IMPROVISATION OF SOLAR STILL: CLEAN WATER PRODUCTION

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DECLARATION

I declare that this thesis is an original report that been written by me and submitted to Universiti Malaysia Sabah as a partial fulfilment for my degree studies. The work presented in this report is completely my own except for the formulas, quotations and summaries otherwise been stated by reference.

1st July 2022

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Peter Advent Stephen

1st July 2022

ABSTRACT

The growth of population globally causes the increase needs of clean water since clean water are needed to be consumed for hydration and for agricultural purposes. Water desalination is a process for producing clean water and the solar water desalination are the method that uses renewable energy source, which is the solar radiation. Improvisation of Solar Still are done throughout this study. Three different Solar Still were designed based on literature reviews. Then all three designs are compared for its feasibility. Several factors are considered and justified before the fabrication of Solar Still. Alongside with the Solar Still, a solar absorber is also implemented, which is made from cotton towel and carbonized sawdust with 55 wt.% of carbon. Then, the Solar Still are tested with seawater sample that is taken from coastal areas of Universiti Malaysia Sabah. Under illumination of the sun for 4 hours, at 10 minutes intervals, readings of evaporation surface temperature and solar radiation were recorded along with the total mass loss of seawater and mass of obtained clean water. The results obtained from this research project shows that the implementation of solar absorber increases the efficiency of Solar Still when compared to bulk seawater setup. Additional features are added in stages which includes reflective surfaces and external thermal insulator and each added features increases the efficiency of Solar Still. The best performing setup, which is the Solar Still setup with solar absorber, reflective surface and external heat insulator shows the efficiency of 60.85%. The quality of produced clean water also examined in this research project and the salinity and pH of produced clean water ranging from 0.01 to 0.03 ppt and 7.41 pH to 7.71 pH respectively and this is within the standards that has been set by the World Health Organization. The fabrication cost for this Solar Still is approximately at RM134.22.

ABSTRAK

Penambahan populasi dunia menyebabkan peningkatan permintaan air bersih kerana air bersih diperlukan untuk tujuan penghidratan dan juga untuk tujuan sektor pertanian. Penyahgaraman air adalah satu proses untuk menghasilkan air bersih dan penyahgaraman air melalui kaedah suria adalah kaedah yang menggunakan sumber tenaga boleh diperbaharui iaitu sinaran suria. Pengoptimuman "Solar Still" dilakukan sepanjang kajian ini. Tiga Solar Still berbeza telah direka berdasarkan ulasan literatur. Kemudian ketiga-tiga reka bentuk dibandingkan untuk kebolehlaksanaannya. Beberapa faktor dipertimbangkan dan dibenarkan sebelum pembuatan Solar Still. Di samping pembuatan "Solar Still", penyediaan penyerap suria juga dilaksanakan, yang diperbuat daripada tuala kapas dan habuk papan dikarbonkan dengan 55 wt.% karbon. Kemudian, "Solar Still" diuji dengan sampel air laut yang diambil dari kawasan pantai Universiti Malaysia Sabah. Di bawah pencahayaan matahari selama 4 jam, pada selang 10 minit, bacaan suhu permukaan sejatan dan sinaran suria direkodkan bersama-sama dengan jumlah kehilangan jisim air laut dan jisim air bersih yang diperolehi. Keputusan yang diperolehi daripada projek penyelidikan ini menunjukkan bahawa penerapan penyerap suria meningkatkan kecekapan "Solar Still" jika dibandingkan dengan konfigurasi air laut pukal. Ciri tambahan diterapkan secara berperingkat yang merangkumi permukaan pemantulan dan penebat haba luaran dan setiap ciri tambahan meningkatkan kecekapan "Solar Still". Konfigurasi "Solar Still" dengan prestasi terbaik, iaitu "Solar Still" dengan penyerap suria, permukaan reflektif dan penebat haba luaran menunjukkan kecekapan sebanyak 60.85%. Kualiti air bersih yang dihasilkan juga diteliti dalam projek penyelidikan ini dan kemasinan dan pH air bersih yang dihasilkan masing-masing antara 0.01 hingga 0.03 ppt dan 7.41 pH hingga 7.71 pH. Nilai ini adalah dalam piawaian yang telah ditetapkan oleh Pertubuhan Kesihatan Sedunia. Kos fabrikasi untuk Solar Still ini adalah lebih kurang RM134.22.

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LIST OF ABBREVIATIONS

WHO	–	World Health Organization

LIST OF SYMBOLS

m_{evap}	–	Mass of evaporated seawater
A	–	Area
t	–	Time
$\dot{m}$	–	Total mass loss
η	–	Efficiency
h_{LV}	–	Enthalpy Change
I	–	Solar Radiation Intensity
C	–	Specific heat capacity of water (4.19 J kg^{-1} $°C^{-1}$)
T	–	Evaporation Surface Temperature (˚C)
T_0	–	Initial Surface Temperature (˚C)
h_{vap}	–	Enthalpy of vaporization at temperature T (kJ kg^{-1})

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CHAPTER 1

INTRODUCTION

1.1 Research Background

As the year goes by, the growth of population of humans will inevitably continue to rise, as for now, the estimated world population is around 7 billion people. Based on previous studies, it is shown that from 1960 onwards, the increase of water shortage cases has been quite rapid, which from 9 % (280 million people) in 1960 to 35% (2.3 billion people) in 2005, with the percentages are proportion to the respective total population (Kummu et al., 2010). A more recent information in 2015 shows that around 663 million people still have no access to safe drinking water sources even though lots of initiatives for making drinking water production facilities has been commenced (Guppy et al., 2017). With this drastic increase, water shortages are expected to continue its incline for the next following years.

Based on a report, annual rate of increase of water demand that has been happening over the 100 years has been around 1.8% (Boretti & Rosa, 2019). A model also suggests that the main drive that will cause increase in water demand will be agriculture, industry and domestic uses. (Wada et al., 2016). So, to counter this issue, one of the ways of increasing the amount of clean water availability is through desalination process. A report states that the most effective counter measure to the issue of clean water scarce is the desalination of seawater but the practicality of this process is quite low due to the expensive and energy demanding process. Moreover, the amount of people with dependency of desalinated sea water is only about 1% of the globally coastal living population which is very low (Boretti & Rosa, 2019).

One of the ways of desalination of seawater is through the reverse osmosis process, currently the reverse osmosis process is the most applied technology of seawater desalination (Tarnacki et al., 2011). This technology, however, have a big demand in costs, the cost to build a facility is quite expensive. A study of energy efficiency comparison of Memstill and Reverse Osmosis process shows that the

Reverse Osmosis desalination process assumed to be needing 2-3 kWh of electrical energy to work which also would vary depending on the plant size and operation (Tarnacki et al., 2011). This electrical energy demand will add to the operational cost of the Reverse Osmosis Process. Hence, this process is more suitable to be carried out in the industrial level due to the expensive cost.

A way around the financial constraint would be to make a smaller scale seawater distillation device with less operational cost. This can be done using the solar distillation process, a device that could do this is the solar still. The way that a solar still works is when the seawater evaporates due to the heat from the sun or known as solar heat and then condensed as a clean water, this device has low cost and can be made only using simple materials (Hunkyun, 2017). Several factors can be considered in designing the solar still, those factors including the inclination of the top cover plate, the thickness of the top cover plate, the materials selection, the selected solar absorber and many more.

Thus, making improvisation of a solar still is important to ensure the maximization of yield of collected clean water from seawater so that more clean water is available for consumption.

1.2 Problem Statement

Due to the growth in population, the demand of clean water increases due to the importance of clean water for living. However, there are limitations of natural fresh water that is available on this planet. Although the Earth has about 71 percent of its surface is covered with water, around 96.5 percent of water that is available on earth is consisting of salt water. There is a way to harness this large body of unconsumable water into consumable water, which is through desalination process. To desalinate sea water, the popular processes are distillation and osmosis. However, for the reverse osmosis process, the cost of building its facility and the operating needs is quite expensive, this is usually done in the industry level. A cheaper alternative for this is to use solar distillation process, which by just using the solar energy to desalinate the seawater, the device that runs this process is the solar still. By making an improvisation of the design of solar still, more clean water can be obtained while using approximately the similar quantity of materials. This can help with the production of clean water especially for those with difficult access to it.

1.3 Research Objectives

The objective of this project is to:

1. Make improvisations on the design of solar stills, to maximize the yield of clean water collection.
2. To determine the efficiency of the Solar Absorber.
3. To examine the quality of obtained clean water, in terms of the pH and salinity levels.

1.4 Scope of Works

Scope of works were established as a way to regulate the flow of this project. The scope of works in this study includes:

i. Studying and reviewing past research papers that is related to Solar Stills as a guide for any considerations for the project.
ii. Planning of a Solar Still prototype which includes the material selections for the body of the Solar Still and for the heat insulating materials. Finding suitable geometric parameters of the Solar Still, such as the inclination angle of the cover plate and, the height difference between the Solar Absorber and the cover plate. Finally, determining the preferable operating method of Solar Still.
iii. Preparation of solar absorber by using carbonized sawdust.
iv. Planning and fabricating of the of the Solar Still.
v. Conducting of experiment, to determine the liquid-vapor efficiency and examining the quality produced clean water, in terms of its pH and salinity levels.
vi. Making documentation of the project.

1.5 General Research Methodology

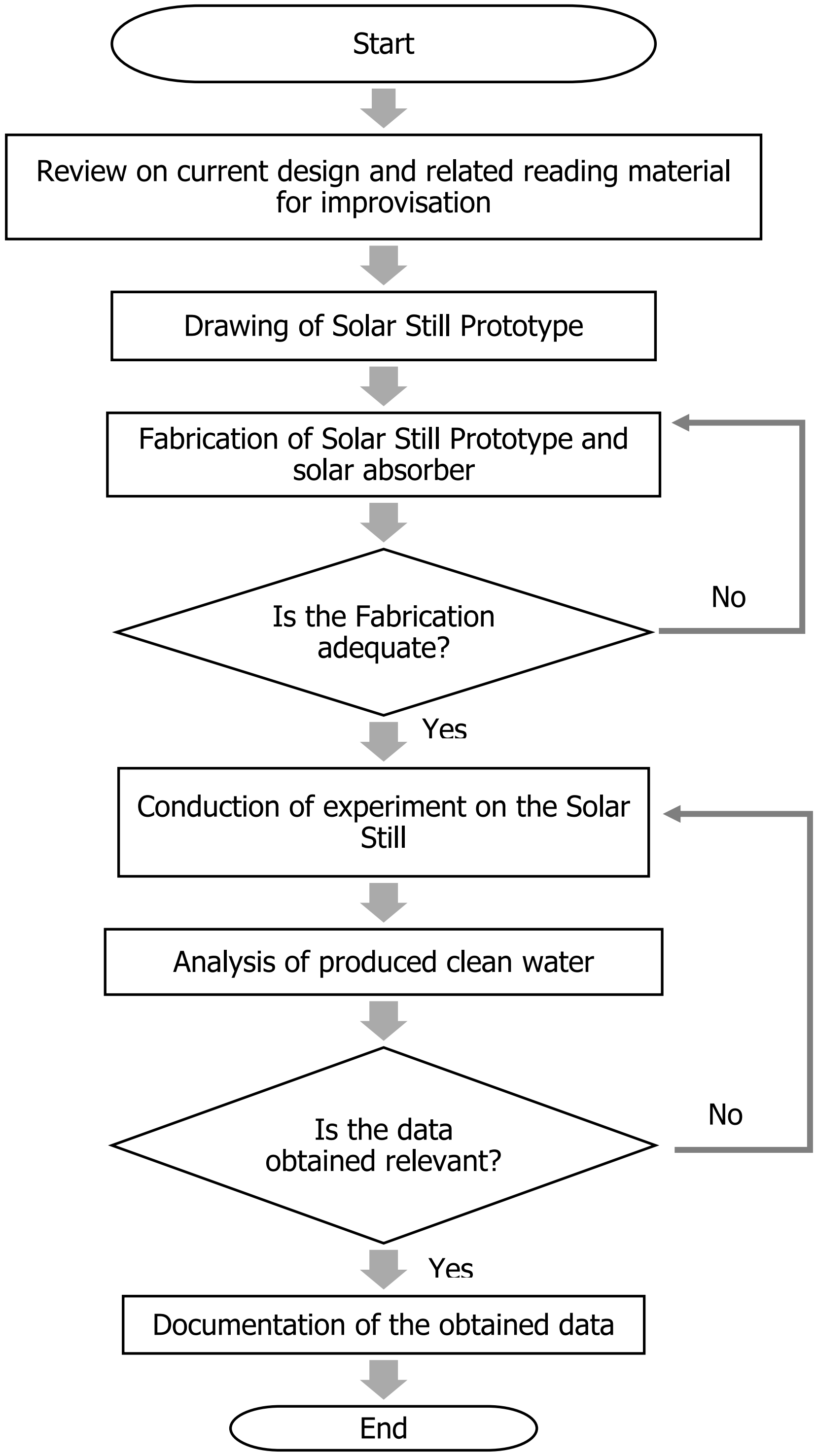

Figure 1.1: Flow Chart for general methodology

1.6 Research Commercialization

The commercial opportunity that would arise for this project are the low cost of production and fabrication of a device that is capable to produce clean water. The cost of operation of solar still are significantly lower compared to another method of water purification such as osmosis. Since solar still only depends on light energy from the sun, there are no additional costs for the operation cost. This project also would give an advantage for community living at coastal areas due to the availability of seawater at the coastal areas.

1.7 Thesis Organization

This report is divided into five different chapters with each chapter discusses the following contents:

Chapter 1 is a brief introduction for the information regarding to the research project, in which includes the project background, problem statement, objectives, scope of works and general methodology of this research.

Chapter 2 exhibits the literature reviews on previous related studies and research to figure out the parameters of design as well as several other factors in the developing a more efficient Solar Still.

Chapter 3 shows all of the process and procedures that has been carried out throughout this research project in which includes the fabrication, experimentation and data analysis of the Solar Still.

Chapter 4 presents the results and data obtained from experimentation throughout the research project and further discussion based on the obtained data are written throughout this chapter.

Chapter 5 conclude the overall writings in this research project and further suggestions for future improvements also written here.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review is carried out for the purpose of surveying on previous and existing studies related to Solar Still. This chapter will be discussing on the principle of solar still, external parameters that affecting productivity of a solar still and improvement to increase productivity of solar still.

2.2 Principle of Solar Still

Solar Still is a device that is used as one of the methods of water desalination. Most of water desalination methods that is used around the world such as Reverse Osmosis, Vapor Compression Distillation and Multiple Effect Distillation requires a high amount of energy demand. Compared to the solar distillation method, the solar distillation method do require some amount of energy but instead of producing energy for the purpose of evaporation of seawater, the Solar Still are able to harness the energy from the Sun, making it a more sustainable method for water desalination (Saidur et al., 2011).

The working principle of a Solar Still is quite the same with the natural hydrologic cycle that is occurring naturally every day (Khawaji et al., 2008). From the hydrological cycle, seawater is evaporated it receives heat energy from the solar radiation from the Sun. The evaporated seawater will then be condensed as it contacted with any cooler surface, usually far above the sea level and making it dissipate its internal energy, thus making the seawater vapor changes its phase to condensate water (Khawaji et al., 2008). By mimicking the naturally occurring hydrological cycle, a Solar Still is able to desalinate seawater.

A basic Solar Still is usually built in an airtight basin which usually filed with seawater, a transparent material that acts as a cover at the upper part of the basin and a collection chamber that collects desalinated water(Manchanda & Kumar, 2015). The desalination process that occurred in a Solar Still starts with the solar radiation rays from the Sun entering the airtight seawater basin through the transparent top cover, causing the seawater in the basin to absorb heat energy (Manchanda & Kumar, 2015; Singh et al., 2021). Then, along with the temperature increase of the seawater, the seawater will undergo the evaporation process which the vapor if seawater would only be consisting of purified water as it leaves the impurities such as salt and mineral in the brine (Manchanda & Kumar, 2015). Then when the evaporated vapor came in contact with the transparent cover, the vapor will change its phase from gas to liquid, forming water droplets at the inner surface of the transparent cover plate (Manchanda & Kumar, 2015; Singh et al., 2021). Then, due to the inclination of the transparent cover, the formed droplets will then be moved into the collection chamber due to the downward force by the gravity (Singh et al., 2021).

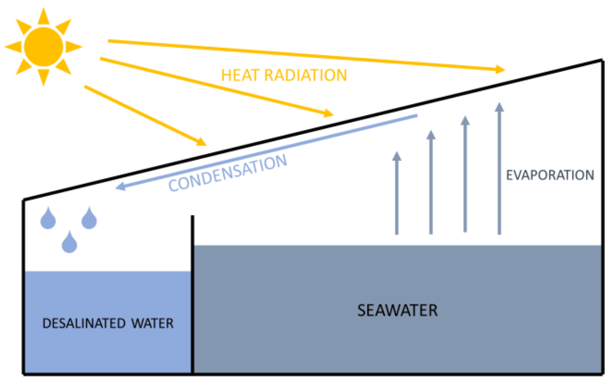

Figure 2.1: Working Principle of Solar Still

Source: Machanda & Kumar (2015)

2.3 Environmental Factors Affecting Performance of Solar Still

Solar Still is an instrument that could produce clean water while utilizing renewable energy source which is the sun. Unlike other water desalination methods such as Reverse Osmosis and Vapor Compression Distillation, Solar Still does not really dependent on any man-made mechanisms for the water production, but the clean water production is highly reliant on the environmental factors such as the intensity of solar radiation, wind speed, ambient temperature and cloud and dust cover.

2.3.1 Intensity of Solar Radiation

With the Sun being the only source of energy for a solar still to operate, the intensity of solar radiation will certainly affect the production of clean water by a Solar Still as the higher the intensity level from the sun, there will be more energy provided unto a Solar Still thus increasing the production of clean water (Jathar et al., 2021). Thus, many experiments that has been done on investigation of relationship between water production and intensity of solar radiation found that the productivity of a Solar Still increase as the intensity of solar radiation increase, making these two variables have a proportional relationship as increase in heat transfer increase yield of clean water (Singh et al., 2021).

2.3.2 Wind Speed

The speed or velocity of the movement of wind outside of the Solar Still is also one of the environmental factors that affects the performance of a Solar Still. Although wind does not provide direct energy for the evaporation of water, the movement of wind causes forced convection in which reducing the temperature of top glass covers making a more easier condensation process for clean water production (El-Sebaii, 2004). This is also supported by a numerical calculation study on effect of wind to the productivity of both passive and active Solar Still, in which, the study concluded that increase in wind speed increases the overall productivity of Solar Still (El-Sebaii, 2004). However, this relationship between wind speed and productivity of Solar Still is only applicable up to 5.5 m/s velocity of wind as decrement in productivity in water production in Solar Still are observed (Castillo-Téllez et al., 2015).

2.3.3 Ambient temperature

The temperature around the Solar Still could also be one of the factors that could alter the productivity of a Solar Still, although the effect of water production is not that large as only about 3% increase in Solar Still productivity can be observed per 5˚C increase of the ambient temperature (Nafey et al., 2000).