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RESEARCH ARTICLE

DEVELOPMENT OF SOLAR DESALINATION SYSTEM BY USING BASIN SOLAR ENERGY

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ABSTRACT

Solar desalination is a process of removing salt content in brackish or saline water and converting it into fresh water by the aid of solar energy. The portable solar basin was utilized to undergo this process and the collected desalinated water was to be compared with the Drinking Water Quality Standard in order to identify the safety and cleanliness of the water produced. The main purpose of this study is to improve the solar basin designs which yield the optimum volume of purified water that achieve the quality of drinking water and low cost. The solar basin was designed with the angle tilt of 15° which it able to achieve maximum sun ray exposure. The solar basin that was used is the conventional type single slope with different component inside the solar basin (without stages and rocks; with stages and without rocks; and with both stages and rocks. The source of water be used in this process is seawater (Pengkalan Balak Beach), ground water (Cherana Puteh Hot Spring) and river (small stream of Sungai Siput). The basin solar design with steps and rocks able to produce maximum desalinated water up to 1120 ml per day with average temperature of 59.7 °C, almost 100% reduction of COD, TDS, conductivity, element traces of Ca, Mg, Na and K with BOD level of 1.55 mg/l which mostly comply with the drinking water standard.

KEYWORDS

Basin solar energy, desalination, solar still.

1. Introduction

Desalination is the solution used to supply potable water throughout the societies by treating the brackish water and removes impurities especially salts, traces metal and micro-organism. Based on the review that has been done by Sethi and Dwivedi about the previous research by Fritzmann and Mowla, the conventional techniques normally used for desalting the water and basically can be classified into membrane based and thermal categories (Fritzmann et al., 2007; Sethi et al., 2014). The techniques include multi-effect distillation (MED), multi-stage flash (MSF), vapor compression distillation (VCD), nano filtration (NF), the latter class comprises reverse osmosis (RO) and electro dialysis (ED). However, all these techniques need a huge input of energy and not effective in terms of cost, especially for a low demand for clean water.

In the thermal desalination, the removing of salts from water can be done by undergoes evaporation-condensation process which it utilized the solar energy for distillation and environmentally friendly. The solar powered distillation device consists of three elements which are the basin structure that contain the contaminated water, a smooth surface above the feed water (for the water vapor to condense: glass pane), and the gutter (channel) to collect the distilled water (Sethi et al., 2014). The use of non-conventional energy for the generation of clean water leads to the research where the device accessible which expends sun-oriented energy that known as solar still (Panchal et al., 2017).

Solar still is a device utilized in sun-oriented distillation process to produce clean water. This device is a cheap unit and can be built from the recycled materials from construction and demolition projects, and other cheap materials. The essential thought of a sun based still is that brine or grimy water in a hermetically sealed holder is warmed by solar energy, causing it to vaporize. Water vapor at that point condenses on a slanted glass covering surface, in order to permit clean water to flow into a collector. Since the pure water dissipates and the impurities do not, the water is distilled and making it secures to drink (Saito et al., 2014).

In this study presents the new approaches on developing the solar desalination system by utilizing three different designs of solar still with three different water resources testing. As the generation of clean water become an issue throughout the whole world especially for the region which far from clean water access, the solar desalination system has been keep developed by researchers and many modifications has been done for improvement up until now. The performance of the developed solar system has been observed for each design to identify which one give the best result for every parameter that be measures according to the standards of drinking water. The desalination system was tested not only specifically for the seawater, but also for the river water and groundwater.

The main type of solar still used is a conventional solar still without any additional component, the other two designs comes with different component inside of the solar still which one of it consist only step (stages), and the other one consists of step (stages) and rocks. This comparison was done in order to identify which solar still has the highest performance and has great contribution towards the research. All three solar still has fixed glass pane with angle tilt of 15° facing towards the sun according to the sun movement from East to West.

1.1 Scope of Study

This project required a lot of considerations regarding the weather, time consuming and the source of the water sample. Throughout these considerations, the solar still project has been implemented at the University of Kuala Lumpur - MICET's tennis court, each test starting from 9.00 a.m. till 6.00 p.m. daily for optimum result. This is due to the range of the time required for heating process will be as long as possible for the maximum yield of the clean water production. This project has been implemented within 27 days period for all design testing.

This project required to design and constructing the device system for the process of desalination (solar still) which at the end of the project, the yield and quality of water for three different solar still being compared. The main type of solar still used is a conventional solar still without any additional component, the other two designs comes with different component inside of the solar still which one of it consist only step (stages), and the other one consists of step (stages) and rocks. This comparison was done in order to identify which solar still has the highest performance and has great contribution towards the research. All three solar still has fixed glass pane with angle tilt of 15° facing towards the sun according to the sun movement from East to West. The solar still orientation was parallel to the sun movement, with the location was set with the coordinate of 2°27'14.2"N, 102°10'21.2"E.

Meanwhile, for the water sampling, there are three types of water involved in this process which are seawater, ground water and surface water (river water). All this type of water be taken at three different locations around Malacca which are Pengkalan Balak Beach for the seawater sample, Sungai Siput stream - near Taman Jati Indah Residential and as for the surface water source and for the groundwater source will be taken at Cherana Puteh Hot Spring. By taking a different source of water will have a different result in terms of water quality and the heating rate of the desalination process.

2. Material and Methods

The project starting from designing the basin solar model by using EDrawMax version 8.4 software in sketching 2-D design of the solar still and identifying the size based on the tilt angle. Then, proceed with the constructing and testing the solar still prototype. The temperature, volume desalinated water and water quality were analysed in comparing the performance of the solar still according to the different design. The water quality was tested by using Atomic Absorption Spectroscopy (AAS) in identifying the element traces (Na, Ca, K and Mg), the Biological Oxygen Demand-5days (BOD5) and Chemical Oxygen Demand (COD) in measurement of organic and inorganic materials in water. The Total Dissolved Solid (TDS), electrical conductivity (EC) and the pH value were measured, and all analysis were compared with the standard of drinking water according to National Drinking Water Quality Standard (NDWQS) by Ministry of Health Malaysia and also based on the International Standard Drinking Water by World Health Organization (WHO).

2.1 Sketching of Solar Basin Model

The 2-D design of the solar basin model was sketched by using EDrawMax version 8.4 software. The main point needs to be considered in order to initiate the drawing with the optimum angle of the glass pane tilt by adjusting measurement through simple trigonometric calculations based on Equation 1:

$$\sin A = \frac{Opposite}{Hypotenuse} \tag{1}$$

where, Sin A is the tilt angle (15°); Opposite is the basin length (cm) and Hypotenuse is the glass pane length (cm).

Figure 1 shows the details of solar still design sketched by using EDrawMax version 8.4 software. Besides, before designing the solar basin, all possible factors need to be considered in order to improve the solar basin system, especially in terms of rate, depth, surface area, coordinate and angle of maximum solar exposure, durability and portability of the model.

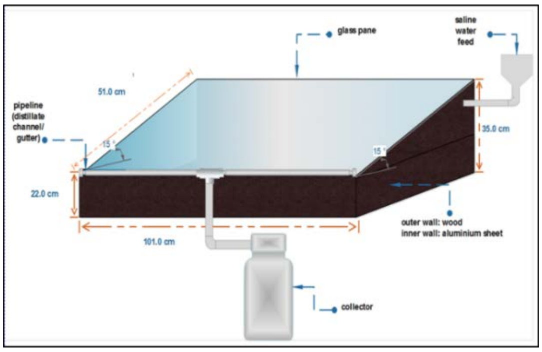


Figure 1: Solar still design sketched by using EDrawMax version 8.4 software.

2.2 Constructing the Solar Still

The basin frame was built up by using slotted angle bar. The slotted angle was cut to the length of 101 cm (2 pieces), 51 cm (2 pieces), 22 cm (2 pieces) and 35 cm (2 pieces). Then, all the slotted angle that has been cut was attached with each other forming into trapezoidal form by using bolts, nuts and bracxkets. The plywood was cut into the size of 101 cm × 51 cm and attach it as the base of the basin. The recycled wood was cut into the suitable size for the wall of the basin (refer Figure 2).

(a)

(b)

(c)

(d)

Figure 2: The construction of the solar still (a) Outer layer by using recycle material. (b) Black covered basin surface. (c) Aluminium basin liner. (d) Finished prototype.

2.3 Solar Still Testing

The basin was filled with the 5 L water sample through the feed pipe. Then, allow the evaporation process to occur for several hours, which in this process it was left for 9 hours, from 9 a.m. till 6 p.m. All three solar still has fixed glass pane with angle tilt of 15° facing towards the sun where the sun movement was from East to West, with the solar still position parallel to the sun movement with the location coordinate of 2°27'14.2"N, 102°10'21.2"E. The latitude, φ = 2.453944 and the longitude, λ= 102.172556. The evaporated water will form droplets of water on the inner surface of the glass pane and flow down towards the gutter at the end of the glass pane (refer Figure 3). The water in the gutter will be collected into the collecting basin for further analysis.

Figure 3: Solar still testing under the sun ray

2.4 Water Quality Analysis

The temperature of the solar still be recorded by using thermometer given (placed at thermometer port inside the solar still). The collected desalinated water sample was transferred into the measuring cylinder and the volume of each sample be recorded. The reading was repeated at least three times in order to obtain an average data at optimum condition. Then, followed by the pH by using pH meter, TDS by using TDS meter and electrical conductivity measurement by using conductivity meter.

As for the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), all the desalinated water samples taken does not required any dilution as it was originally clean. Therefore, the measurement of BOD of each sample has been taken directly by filling up 300 ml full of the BOD bottle. Meanwhile, for COD measurement, a low range COD vials which has maximum limit of 150 mg O_2/l has been used by adding 2.0 ml desalinated water sample into the digestion vial.

The AAS was used to identify the concentration of the Na, K, Mg and Ca presence in the water sample. The stock solution and the standard solution have been prepared for each chemical which for the Na, the 0.245 g of sodium chloride, NaCl being used and diluted into 0.25 ppm, 0.5 ppm and 0.75 ppm. Meanwhile, for the K, the 0.2 g of potassium chloride, KCl being used and diluted into 1 ppm, 3 ppm and 5 ppm. 2.5 ml of magnesium solution has been used for Mg determination by the dilution into 0.15 ppm, 0.3 ppm and 0.45 ppm. As for Ca, the 2.5 ml of Calcium solution has been used with dilution into 2 ppm, 4 ppm and 6 ppm.

3. Results and Discussion

Basically, most of the parameters that was observed throughout this process was part of characteristics which required in complying to the Standard Drinking Water as according to the third objective which to identify the characteristics of water to meet the standard of drinking water. All the parameters stated above was analyzed statistically through General Linear Model (Two-way ANOVA) method using Minitab 17 software in identifying performance of the solar basin in heating up the water sample until it undergoes further desalination process and complying with the standard and comparing the performance with the previous research with the same solar still type. Table 1 show the overall result obtained with the best performance (steps and rocks for seawater) of solar still (Anonymous, 2004).

Table 1: The overall result in complying with drinking water standard.

Parameter	Before desalination	After desalination	Percentage reduction (%)	National Drinking Water Standard (MOH)
pH level	7.94	4.9	38.29	6.5 - 9.0
Biochemical Oxygen Demand, BOD (mg/l)	2.16	1.55	28.24	-
Chemical Oxygen Demand, COD (mg/l)	160	0	100	-
Total Dissolved Solid, TDS (mg/l)	4840	6	99.88	1000
Conductivity (µS/cm)	9680	12	99.88	-
Na	273.90	1.112	99.59	200
Mg	9.154	0.400	95.63	150
Ca	40.920	1.086	97.35	-
K	134.50	0.536	99.60	-

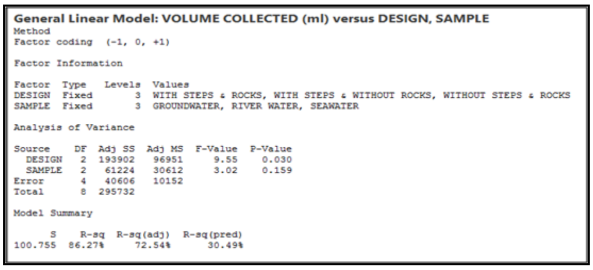
3.1 Temperature

The main parameter is the temperature measurement inside the solar still system because it is one of factor in order to undergo desalination process. The temperature was measured for each design of solar still tested with different water source for every 1 hour starting from 9 a.m. until 6 p.m. The solar still design with the stages (steps) and without rocks has achieved the highest temperature which is 61.3 °C that using the seawater as water sample, followed by the design with steps and rocks that achieved maximum temperature of 59.7 °C and the design without stages and rocks that only able to achieved maximum temperature of 52.5 °C for the seawater.

This is because the temperature changes affected by some factors which in this case, the presence of stages and rocks (specifically pebbles) absorb heat from the sun and release the heat to the surroundings (water) which it increases the heat of water. Thus, the increasing of heat leads to increasing the temperature of water for evaporation. Besides, by the usage of Aluminum sheet with black surface which act as conductor also absorb heat which helps in heating up the water.

3.2 Volume

The volume measurement of desalinated water obtained from each tested solar basin design was observed and based on the data obtained; it shows that the solar still with stages and rocks which using seawater has the highest yield of desalinated water which is 1120 ml. Meanwhile, the solar still that comes without the presence of stages and rocks has the lowest volume of desalinated water for all water samples which is below than 700 ml.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General Linear Model: VOLUME COLLECTED (ml) versus DESIGN, SAMPLE
Method
Factor coding  (-1, 0, +1)

Factor Information

Factor  Type   Levels  Values
DESIGN  Fixed       3  WITH STEPS & ROCKS, WITH STEPS & WITHOUT ROCKS, WITHOUT STEPS & ROCKS
SAMPLE  Fixed       3  GROUNDWATER, RIVER WATER, SEAWATER

Analysis of Variance

Source    DF  Adj SS  Adj MS  F-Value  P-Value
  DESIGN   2  193902   96951     9.55    0.030
  SAMPLE   2   61224   30612     3.02    0.159
Error      4   40606   10152
Total      8  295732

Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
100.755  86.27%     72.54%      30.49%
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Figure 4: The statistical analysis of volume by using General Linear Model (GLM).

The volume desalinated water collected from seawater sample gradually increase by every presence of component in each design. This shows that, with the presence of stages and rocks was basically can be the factors that helps in increasing the volume of desalinated water. This is due to the components absorb heat from the sun ray and release the heat to the water which increase in temperature of water. At particular temperature, the water will be vaporized, and volume desalinated water collected can be measure. According to the statistical test done by using GLM in Figure 4, the p-value for the solar basin design was 0.03 which it shows that (p - value < α =0.05). This indicates that there is a significant between the design and the volume of desalinated water collected. However, for the water sample, the p-value was 0.159 which shows that there is no significant between the water sample and the volume of desalinated water. As for the R-square value, the variation was quite high with 86.27 % in the respond. Meanwhile, the R-square (adj) is 72.54 % and the R-square (pred) value is 30.49 % which it shows that the data least fit to the model.

3.3 Total Dissolve Solid

The acceptance for TDS in drinking water may divided into several level rated by penal of testers which for the excellent: TDS less than 300 mg/l, good: 300 mg/l to 600 mg/l, fair: 600 mg/l to 900 mg/l, poor: 900 mg/l to 1200 mg/l and unacceptable: TDS more than 1200 mg/l (Graham, 1999). However, water with too low concentration of TDS also may not accept as it will become unpalatable. The TDS concentration may not affect human health yet, with zero of TDS concentration also not good as it does not contain minerals which needed by the body.

The seawater initially has high concentration of TDS which is 4840 ppm equivalent to 4840 mg/l. This indicates that the TDS for seawater is unacceptable and required a reduction by undergoes desalination in order to comply with the standard. Throughout desalination process with three different design of solar basin, the TDS able to reduce to 19 mg/l, 8 mg/l and 6 mg/l for the three consecutive designs without steps and rocks; with steps and without rocks; and with steps and rocks, respectively.

According to the Drinking Water Quality Standard by Ministry of Health Malaysia, the maximum allowance of the TDS value in drinking water is 1000mg/l. Therefore, based on the overall result obtained by applying the solar basin design in desalination process, it shows that the water follows the standard which all the concentration of TDS of desalinated water was 6 mg/l. In addition, the TDS of desalinated water was categorized under excellent level of palatability according to the World Health Organization which below than 300 mg/l.

3.4 Conductivity

The conductivity and TDS are related with each other where the conductivity measure the capability of water to allow electrical flow and used in measurement of TDS in identifying the ions presence in the water. As more presence of ions in the water, the water conductivity will be higher. The seawater normally has high conductivity as it consists of high ions content primarily sodium, chloride, calcium, potassium and sulphate ions.

The conductivity of seawater before undergoes desalination process was higher than other water sample, which is 9680 µS/cm as seawater has high TDS concentration as it consists of high constituents of anions and cations. Meanwhile, the conductivity before desalination process for groundwater is 405 µS/cm and river water with 305 µS/cm. After undergoes desalination process for each solar basin design, the water conductivity for all sample drastically drop to the range of 12 µS/cm to 58 µS/cm which is below than the maximum allowable conductivity for drinking water according to National Drinking Water Quality Standard, NDWQS which is 1000 µS/cm (Rahmanian et al., 2015).

3.5 pH value

The pH refers to the measurement of alkalinity or acidity of a solution by the measure of the concentration of the hydrogen ion. Even without the presence of solutes in the liquid water, the hydrogen ion, H+ and hydroxide ion, OH- able to be formed by breaking down few H2O molecules. This dissociation process in chemical equilibrium condition can be written as H2O (l) ↔ H+ + OH-. The pH measurement identified by the concentration H+ ions in the water which pH = -log [H+]. With high concentration of H+ ions causing the water turns acidic, thus lowering the pH value and high concentration of OH- leads to increasing of pH value (Hem, 1985).

The pH was changed with some of it lies within the range of optimum pH standard. However, most of the sample turns acidic after undergoes desalination which it fails to follow the standards. This indicates that the concentration of H+ ions was increased by undergoes desalination process. The pH value was not only affected by the concentration of H+ and OH- ions, it also affected by the temperature. This can be explained as the water undergoes auto ionization or self-ionization by changes of temperature, pressure or concentration. According to Le Chatelier's Principle, the disturbance of the equilibrium condition causing the system will respond by restore into new equilibrium state. As in this case, the increase of temperature causes the disturbance towards the equilibrium state which it increases the water ionization constant, Kw. The increasing of temperature cause shifting towards a lower temperature by absorbing extra heat in order to reach a new equilibrium state.

3.6 Biochemical and chemical oxygen demand (BOD & COD)

The BOD refers to the measurement of oxygen required or used by microorganism in degradation of organic material in wastewater, polluted water and effluents (Anonymous, 2001). The BOD measurement was done within the 5 days period for all water samples before and after desalination process. BOD is one of the criteria that required in complying with the standard. The BOD measurement also indicates the presence of microorganism (bacteria) in water which the BOD level increase when high oxygen used by microorganism in oxidation of organic material.

Meanwhile, the Chemical Oxygen Demand was used to identify the total oxygen used to oxidize all organic material. Basically, there is no specific limit of COD and BOD for the drinking water standards set by Ministry of Health Malaysia. However, the removal of COD and BOD are required in the water treatment process to ensure that the water is safe to be release to the environment and less pollute. A high BOD level will lead to increase of bacterial growth where the bacteria will affect other aquatic life by consuming oxygen in the water (Ismail et al., 2012).

The BOD level for all samples drop by undergoes desalination process except for the river water which was tested by solar basin design with steps and rocks where the BOD level increases. Initially, the BOD level of water samples was within the range of 2.16 mg/l to 2.59 mg/l, which basically below the allowable level of 6 mg/l by WHO. The BOD level drop to the range of 0.42 mg/l to 2.74 mg/l after undergoes desalination process which the water quality become much better and secure to be consumes.

The COD value of seawater was extremely higher than other water sample with the COD value of 160 mg/l. This is due to the high salinity presence in seawater. The COD level of seawater was drastically dropped to the range of 0mg/l to 5 mg/l which nearly to 100 % reduction after undergo desalination process by using solar basin. According to WHO drinking water standard, the acceptable COD value was 10 mg/l which shows that the COD level of desalinated water produced from seawater sample by using all three design of basin solar was comply with the WHO standard.

3.7 Traces of elements of sodium, magnesium, calcium and potassium

Sodium is one of the main constituents of element which normally exist in water. The seawater has high concentration of sodium and it is highly soluble. As desalination occur leaving behind the salts and other minerals that unable to vaporize in the solar still, the performance of solar still with different water source towards the reduction of mineral like sodium has been observed in different solar still design. In the seawater sample by using solar still with steps and rocks showing that it reaches the highest reduction of sodium by 99.59 % reduction which the sodium concentration in the seawater was initially from 273.9 mg/l to become only 1.11 mg/l. Meanwhile, the solar still design without steps and rocks has the lowest reduction of sodium with only 92.94 % reduction which reduced from 273.9 mg/l to 19.33 mg/l. According to the drinking water standards set by both NDWQS and WHO, the maximum allowable of sodium concentration was 200 mg/l. This shows that all the desalinated water produced for every design of solar still and water source able to follow both standards as the sodium content in all desalinated water produced was below than maximum allowable sodium concentration.

The magnesium concentration which initially with 9.154 mg/l for the seawater, 3.518 mg/l in the river water and negatively presence of magnesium in groundwater has been reduced nearly to 0 mg/l through desalination process which relatively below than the allowable magnesium concentration set by NDWQS with 150 mg/l and WHO with 500 mg/l maximum. Therefore, the desalination process able to reduce the magnesium content and achieving the drinking water standard.

The calcium concentration has been cut off for all tests with the highest reduction of 97.35 % calcium was obtained in seawater sample by using basin solar with steps and rocks from 40.92 mg/l to 1.086 mg/l of calcium concentration. Generally, the calcium is needed by human as it is important in bones, heart function, muscle system and teeth (Linkon et al., 2015). Therefore, the calcium in water sample are not necessarily have to be cut off as it needed by the body and most of the sample was initially has low concentration which already below the range of the standard (100 mg/l – 300 mg/l) set by WHO.

The potassium concentration in seawater sample has reduced from 134.5 mg/l to 0.536 mg/l which indicates that 99.6 % of potassium has be reduced by the utilization of solar basin with steps and rocks with seawater. Meanwhile, solar basin design with steps and without rocks able to achieve 99.136 % reduction and followed by solar basin design without steps and rocks with 98.553 % of potassium reduction through desalination process on seawater sample.

3.8 The best performance of solar still towards improvement from previous research

In achieving the main objective of the study which to improve and build up the existing solar basin design which yield the optimum volume of purified water that achieve the quality of drinking water, the best performance of solar still has been compared with the previous research (Hakim et al., 2018). Throughout the comparison, they could yield maximum of 1305 ml of desalinated water for solar still with the size of 100 cm × 50 cm. However, in this current project, it was only able to obtain maximum of 1120 ml of desalinated water with the same size of solar still (100 cm × 500 cm) by using basin solar designed with steps and rocks. The solar still designed with steps and rocks has not improve in terms of yield but it able to achieve most of the criteria according to the drinking water standard set by the NDWQS and WHO with the higher average temperature of 59.7 °C than the previous research with only 48 °C of average temperature. Table 2 shows the comparison of the parameters of desalinated water between the result of previous research and this study.

Table 2: The comparison result of desalinated water produced.

Parameter	Previous research by A.B.A. Hakim and M. E. Azni	This study

pH level	5.05	4.9
Biochemical Oxygen Demand, BOD (mg/l)	N/A	1.55
Chemical Oxygen Demand, COD (mg/l)	N/A	0
Total Dissolved Solid, TDS (mg/l)	N/A	6
Conductivity (µS/cm)	578	12
Traces of element:		
Na	142	1.1116
Mg	2.603	0.400
Ca	74	1.086
K	17.67	0.536

The criteria for the desalinated water produced has meet the standard as the result obtain was below the maximum allowable level. However, the pH of the desalinated water was out of the range of drinking water standard as it is quite acidic. These occur due to the water tends to lower the pH in order to achieve equilibrium state when in high temperature. The Calcium content also fall out of the range of the standard as the water sample was originally has low content of calcium before the desalination process.

4. Conclusions

In this study, the desalination process varies depending on the usage of different techniques and materials. Throughout this project, by improving the usage of material for construction with the usage of a black covered aluminum sheet with the additional insulator and additional of component presence in every design (steps and rocks), would help in increasing the heat absorption and also will increase the evaporation rate of the brackish water to be converted into clean water. Thus, increase the yield of the clean water production which up to 1120 ml with the maximum average temperature of 59.7 °C.

Furthermore, some recycle materials be used to construct the solar still which of course will reduce the cost for construction. The quality of desalinated water has been tested and most of the characteristic (BOD level, COD level, electrical conductivity, TDS level, and elements traces) has met the standard drinking water according to the NDWQS (MOH) and IDWS (WHO). Although the pH and calcium did not meet the standard, the desalinated water are still considered to be safe and secure to be consume as the pH and calcium content does not have adverse effect towards human health. Therefore, it can be concluded that this project able to achieve the all the objectives by improving the basin solar design, lowering the cost and met the drinking water standard.

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