Journal of Engineering Technology and Applied Physics

Design and Development of A Hemisphere Flat Base Solar Thermal Water Distillation System

Shen Yee Pang, Wei Jun Teh, Tick Hui Oh* and Shing Chyi Chua
Faculty of Engineering and Technology, Multimedia University, Melaka, Malaysia.
**Corresponding author*: thoh@mmu.edu.my, *ORCiD*: 0000-0002-0823-1466
https://doi.org/10.33093/jetap.2024.6.1.7
Manuscript Received: 10 August 2023, Accepted: 26 September 2023, Published: 15 March 2024

***Abstract* — The clean water crisis around the world is mainly caused by the pollution and depletion of freshwater. There is only less than 1% of the water on Earth is in a pure and consumable state. Many people around the world actually die every single day due to the lack of access to clean, potable water and to proper sanitation which resulted in many waterborne diseases. Hence, water purification plays an extremely important role as access to clean water is fundamental to basic human rights. The objective of this paper is to develop a solar-thermal water distillation system with solar energy as its main power source to distilled water for safe consumption, hence achieving clean water purification through clean energy. The proposed hemisphere flat-based solar thermal distiller works well with the absorption of sun radiation from almost every angle with its spherical surface. The prototype works best under full sunlight conditions and is capable to purify water from various water sources to safe and ideal pH value for consumption. Solar radiation, being a clean energy and available in abundance at no cost, makes this design feasible for many and easy to scale up whenever the need arises. The simple working principle and fabrication at low cost also makes it an ideal solution in helping communities that have difficulty or no access to clean water supply.**

Keywords— Water distillation, Purification, Solar-thermal, Hemisphere

I. INTRODUCTION

It is common knowledge that human needs food, water and air in order to survive. Water is the only known substance that can occur naturally in gas and liquid in the form of water vapour and as a solid in ice form. Fresh water is normally available from rivers, lakes and underground water reservoirs although the distribution of water on Earth's surface is extremely uneven. Although 72.5% of Earth is covered in water, oceans hold about 95.5% of that. The rest exists in the air as water vapour (0.001%), in rivers and lakes (1.8%), in icecaps and glaciers (1.6%), in the ground as soil moisture and in aquifers. There are just 2.5% to 4% of the planet's water is safe for human consumption and 98.8% of that is in groundwater and ice [1].

Less than 1% of freshwaters is in lakes, rivers and the atmosphere layer. Although more than two-third of the Earth's surface is water-covered, the percentage for freshwater is extremely low. Studies and reports from the World Summit of Sustainable Development show that contaminations of water sources and the scarcity of freshwater itself are the major reasons for the lack of safe drinking water on the planet. Another contributing factor to this is found to be the inadequate maintenance and short of investment in proper water filtration systems. According to statistics, 50% of freshwater in the water supply systems is lost to non-legal hook-ups, leakages and vandalism in developing countries. In some countries, fresh and safe drinkable water is made accessible only to those who can afford to connect to the system, while the poor ones have to rely on either unsafe sources or the more expensive private sellers in the market. The United Nations Children's Fund (UNICEF) stated that short of access to clean and safe drinking water is having a grievous impact on children all over the world. From the latest report and statistic, there are around 2.2 million children die annually from diseases caused by unsafe water sources as well as water borne diseases [2]. Additionally, the World Health Organization (WHO) estimates approximately half of all peoples in developing countries are suffering from the diseases caused by poor or dirty water supply. This is a global issue that needs to be solved as everyone should have the rights to clean water access.

The objective of this project is to design and develop a hemisphere flat base solar-thermal water distillation system prototype that is capable to produce clean drinking water. Solar as a form of energy source that is readily available, is also green and creates zero carbon footprint and greenhouse gases. Thus, the utilization of solar energy in water distiller systems will be cheap, pollution-free, and rather efficient, depending on the environment and condition they operate in. At the same time, the prototype needs to be portable and light enough to be easily moved from one location to another. Affordability is also key during the fabrication process because cost and pricing need to be kept low as it is primarily targeted at those dwelling in third-world and developing countries in mind.

II. LITERATURE REVIEWS

Issues surrounding clean water accessibility and water source pollution around the world have led to numerous studies and research on water purification methods to produce clean and safe drinking water. Among them is the solar distillation method which is the most popular passive distillation system due to its simple operation, low maintenance and also environment friendly [3-7]. Solar itself is the most widely used and cleanest renewable energy available with zero pollutant released to the environment. Since there is no mechanical moving parts and control mechanism in a passive distillation system, no electricity is required for its operation. A solar distil system consists of a basin, in which a constant amount of seawater or impure water is enclosed in a glass envelope [8, 9]. When the water gets heated up through solar radiation, it will vapourize into the air. A transparent roof where the condensation will take place on its surface, traps all the vapour. In the end, the clean, purified distilled water produced from the condensation stage is collected for consumption or for other means of usages. Solar energy is also considered as a best and affordable solution to help solve the clean water shortages in remote areas where access to supplied electricity is limited. However, the low production rate and efficiency of such distil method has always posed a challenge to researchers [3, 7].

Throughout the years, researchers have developed various designs of solar distillation systems with the aim to increase the efficiency to meet safe water demand at an affordable cost. Among the more popular shapes of design are the inclined (see Fig. 1), stepped, tubular, pyramid, V-shape, spherical and hemispherical [3].

The main issue with the inclined design is the directional change of the sun radiation. Hence, some researchers have improvised by integrating a sun tracking system to it [10], while others explored the optimal inclined angle to maximize the output [11] and some proposed to use mirror on the inside wall to control the radiation losses [12]. The effect of dimension change in width, length and height of the still has been studied by [13]. The efficiency of the still improves when the length and width are increased but is inversely proportional to the increase in height. Besides this, a simple modification of stepped still with internal and external (top and bottom) reflectors proposed by Z. M. Omara *et. al.* [14] is able to increase the daily productivity of a stepped solar still by about 125% over a conventional still.

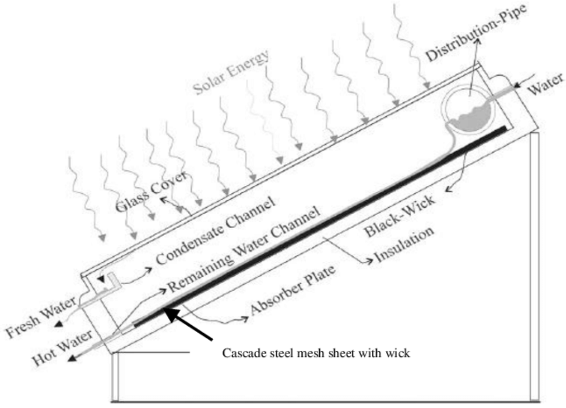

Fig. 1. Inclined solar distillation system [10].

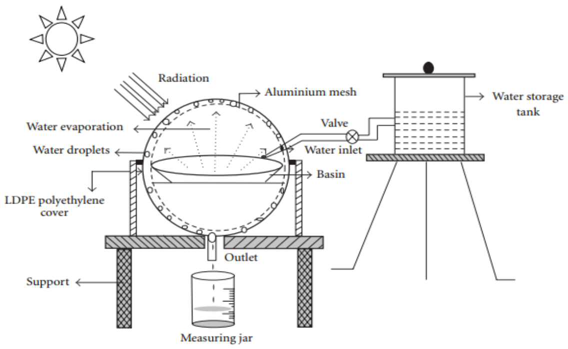

Fig. 2. Spherical design [9].

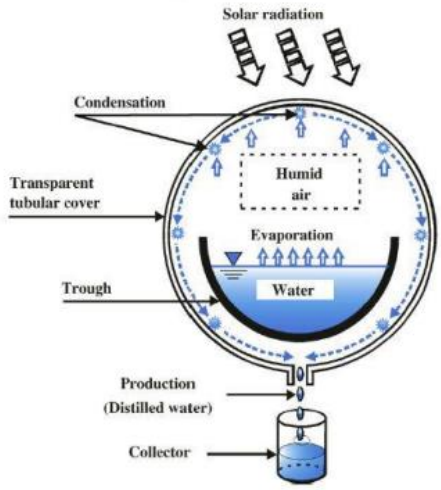

Fig. 3. Tubular design [16].

A spherical solar distillation unit with large and round collector area is illustrated in Fig. 2. The circular absorber basin is covered with black paint to enhance the absorption of solar radiation. The spherical design is used to absorb maximum sunlight from every angle. Basin in the spherical solar distillation unit is fitted without any contact with the top cover made of LDPE which is a type of low-density polyethylene sheet [9].

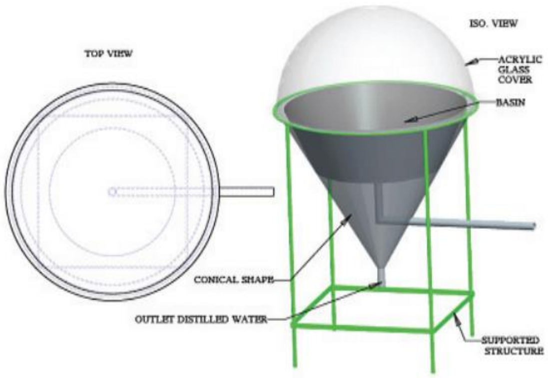

Fig. 4. Hemispherical design [14].

This spherical design is capable to absorb more sunlight on its overall surface in average compared to the inclined or stepped design [15].

Tubular solar still (TSS) in Fig. 3 was first proposed by Tiwari *et. al.* in 1988, and they proved that heat loss from the bottom of the TSS was much lower than a conventional basin still, for the basin was placed inside the tubular shell to form an insulation air gap between the basin and the shell bottom [16]. The latest improvised and more innovative self-sustaining solar TSS desalination system featured with water immersion cooling and vacuum operation revealed a greater improvement on existing desalination technique that includes a significant daily freshwater yield of 9.8 kg/m^2/d achieved at 40 kPa pressure, a maximum daily performance ratio of 1.87 and an extremely low estimated cost of \$0.012/L for the distilled water, as reported in [17]. Meanwhile, T. Arunkumar *et. al.* [18] found that the use of water cooling is more efficient than air cooling for the compound parabolic concentrator-concentric tubular solar still.

The hemisphere solar distillation system design in Fig. 4 also has hemisphere head to optimize solar radiation absorption. The water temperature and distillate production are in good accordance with the actual results of the experiment as presented in [19]. A study of water-cooling effect on hemispherical design with rectangular basin was carried out by Arunkumar *et.al.* [20], and found that the efficiency improved in the range from 34% to 42%. However, the drawback of this set up is water wastages that is used as cooling medium.

Figure 5 depicts the solar still that uses the shape of a pyramid as its main body structure for the process to take place. The pyramid design is a transparent glass that let the sunlight passes through and heat up the water. For larger condensing area, it reduces the side wall shadow effect within the pyramid solar still [5]. Although radiation tracking mechanism is not required in this design [9, 22], the problem is that, the structure is normally not that portable.

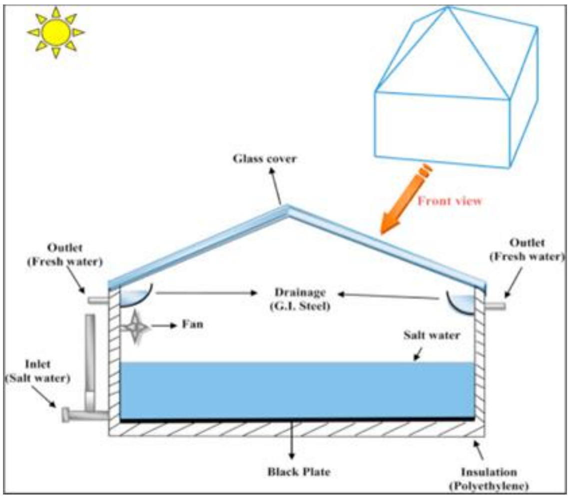

Fig. 5. Pyramid shape of solar distillation system [21].

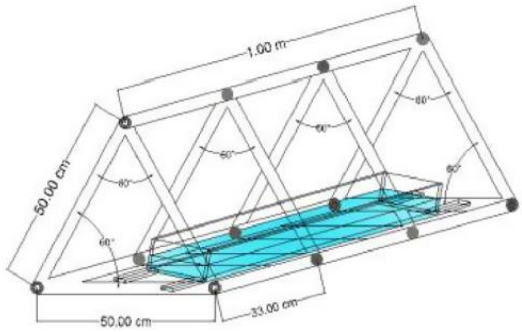

Fig. 6. Schematic diagram of triangular solar still [22].

A. Ahsan *et. al.* [23] investigated the parameters affecting a triangular water solar still such as solar radiation intensity, ambient air temperature and the initial water depth, and concluded that the daily water productivity is inversely proportional to the initial water depth but is nearly proportional to the daily solar radiation while ambient temperature has a relative effect on the productivity as well. These findings are further supported by another study of triangular pyramid solar still [24]. Nevertheless, it was found that increasing the wind speed from 1.5 to 3 m/s and to 4.5 m/s has the effect of increasing the still productivity by 8% and 15.5%, respectively [24].

Various methods on how to increase the amount of distilled water output have been studied and investigated by many researchers worldwide [25]. The common factors that affect the productivity of distilled water are basically based on climatic conditions such as solar radiation, windspeed, evaporation, condensation, and ambient temperature. Table I summarizes the productivity enhancement method for solar radiation, evaporation, and condensation rate from various studies. To optimize sunlight absorption, the solar stills were designed into different shapes and geometrical configurations including inclined, spherical, pyramid, tubular, and other wick types [9, 12, 19, 20, 21, 22, 24]. Water production and water temperature are found to be almost proportional to solar intensity [26]. But most enhancement methods for this factor have avoided incorporating sun tracking systems as it will cost much more.

Table I: Enhancement method for increasing productivity.

Factors Affecting Still Productivity	Enhancement Method
Solar radiation	• Slope and inclination angle [14, 35] • Sun tracking [10, 34] • Wick type design [9, 12, 19, 20, 21, 22, 24]
Wind Speed	• Install fan [26]
Evaporation	• Water depth [23, 26, 27, 28] • Storing material: Wick-type material added in stills (cotton cloth, jute cloth, clay pot) [25, 27, 29, 30], phase change material [31], Aluminium filling as thermal storage material beneath the absorber plate [32] • Energy absorption: solar air heater [32] • Internal and external reflectors [14], [26, 29, 33] • Concentrator [26, 29, 31, 34, 36]
Condensation	• Water-cooled, Air Cooled: cooling on top cover [18, 20], vacuum pressure [16, 17] • Area of condensation: Evacuated tube [4], increasing area of condensation surface [9, 37], fin [1, 15]

The water production of solar stills is inversely proportional to the depth of the water in the basin [26, 27, 28]. Materials such as jute cloth, charcoal cloth, mild steel pieces, and cow dung cakes are among the various more popular wick materials that are added to the stills to increase heat absorption and speed up the evaporation rate [25, 27, 29, 30]. Concentrators, solar water heating, and solar ponds help to increase temperature through the raised amount of absorbed solar radiation and significant results were reported in [26, 29, 31, 36]. Increasing wind speed by fan installation was studied in [26] and it also showed positive results in productivity improvement.

To increase the condensation rate, the simplest method is to increase the condensation area such as building an evacuated tube [4] and fin [1, 15] inside the stills. On the other hand, water-cooled top covers of stills are used to expedite condensation as the temperature is cooler, but this will result in more water wastage. There are also modern and advanced stills that apply vacuum pressure to accelerate the condensation process, but such system is meant for larger-scale distilled water production.

III. PROTOTYPE DESIGN

A solar still unit works on the principle of evaporation and condensation of water to produce safe-drinking water for user with balanced pH value with most of the impurities removed. Hence, the design of such solar still unit comprises few major components such as:

- Basin (absorber plate) where saline or impure water is placed
- Transparent glass or plastic cover
- Stable body base support
- Inert for the saline or impure water
- Collector of condensed water
- Outlet for purified water

In this design, a basin of certain volume is used for muddy water, impure water or saline water is placed for purification process. A transparent glass or plastic cover is used for sunlight to pass through it for the heat. Glazing or transparent plastic material will allow maximum possible solar radiations and minimize heat loss at the same time. Glass is used as the main material for the cover where the heat transfer takes place, because it can transmit more than 92% of the incident short waves radiation. Although glass is the most suitable material for the cover, it is costly and fragile compared to plastic material which is cheaper and tougher. Plastic is also durable enough to not break easily after sitting in the sun constantly. The schematic design of hemisphere flat base still and the completed prototype are shown in Fig. 7 and Fig. 8 respectively.

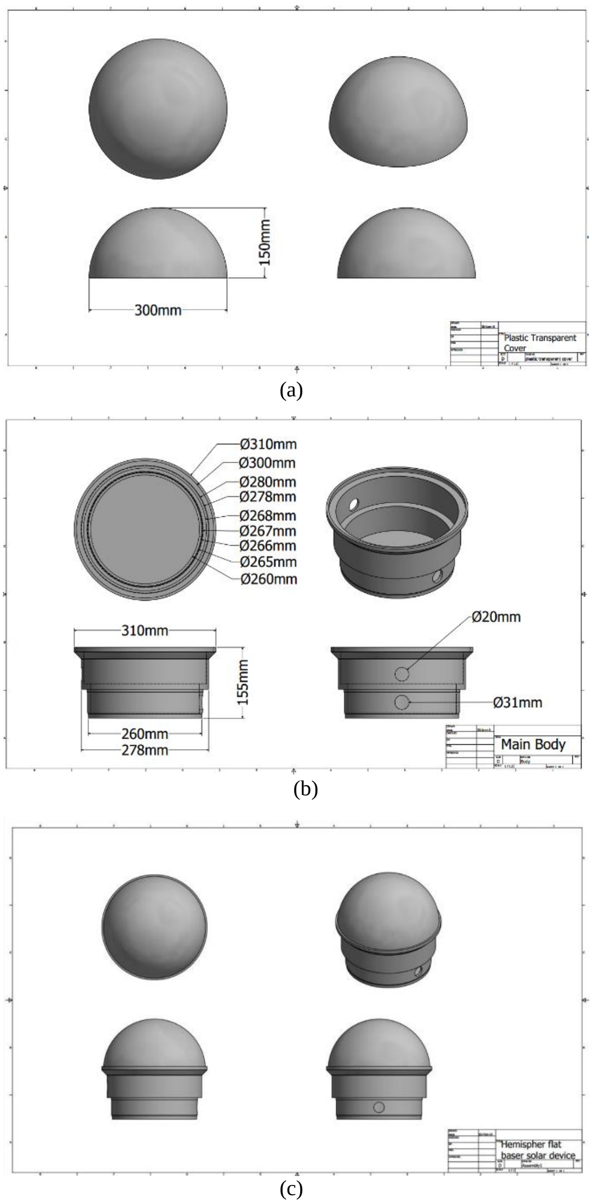

Fig. 7. 2D isometric view of (a) transparent polystyrene (PS) cover, (b) solar still base and (c) complete unit.

Fig. 8. The complete prototype design of the hemisphere flat based solar still structure.

IV. METHODOLOGY

Several experiments are set up to verify the reliability and functionality of the solar-thermal distillation system prototype. The effect of different types of production enhancements are also tested.

A. *Different Type of Water Sample*

To find out the performance of the prototype on different types of water is the main objective in the first experiment. There are four water samples used in this experiment; tap water (water that comes directly from a tap), river water (obtained from Melaka River), muddy water (water mixed with soil), and seawater (obtained from Klebang beach). The reason for using different water sources is because each of them has different composition and density. For example, seawater contains huge amount of salt which is formed by chloride, sodium, sulphate, calcium, magnesium and potassium, hence the term salinity is used to indicate the amount of salt content in it, which is defined as the amount of salt in gram dissolved in 1 kilogram of seawater. Normally, the salinity of seawater is in the range from 34 to 37 practical salinity units (psu). Because of this, the density of seawater is much higher than the other 3 types of water samples. On top of that, more impurities are also found in seawater and river water that would affect the distillation rate as well [8, 10]. Once all the water samples are collected, they are placed inside the basin and the prototype is placed in a fixed same position over a period of 2 days each, whereby the weather condition for each sample during their respective 2-day period was taken to be almost identical through weather forecast data. The amount of distilled water collected from each water sample is then recorded. Due to the rather lengthy test period and the uncertainties and sometimes inaccurate weather forecasts, only one test is conducted for each water sample type. There were incidents when a test has to start over again due to sudden unpredictable rain or lengthy period of cloudy condition, so that the data collected can be as accurate as possible for a meaningful comparison to be achieved.

B. *pH Test*

The pH value of water can provide the information whether the water is safe for consumption or not. For this test, pH test strips and alkaline acid 1-14 litmus test paper indicator strips are being considered. Both pH strip and litmus strip can be used to test the acidity of water, but with a minor difference; pH paper can give the pH value of the solution whereas litmus paper is a pass or fail type of test that determines if a solution is acidic or basic. The official pH scale is from 0 to 14, where 0 is very acidic and 14 is very alkaline. pH test strip will discolour after dipping into a substance, whereby the colour change is then referred to the indicator scale provided to determine how acidic or alkaline the substance measured. On the other hand, litmus paper is a strip of paper that can tell if a substance is either acidic (red) or alkaline (blue). During a test, the red strip turns blue if the solution is alkaline while the blue strip turns red if the solution is acidic. It can provide the fastest and cheapest way to know whether a solution is acidic or alkaline. In this test, pH papers are used.

C. *Functionality Test*

1. *Distilled Water Produced in Day Time*

This test gauges how much distilled waters can be produced by the prototype at different time interval over a span of a day. A period of 4-hour each at three different time intervals over a total span of 12 hours are being measured and recorded: morning (7am – 11am), afternoon (11am – 3pm), and evening (3pm – 7pm).

2. *Weather Effect*

The amount of condensed water collected has direct effect under different weather condition; sunny, rainy, windy, or cloudy day, as different weather conditions will have different temperature range, humidity and wind speed. All these attributes impact the condensed water collection and hence, the distilled water production as well. The experiment was conducted in January 2022 in Malacca, and all the weather's attributes are obtained from the AccuWeather website.

D. *Productivity Enhancement Test*

Two simple tests are conducted to study the feasibility in improving the productivity of the prototype; (a) use aluminium foil as a solar reflector sheet and, (b) cover the body of the prototype structure with black cloth to absorb more heat. Both tests are conducted on a same unit on two separate occasions. Aluminium foils or also known as tin foils, are paper thin, shiny surface aluminium metal sheets. Normally, they are made by continuously rolling huge slabs of aluminium to the thickness of less than 0.25mm. Aluminium foils serve many purposes, be it in industries or household applications that include packaging, transportation, and insulation, to name a few. One of the properties of aluminium foil is its shiny surface which means it is highly reflective and hence can be used as a simple solar reflector.

Furthermore, aluminium foil is easily shaped and adjusted to the desired angle to reflect sunlight.

Another enhancement is coming from the concept that dark-coloured body absorbs more heat in general, and black colour has the best absorption. Hence, a piece of black cloth is used to cover up the body of the prototype structure.

V. RESULTS AND DISCUSSIONS

A. *Different Type of Water Sample*

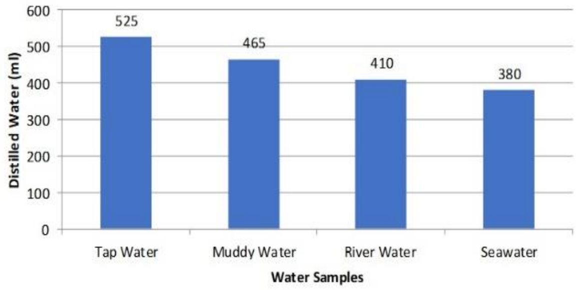

Fig. 9. Amount of distilled water collected from the four different water samples.

The amount of distilled water collected from each water sample and left for 2 days is recorded and illustrated in Fig. 9.

The result was collected over two sunny days with an average temperature of 30°C and more than 40 hours for each water sample. From Fig. 9, tap water recorded the highest amount of condensed water obtained (525ml) and followed by muddy water, river water and seawater. This is because tap water is already processed at water treatment plant and since that most of the impurities and tiny substances within the water have been filtered, hence the accelerated evaporation that resulted in highest volume of distilled water collected. Muddy water, which is basically a mixture of soil and tap water, ranks behind tap water in the volume of distilled water collected. The lowest volume of distilled water collected comes from seawater and this can be due to several factors; salt is nonvolatile substance which does not evaporate, and they stay in the solution. As such, unlike pure water, water molecules in seawater do not have large enough surface area to evaporate. Hence, seawater has the highest density among all water samples and will take longer time to evaporate compared to all the other samples.

B. *pH Test*

When the pH paper is dipped into the tap water, its colour changed from light yellow (neutral, pH value 7) to light green (pH value of 8), which indicates the tap water is slightly alkaline. Meanwhile, the discolouring of the pH paper on the seawater is more significant; from light yellow (neutral) to deep blue colour (pH value of 10 to 11), which showed that seawater is very alkaline due to the huge amount of salt content in it. Both river water and muddy water exhibited alkaline property by the colour change from light yellow to blue, whereby river water is slightly more alkaline compared to muddy water.

Distilled water is formed from the process of evaporation and condensation. The seawater will absorb the energy from the sun and transform into vapour state leaving most of the impurities and substances in the solution. The water vapour will then condense at the transparent cover and transform back into liquid form, which is the distilled water, and flow into the channel prepared due to gravity. Distilled water is tasteless, odourless, colourless and safe for consumption. Once distilled, all four water samples give the same neutrality as shown in Table II.

Table II. pH value test results.

Water Sample	Before Distillation			After Distillation		
	Colour	*pH*	*Property*	*Colour*	*pH*	*Property*
Tap	Light green	8	Alkaline	Light yellow	6	Neutral
Sea	Deep blue	12	Alkaline	Light yellow	6	Neutral
River	Light blue	10	Alkaline	Light yellow	6	Neutral
Muddy	Green	9	Alkaline	Light yellow	6	Neutral

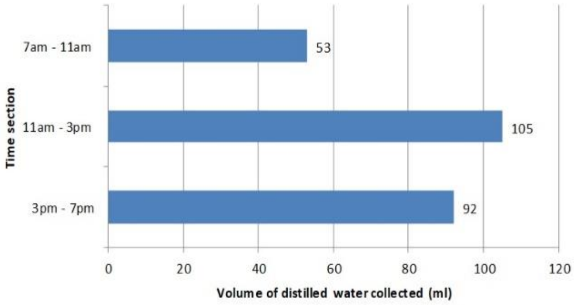

Fig. 10. Volume of distilled water collected on specific time.

C. *Functionality Test*

1. *Distilled Water Produced in Day Time*

The average temperature at each of the 3 intervals is recorded at 26.2°C, 31.2°C and 30.6°C, respectively. The solar-thermal prototype device was placed stationary under the sun and tap water sample was used as the reference in this test as we just need to find out how much difference of distilled water can be produced over the different time intervals. The volume of the distilled water produced is recorded and illustrated in Fig. 10. As to be expected, the highest volume of distilled water is produced between the 11am – 3pm interval because the temperature at noon can reach up to 35°C on a cloudless sunny day in Malaysia. This is evident with the highest average temperature recorded at 31.2°C, the highest among the three average temperatures. Solar radiation was the highest during that period, caused the water in basin evaporates the fastest and produces the highest volume of distilled water during that time interval. This test shows that the amount of distilled water produced is directly affected by the surrounding temperature at any given point of time.

2. Weather Effect

All the weather's attributes are obtained from the AccuWeather website and shown in Table 3. By referring to Fig. 11, the most favourable weather condition that resulted in the most amount of distilled water produced is on a sunny day when the temperature is at its highest while the humidity at its lowest. On contrary, the amount of distilled water produced on a rainy day is only around one-tenth (55 ml) of the amount produced on a sunny day (525 ml). This is to be expected because the higher the temperature, the more heat energy is being absorbed by the water molecules and this will hasten the whole process. Meanwhile, the evaporation rate is also affected by humidity, as higher percentage of humidity means higher content of water vapours and less space in between water molecules to move about to accelerate the evaporation process. Although the water produced on a rainy day is significantly low, the production on windy and mild cloudy weather conditions are not too far off from the sunny day, at 435 ml and 500 ml, respectively. Therefore, higher temperature and lower humidity are essential factors that contribute to higher distilled water production.

Table III. Weather data at different condition (sunny, rainy, windy and cloudy day).

Weather condition	Temperature (°C)		Humidity (%)	Wind speed (km/h)
	High	***Low***		
Sunny	33	30	60-70	5-6
Rainy	22	24	88-92	6-8
Windy	31	29	65-75	14-16
Cloudy	32	31	67-71	5-7

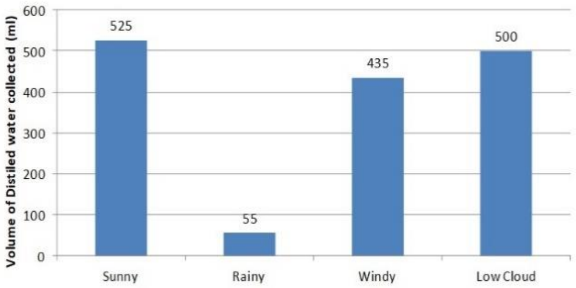

Fig. 11. Relationship between weather and the amount of distilled water produced.

D. Productivity Enhancement Test

An aluminium foil is used to direct more sunlight towards the transparent polystyrene plastic cover as shown in Fig. 12(a) in order to increase the evaporation rate. And then a piece of black cloth is used to cover up the body of the prototype structure as shown in Fig. 12(b) with the intention to maximise solar radiation absorption and retain more heat at the same time, to improve the evaporation rate of the prototype.

To compare with the earlier result (prototype in its original state without any enhancement) and to ensure consistent experimental set up, experiments were conducted on a sunny day with a recorded average temperature of around 30°C, over a span of 12 hours, divided into 3 intervals: 7-11am, 11am-3pm and 3-7pm. The outcome of these two set up are measured from the amount of distilled water collected. The data from these two experiments with enhancement are collected and compared with the data collected earlier in Fig. 13 with the prototype in its original state.

(a)

(b)

Fig. 12. Prototype is covered by (a) aluminium foil and (b) a piece of black cloth.

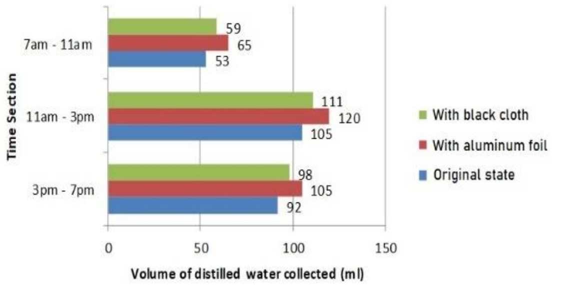

Fig. 13. Comparison of distilled water collected (ml) with different condition.

From data collected, it can be observed that once the aluminium foil is incorporated into the prototype, the distilled water production increases rather significantly as the foil is highly reflective and this directs more amount of sunlight towards the water in the basin. This maximises the amount of solar radiation onto the water surface and subsequently boosts the evaporation rate. With water molecules getting more energy from the sun and escape faster into the air in vapour form, more vapours are then condensed at the top transparent cover and thus, more amount of distilled water is produced. In the afternoon slot when the sun is at its strongest, the foil enhanced prototype is able to increase the production to 120 ml from the initial 105 ml when without any enhancement in place. Meanwhile, the usage of black cloth also improves the production, albeit in a lesser quantum to 111 ml.

VI. CONCLUSION

The proposed prototype of low-cost hemisphere-flat base solar distiller mainly targeted the poor in rural areas with three primary objectives. First and foremost is affordability. The people who need it the most must be able to buy one or fabricate one on their own at minimal cost. The idea is that it must be easily accessible by whoever needs it. If the technology involved is too complicated and costly, it will defeat the whole purpose of it in this scenario. The second objective is safety. The distilled water produced and collected from the prototype must be safe for human consumption all the processes involved do no harm to the environment. Finally, the last objective is, it must be portable and easily movable as many common solar distillers are fixated to a compound and bulky in size. Whereas our prototype has fulfilled this convenience criterion as it is compact and can be disassembled and assembled easily.

The performance evaluations of the prototype in converting tap water, seawater, river water and muddy water into clean drinking water for drinking have been presented. From the results, the solar still prototype has shown that the best productivity comes from processing tap water it has the least impurities. Yet, the time length of the other water samples is still fairly decent, considering all the distilled water produced have been tested safe for consumption, which is a more important aspect.

Since temperature and the weather parameters have direct effect on the amount of distilled water produced, some simple enhancements such as utilising aluminium foil or black cloth to the prototype do improve the outcome by a fair bit. The combination of aluminium foil to the structure as a sunlight reflector proved to be more efficient than covering the basin with a piece of black cloth.

REFERENCES

[1] M. Appadurai and V. Velmurugan, “Performance Analysis of Fin Type Solar Still Integrated with Fin Type Mini Solar Pond,” *Sustain. Ener. Technol. Assess.*, vol. 9, pp. 30–36, 2015.

[2] M. Huq and S. Ahmed, “Prospects of Incorporation of Nanoparticles in Molten Salt for Water Purification,” *Renew. and Sustain. Ener. Rev.*, vol. 82, pp. 2814–2819, 2017.

[3] H. Manchanda and M. Kumar, "A Comprehensive Decade Review and Analysis on Designs and Performance Parameters of Passive Solar Still," *Renew.: Wind, Water, and Solar*, vol. 2, no. 17, 2015.

[4] T. Arunkumar, H. W. Lim and S. J. Lee, "A Review on Efficiently Integrated Passive Distillation Systems for Active Solar Steam Evaporation," *Renew. and Sustain. Ener. Rev.*, vol. 155, no. 111894, 2022.

[5] A. K. Singh, "An Inclusive Study on New Conceptual Designs of Passive Solar Desalting Systems," *Heliyon*, vol. 7(2), no. e05793, 2021.

[6] R. Balan, J. Chandrasekaran, S. Shanmugan, B. Janarthanan and S. Kumar, "Review on Passive Solar Distillation," *Desalination and Water Treat.*, vol. 28(1-3), pp. 217–238, 2011.

[7] P. Kalita, A. Dewan and S. Borah, "A Review on Recent Developments in Solar Distillation Units," *Sadhana*, vol. 41(2), pp. 203–223, 2016.

[8] S. A. Kalogirou, "Seawater Desalination Using Renewable Energy Source," *Prog. Ener. Combust. Sci.*, vol. 31(3), pp. 242–281, 2005.

[9] T. Arunkumar, K. Vinothkumar, A. Ahsan, R. Jayaprakash and S. Kumar, "Experimental Study on Various Solar Still Designs," *ISRN Renew. Ener.*, vol. 18, pp. 1–10, 2012.

[10] K. Shalabi and A. Ghandour, "Improving Productivity of Solar Energy Distillation Still for Sea Water," *Int. J. Eng. Res. and Technol.*, vol. 5(9), pp. 498–502, 2018.

[11] R. Dev and G. N. Tiwari, "Characteristic Equation of A Passive Solar Still," *Desalination*, vol. 245(1–3), pp. 246–265, 2009.

[12] I. Al-Hayeka and O. O. Badran, "The Effect of Using Different Designs of Solar Stills on Water Distillation," *Desalination*, vol. 169(2), pp. 121–127, 2004.

[13] M. Feilizadeh, M. Soltanieh, M. R. Karimi Estahbanati, K. Jafarpur and S. S. Ashrafmansouri, "Optimization of Geometrical Dimensions of Single-slope Basin-type Solar Stills," *Desalination*, vol. 424, pp. 159–168, 2017.

[14] Z. M. Omara, A. E. Kabeel and M. M. Younes, "Enhancing the Stepped Solar Still Performance using Internal and External Reflectors," *Ener. Conver. and Manage.*, vol. 78, pp. 876–881, 2013.

[15] T. Suresh, A. Syed Abuthahir, A. Tamilazhagan, T. R. Sathishkumar, S. Jegadeeswaran and U. G. Scholar, "A Review on Modified Solar Stills with Thermal Energy Storage and Fins," *Int. J. Res. Eng. and Technol.*, vol. 4(10), pp. 1216–1236, 2008.

[16] G. Xie, L. Sun, T. Yan, J. Tang, J. Bao and M. Du, "Model Development and Experimental Verification for Tubular Solar Still Operating under Vacuum Condition," *Energy*, vol. 157, pp. 115–130, 2018.

[17] T. Yan, G. Xie, W. Chen, Z. Wu, J. Xu and Y. Liu, "Experimental Study on Three-Effect Tubular Solar Still under Vacuum and Immersion Cooling," *Desalination*, vol. 515, no. 115211, 2021.

[18] T. Arunkumar, R. Jayaprakash, A. Ahsan, D. Denkenberger and M. S. Okundamiya, "Effect of Water and Air Flow on Concentric Tubular Solar Water Desalting System," *Appl. Ener.*, vol. 103, pp. 109–115, 2013.

[19] H. N. Panchal and P. K. Shah, "Experimental and ANSYS CFD Simulation Analysis of Hemispherical Solar Still," *Int. J. Renew. Ener.*, vol. 8(1), pp. 1–14, 2013.

[20] T. Arunkumar, R. Jayaprakash, D. Denkenberger, A. Ahsan, M. S. Okundamiya, S. Kumar, H. Tanaka and H. S. Aybar, "An Experimental Study on A Hemispherical Solar Still," *Desalination*, vol. 286, pp. 342–348, 2012.

[21] K. H. Nayi and K. V. Modi, "Pyramid Solar Still: A Comprehensive Review," *Renew. and Sustain. Ener. Rev.*, vol. 81, pp. 136–148, 2018.

[22] G. Angappan, S. Pandiaraj, H. Panchal, T. Kathiresan, D. Ather, C. Dutta, M. K. Subramaniam, S. Muthusamay, A. E. Kabeel, A. S. El-Shafay and K. K. Sadasivuni, "An Extensive Review of Performance Enhancement Techniques for Pyramid Solar Still for Solar Thermal Applications," *Desalination*, vol. 532, no. 115692, 2022.

[23] A. Ahsan, M. Imteaz, U. A. Thomas, M. Azmi, A. Rahman and N. N. Nik Daud, "Parameters Affecting the Performance of A Low Cost Solar Still," *Appl. Ener.*, vol. 114, pp. 924–930, 2014.

[24] R. Sathyamurthy, H. J. Kennady, P. K. Nagarajan and A. Ahsan, "Factors Affecting the Performance of Triangular Pyramid Solar Still," *Desalination*, vol. 344, pp. 383–390, 2014.

[25] M. Jobrane, A. Kopmeier, A. Kahn, H. M. Cauchie, A. Kharroubi and C. Penny, "Internal and External Improvements of Wick Type Solar Stills in Different Configurations for Drinking Water Production – A Review," *Groundwater for Sustain. Develop.*, vol. 12, no. 100519, 2021.

[26] R. Sathyamurthy, H. J. Kennady, P. K. Nagarajan and A. Ahsan, "Factors Affecting the Performance of Triangular Pyramid Solar Still," *Desalination*, vol. 344, pp. 383–390, 2014.

[27] T. Rajaseenivasan, T. Elango and K.Kalidasa Murugavel, "Comparative Study of Double Basin and Single Basin Solar Stills," *Desalination*, vol. 309, pp. 27–31, 2013.

[28] R. V. Singh, S. Kumar, M. M. Hasan, M. E. Khan and G. N. Tiwari, "Performance of a Solar Still Integrated with Evacuated Tube Collector in Natural Mode," *Desalination*, vol. 318, pp. 25–33, 2013.
[29] T. Rajaseenivasan, P. Nelson Raja and K. Srithar, "An Experimental Investigation on A Solar Still with An Integrated Flat Plate Collector," *Desalination*, vol. 347, pp. 131–137, 2014.
[30] A. K. Singh, "An Inclusive Study on New Conceptual Designs of Passive Solar Desalting Systems," *Heliyon*, vol. 7(2), no. e05793, 2021.
[31] T. Arunkumar, D. Denkenberger, A. Ahsan and R. Jayaprakash, "The Augmentation of Distillate Yield by using Concentrator Coupled Solar Still with Phase Change Material," *Desalination*, vol. 314, pp. 189–192, 2013.
[32] A. S. Abdullah, "Improving the Performance of Stepped Solar Still," *Desalination*, vol. 319, pp. 60–65, 2013.
[33] H. Tanaka, "Monthly Optimum Inclination of Glass Cover and External Reflector of A Basin Type Solar Still With Internal and External Reflector," *Solar Ener.*, vol. 84(11), pp. 1959–1966, 2010.
[34] Z. M. Omara and M. A. Eltawil, "Hybrid of Solar Dish Concentrator, New Boiler and Simple Solar Collector for Brackish Water Desalination," *Desalination*, vol. 326, pp. 62–68, 2013.
[35] A. F. Muftah, M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed and K. Sopian, "Factors Affecting Basin Type Solar Still Productivity: A Detailed Review," *Renew. and Sustain. Ener. Rev.*, vol. 32, pp. 430–447, 2014.
[36] T. Arunkumar, D. Denkenberger, R. Velraj, R. Sathyamurthy, H. Tanaka and K. Vinothkumar, "Experimental Study on a Parabolic Concentrator Assisted Solar Desalting System. *Ener. Conver. and Manage.*, vol. 105, pp. 665–674, 2015.
[37] R. Bhardwaj, M. V. Ten Kortenaar and R. F. Mudde, "Maximized Production of Water by Increasing Area of Condensation Surface for Solar Distillation," *Appl. Ener.*, vol. 154, pp. 480–490, 2015.