source.

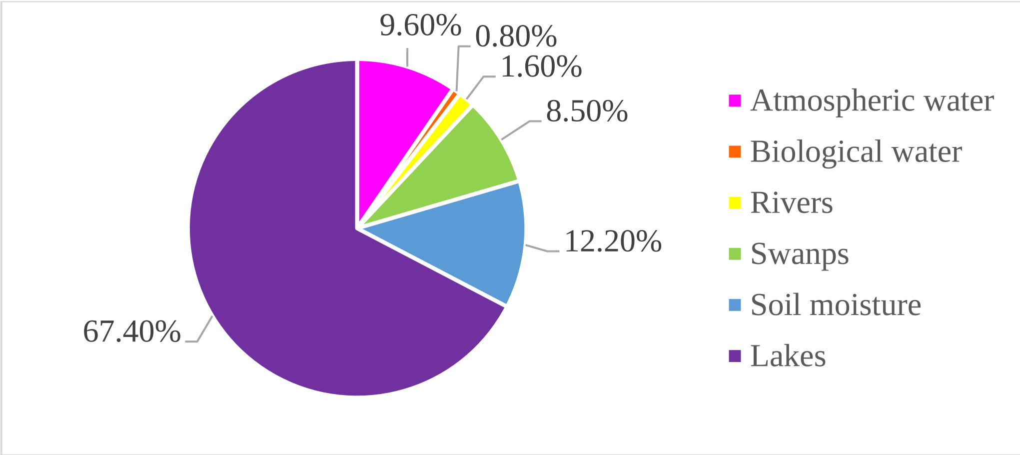

Figure 1. 1: Distribution of global surface water (Peeters et al., 2020).

Using atmospheric water as a water source is more flexible compared to other water source. As there is water in the atmosphere everywhere, the usage of atmospheric water is not limited by geological location like the usage of river and lake water. Hence, it is suitable for isolated areas especially rural areas and arid areas, where there are no readily accessible water resources. Moreover, when there is an emergency, such as natural disasters, causing the cut off of other water supplies, atmospheric water can be the alternative water supply. In the extraction and treatment of atmospheric water, there is almost no waste produced. So, no addition waste treatment is needed, making it more cost effective and convenient. There are many methods in the extraction of atmospheric water. Some of them can be more environmental-friendly compared to other non-conventional water sources depend on the type of energy sources used. All in all, the usage of atmospheric water shows potentials to supply water in a larger scale. It can diversify the current water sources used around the world so that the global populations are less dependent on conventional water sources.

As a tropical country, Malaysia has a high humidity and temperature all year long. The average temperature in Malaysia is 26°C, while the humidity is 80% due to high evaporation rate. (Food and Agriculture Organization of the United Nations, 2011). High humidity means that there is a higher concentration of moisture in the air. Besides, the average time that Malaysia receives bright sunlight is around 1764 hours to 2664 hours every year (The Malaysia Water Partnership, 2001). Because of that, it is possible to extract atmospheric water using solely solar energy in Malaysia. Therefore, Malaysia has the potential to employ atmospheric water as an alternative water resource.

1.2 Problem Statement

Water pollution has affected the water supply in Malaysia. According to the national river water quality monitoring programme in Malaysia, 161 rivers (34%) are found to be slightly polluted while 34 rivers (7%) are found to be polluted (Department of Environment Malaysia, 2012). The sources of pollution are non-point sources, including agriculture, and point sources, including sewage treatment plant, manufacturing industries and domestic sewage. In Sarawak, the water pollution problem is less severe. However, the water supply network in Sarawak is incomplete as there are still areas without access to public water supply. The coverage of the existing water supply network in Sarawak is around 83.4%, while the coverage in the rural areas of Sarawak is only 66.5% (Aubrey, 2021).

Without a doubt, the world is now facing a water problem that is getting serious. So, it is necessary to find alternative water sources to keep up with the global water demand as well as to solve water scarcity. As mentioned before, atmospheric water is flexible and can be obtained at any place. However, the technology for water extraction from air is still not mature enough. Depend on the methods, the carbon footprint created during the extraction of atmospheric water can be larger than that by other water sources when non-renewable energy, like coal, is used. It is because the extraction of water from air requires a larger amount of energy, which has become a challenge in applying atmospheric water as water source. The efficiency of water extraction from air also relies on the surrounding conditions, especially temperature and humidity. Therefore, in this study, the potential of water extraction from air technology powered by solar energy to be used in Malaysia, specifically in Kuching, Sarawak will be explored.

1.3 Research Question

The focus of this study is on water extraction from air in Sarawak, Malaysia. The research questions are as follow:

i. How to design and build an effective passive desiccant atmospheric water extraction system?

ii. How do a passive desiccant system and an active air conditioner powered by solar energy produce water from air?

iii. What are the performances of different systems in producing water from air?

1.4 Objectives of the Study

The aim of this project is to study the potential of water extraction from air as alternative water resource in rural areas Sarawak. To ensure the aim of the study can be achieved successfully, the objectives of this study are:

i. To design and test a passive desiccant atmospheric water extraction system powered by solar energy.

ii. To produce water from air through passive desiccant system and active air conditioner powered by solar energy.

iii. To analyse and compare the water production performance of both systems.

1.5 Scopes of the Study

This study focuses on the methods and the associated mechanisms of water extraction from air as well as the environmental factors that affect the processes. Devices used to extract water from air were design and built, which operate by means of solar energy. Two different water extraction methods, which were passive desiccant method and active condensation method, were carried out and were compared in term of water production rate and efficiency. For the passive method, the factors that affect the water productivity, including weather, temperature, desiccant concentration and orientation of the collector were studied. For the active method, the water productivity and the relative humidity were focused.

1.6 Significance of the Study

The significances of the study based on the findings of this research project are as followed:

i. The performance of the water-from-air devices in the research can reveal the possibility of using atmospheric water as an alternative water source to diversify the water sources used in Malaysia and to solve the water scarcity in rural areas.

ii. Extraction of water using solar energy can solve the limitation of using atmospheric water as an alternative water source, which is the high carbon footprint caused by the usage of non-renewable energy.

iii. The comparison between different methods and the rate of water extraction from air at different conditions provide important information for the design of a water-from-air device that is suitable to be implemented in Malaysia, especially rural areas in Sarawak.

1.7 Summary

In this chapter, different types of conventional and non-conventional water sources are introduced. As the population in the world continues to grow, accompanied with the growth of human activities, the global water demand has been increasing. In contrast, the water sources available in the world are depleting due to water pollution problems caused by agricultural activities and industrial activities. In Malaysia, some of the rivers, which are the main water source, are polluted. Other than that, in the case of Sarawak, the water distribution is not equal for urban areas and rural areas. The public water supply coverage in rural area is less than that in urban areas. To solve the water issues faced globally as well as in Malaysia, specifically in Sarawak, the usage of non-conventional water sources should be explored. The benefits of atmospheric water and its potential to be used as an alternative water source in Malaysia have also been explained. In this research project, the potential of extracting water from air as a water supply will be studied. Therefore, in the next chapter, details about water extraction from air will be explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Type of Global Water Resources

As the most abundant compound on the Earth, water has supported the live of countless living things. Since the 20th century, the global freshwater usage has continuously raised nearly six-fold, from around 670 billion m3 to almost 4 trillion m3 (Ritchie & Roser, 2017). Water is not only crucial for maintaining the health and lives of all kinds of living things, but also an indispensable component for a lot of human activities, including agricultural activities, industrial activities, and domestic use. Agricultural activities are the most water-intensive activities, which take approximately 69% of the global water used. Industrial activities have the second most water use, which is around 19% of the global water used, while the last 12% of the water use is by domestic use (Piesse, 2020).

Though water is widely available almost everywhere on the Earth, not all the water is readily usable. Most of the usable water sources are groundwater, lakes, and rivers. Groundwater is the water obtained below the ground with 100% saturation (Mullen, 2021). It is formed when water flows into the ground and fills in pores of layers of rocks known as aquifers (United States Bureau of Reclamation, 2011). Groundwater takes up 98% of freshwater available on the Earth (Mullen, 2021). It is approximated that groundwater has become the source of drinking water for at least 50% of the global population and provided water for more than 40% irrigation (Piesse, 2020). On the other hand, lake and river are both considered as surface water, along with ocean, wetlands, and reservoirs, as they are available on the surface of the Earth. Since they can be obtained more easily compared to groundwater, they account for around 80% of water consumed daily (Mullen, 2021).

Groundwater and surface water can be considered as conventional water resources that are widely used all around the world. Recent years, the researchers have started to explore the potential of using non-conventional water resources, such as seawater, reclaimed wastewater, rainwater or stormwater and atmospheric water. Those water resources are usually not readily usable and require specific treatment processes. Seawater is the most available type of water on the Earth. It makes up 97.2% of water on the Earth (Mullen, 2021). However, the salt content in seawater is too high for it to be used in most domestics use, agricultural activities or industrial activities. To reduce the salt content in seawater to an acceptable level, desalination process is needed. On the other hand, reclaimed wastewater is wastewater released by buildings and industrial processes that undergoes wastewater treatment to be reused in irrigation and industries (Office of Energy Efficiency & Renewable Energy, 2012). The wastewater can be domestic sewage, industrial effluents, and stormwater.

2.2 Water Scarcity in the Global and in Malaysia

The global water demand has raised drastically throughout the years. The direct cause of the increment is the growth of the world population. In the 20th century, the world population is estimated to grow from 1.65 billion to 6.0 billion, which is a population growth of around 260%. To date, it is estimated that there are close to 8.0 billion people in this world and is forecasted to have 9.7 billion people in 2050 (Worldofmeters.info, 2021). The population growth has direct impact on the household water demand. From 1960 to 2014, the water demand for domestic use has increased by more than six-fold (Piesse, 2020). According to Islam and Karim (2020), it is estimated that the demand of the global population on clean water will reach 5425 km3 in 2050, which is a raise of 55% since 2000.

On top of that, the water resources have been reducing due to the increase of human activities, including agricultural activities and industrial processes. Water is a necessity in agricultural activities, especially for irrigation. As the global population increases, the agricultural activities also increase to keep up with the global demand for food, which is expected to increase about 59% to 98% (Valin et al., 2014). Besides, the agricultural activities are also affected by increase of calories intake and demand for more complex food due to the growth of income. Hence, it is approximated that the agricultural activities have to expand by 70% in 2050 (The World Bank, 2020). At the same time, the industrial activities are also growing. Among the industrial activities, energy generation makes up three-fourth of the industrial water demand, while the rest is contributed by manufacturing (United Nations World Water Assessment Programme (WWAP), 2014).