Solar powered desalination system using Fresnel lens

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Abstract. The Philippines is surrounded by coastal areas and these areas can be a potential source for potable water. This study aims to design and construct a solar powered desalination system using Fresnel lens. The experimental study was conducted using polluted salt water for the sample and desalination was carried out using the designed system. The desalination system was composed of the solar concentrator, solar still and the condenser system. The Fresnel lens was made of acrylic plastic and was an effective solar concentrator. Solar stills made of dark colored glass bottles were effective in absorbing the solar energy. The condenser system made of polybutylene and polystyrene were effective in condensing the vapor at ambient temperature. The shortest time of vaporization of the salt water was at 293 sec and the optimum angle of position of the lens was 36.42°. The amount of condensate collected was directly proportional to the amount of salt water in the solar still. The highest mean efficiency of the designed set-up was 34.82%. The water produced by the solar powered desalination system using Fresnel lens passed the standards set by WHO (World Health Organization) for drinking water.

1. Introduction
The Philippines is an archipelago composed of about 7,107 islands and 18,000 km of coast line. Only 14% of these islands are inhabited but about 60% of the population live in coastal areas. These coastal areas provide food, livelihood and economic support to the people who live there but sometimes these areas can also be a threat to the populace when natural disasters occur. Natural disasters like typhoons, flash floods and drought can affect their day to day living when mass shortages of food, clean water and shelter happens.

Clean water is very important because the human body is composed principally of water which comprises about 60% of the body weight. The human body is dependent on water because it carries out the toxins from the vital organs, transfers the nutrients to the cells and provides a moist environment to the ear, nose and throat tissues. Humans need to drink an average of 2.5 liters of potable water per day in order to prevent dehydration [1].

Bacolod City is located in the northwestern coast of the Negros Island Region. BACIWA (Bacolod City Water District) is an agency that is mandated to maintain and operate the water supply and distribution systems for domestic, industrial, municipal and agricultural uses within the district of Bacolod. It has to supply about 1.25 million liters of water per day to the consumers in order to meet the average daily requirement of human consumption excluding other water requirements like cooking, bathing and washing. Presently, the Bacolod district is suffering from the effects of El Niño and BACIWA claims that there will be a water crisis by 2025 if other alternatives for water resources are not found [2]. Unfortunately, BACIWA can only serve about 42% of the population within the service area and about 28% within the service area cannot be supplied with water [3]. As a result, many people still do not have access to adequate supply of potable water because there is insufficient supply of potable water. There is a need to look for other sources of potable water.

The sun’s energy is a renewable energy source and this is free. Bacolod City receives on an average of 300 W/m² of incoming solar radiation [4]. This energy can be used in many ways and they offer minimal environmental problems. This renewable energy resource can be used to power a household desalination system using Fresnel lens.
Solar powered desalination technology using Fresnel lens is not yet developed and used in the Philippines. The plan to use the solar energy from the sun to power the desalination system is not new but the design of using Fresnel lens to speed up the evaporation rate has not been tested in the Philippines.

Harnessing the sun’s energy to power the desalination system using Fresnel lens can be another alternative source for potable water; therefore this study was conducted in order to determine whether a solar powered desalination system using Fresnel lens can produce potable water.

2. Materials and Methods
The study was divided into two phases. The first phase included the design and construction of the desalination system. The second phase of the study included the pilot testing of the solar powered desalination system and the testing of the parameters of the product from the solar powered desalination system as required by World Health Organization for drinking water quality.

The first phase of the research design involved the design and construction of the desalination system. The design set-up of the desalination system included the solar concentrator, the solar still, the condenser tubes, and the condensate collector. The illustration for the design set-up of the desalination system is shown below.

![Design set-up of the desalination system](image)

**Figure 1.** Design set-up of the desalination system

The solar concentrator was composed of the Fresnel lens and its support. Solar concentrator used was Fresnel lens that was made of acrylic plastic and had the following dimensions: 1067 mm high and 584 mm wide. The framed Fresnel lens was hinged to two galvanized iron pipes 857 mm high and spaced 792 mm apart. The hinges allowed the lens to rotate 360° in vertical motion. The galvanized iron stands were attached to a revolving disk made of galvanized iron pipe that rotated the panel in any direction and was about 190 mm high. The revolving disk was attached to two galvanized iron pipe supports spaced 792 mm apart. Galvanized iron was chosen because the stand had to be stable enough to support the lens even during windy conditions. See figure below.
The solar still that held the salt water were 1000 ml capacity dark colored glass bottles. Dark colored glass bottles have 92% heat absorption property [5]. Solar still holder was made of galvanized iron No. 22 with a gage thickness of about 0.79 mm. Condenser system was composed of the condenser tubes and the condensate collector. Condenser tubes were made of 12.7 mm diameter hose made of polybutylene. The condensate collector was made of 500 ml glass bottles enclosed in a polystyrene container measuring 240 mm x 300 mm x 330 mm. The polystyrene was 12.7 mm thick.

The second phase of the study included the pilot testing of the desalination system and the testing of the parameters. The design set-up was tested by adjusting the angle of the lens with respect to the altitude of the solar noon measured in degrees. The altitude of the solar noon was taken from the daily monitoring of the website of PAGASA and DOST. The angle of the lens was measured relative to the ground. The position of the sun varies every hour so three different angles were used in the experiment taken every 20 minutes per hour to determine the angle and the time at which vaporization starts. Testing time was only from 10 am to 2 pm. No definite angle was used because actual data was taken during the experiment. The angle of the lens and the time of the day with the shortest time of vaporization was deduced to be the optimum position for the design.

The desalination of the salt water was based on the optimum design set-up. The salt water from Purok Bolinao of Barangay Banago coastal area was tested for the following parameters before desalination.

Three different volumes of salt water were passed through the desalination system using the optimum position. The volumes were 300 ml, 500 ml and 600 ml based on the 1000 ml capacity of the still. Time of vaporization and the amount of condensate collected was determined for each volume of salt water that was tested.

The efficiency of the method was measured in terms of the energy required for the vaporization versus the energy of the sun’s radiation. Equation (1) was used to determine the efficiency:

![Figure 2. Design of solar concentrator](image-url)
Energy required for the vaporization of distillate recovered

Efficiency = \frac{\text{Energy required for the vaporization of distillate recovered}}{\text{Energy in the sun’s radiation that falls on the still}} \times 100\% \quad (1)

The efficiency was calculated for the different amounts of salt water used based on the energy required for the vaporization of distillate recovered per energy in the sun’s radiation that falls on the still. The formula of List was used to solve for the energy in the sun’s radiation and software developed by David Lawrence was used to calculate for the conditions required by List’s formula [6].

3. Results and Discussions
For the design set-up of the desalination system, the angle of inclination of the solar still with respect to the ground was maintained at 23° all throughout the experiment. Using this angle to distill the salt water proves that the sun’s position does not vary much in the Philippines [7].

Results of the study showed that the mean angle of the lens was at 39.5°. Vaporization time occurred faster between 11:40 am to 12:40 pm. Angle of the position of the lens also did not vary much at this period because Bacolod is situated on the equator so the sun’s position does not vary much in this location. The shortest time of vaporization was at 293 sec so the optimum angle of position of the lens was 36.42°.

Results of the condensate collected indicates that the amount of condensate collected was directly proportional to the amount of salt water in the solar still. Only about 25% of the salt water in the solar still evaporated and condensed. Evaporation is dependent on the solar energy emitted by the sun and this solar energy was affected because the experiment was performed during the rainy months. Furthermore, the sun moves farther from the equator during the last half of the year so the solar energy was not intense enough to increase the amount of vaporization. The figure below shows the relationship between the amount of condensate collected of the designed set-up and the amount of saltwater in the solar still.

![Figure 3. Amount of saltwater vs amount of condensate](image)

The graph above shows that the amount of condensate collected is directly proportional to the amount of salt water in the solar still. This means that more condensate can be collected if the amount of salt water in the solar still was increased. The reason behind this is that there is less air space above the liquid when the amount of salt water in the solar still is increased. Less air space indicates that fewer vapor molecules would come into contact with the air molecules thereby increasing the amount of liquid.
to vaporize. When vapor molecules become entrapped with the gases in the air space, their kinetic energies decreases leading to condensation back into the solar still.

The salt water was taken from the shores of Purok Bolinao in Barangay 1 of Banago. The sample salt water was slightly cloudy in color and presence of sediments were evident.

Table 1 shows the results of the parameters of the salt water that were tested:

| Parameter                  | Methodology          | Results     | WHO Standards |
|----------------------------|----------------------|-------------|---------------|
| A. Physical                |                      |             |               |
| Color                      | colorimetric         | 126 PtCo units | 5PtCo units  |
| turbidity                  | nephelometric        | 44.7 NTU    | 5 NTU         |
| B. Chemical                |                      |             |               |
| chloride                   | titrimetric          | 2615 ppm    | 250 ppm       |
| Iron                       | spectrophotometric   | 0.37 ppm Fe | 1 ppm Fe      |
| manganese                  | spectrophotometric   | 0.80 ppm Mn | 0.5 ppm Mn    |
| pH                         | electrode membrane   | 7.21        | 6.5 – 8.5     |
| sulfate                    | spectrophotometric   | 370 ppm     | 250 ppm       |
| total dissolved solids     | electrode membrane   | 664 g/L     | 500 g/L       |
| C. Bacteriological         |                      |             |               |
| Most Probable Number       | Multiple Tube Fermentation Technique | 21.6 x 10⁴ MPN/100 ml sample | 0 – 50 MPN/100 ml sample |

Results of Table 1 shows that concentrations for color, turbidity, chloride, manganese, sulfate, total dissolved solids and most probable number for the salt water were higher than the standard values set by World Health Organization for drinking water. High concentrations for these parameters indicate the presence of pollutants in the salt water. The high level of MPN is due to the fact that people living near the coastal area of Purok Bolinao do not have access to proper sanitary disposal systems so direct dumping of waste water is directly done into the seawater. The existing characteristics of the salt water in Purok Bolinao implies that it was not potable since it did not pass the standards for drinking water set by WHO.

The condensate collected was observed to be colorless and very clear. Table 2 shows the results of the parameters of the condensate that were tested.

| Parameter                  | Methodology          | Results     | WHO Standards |
|----------------------------|----------------------|-------------|---------------|
| A. Physical                |                      |             |               |
| Color                      | colorimetric         | 9 PtCo units | 5PtCo units   |
| turbidity                  | nephelometric        | 5.35 NTU    | 5 NTU         |
| B. Chemical                |                      |             |               |
| chloride                   | titrimetric          | 30 ppm      | 250 ppm       |
| Iron                       | spectrophotometric   | 0.03 ppm Fe | 1 ppm Fe      |
| manganese                  | spectrophotometric   | 0.4 ppm Mn  | 0.5 ppm Mn    |
| pH                         | electrode membrane   | 7.11        | 6.5 – 8.5     |
| sulfate                    | spectrophotometric   | 2 ppm       | 250 ppm       |
| total dissolved solids     | electrode membrane   | 7 g/L       | 500 g/L       |
| C. Bacteriological         |                      |             |               |
| Most Probable Number       | Multiple Tube Fermentation Technique | < 1 | 0 – 50 MPN/100 ml sample |
Results of Table 2 shows that all parameters passed the standard value set by WHO standards for drinking water except for color and turbidity. The condensate is slightly turbid because its value is 7% higher than the accepted value but the value for color is higher than the accepted value. Color is an aesthetic parameter which means that it is an indication of the presence of a coloring matter in the water. Since the bacteriological parameter passed the test, the presence of color may be due to matter of chemical origin. The presence of this chemical was not tested since the parameters set by WHO were just limited to the parameters mentioned in Table 1.

The characteristics of the condensate produced by the designed set-up using the Fresnel lens implies that it is potable since it passed the standards for drinking water except for the aesthetic parameter. Table 3 shows the mean efficiency of the designed desalination set-up using different amounts of saltwater.

| Amount of Saltwater [ml] | Efficiency [%] |
|-------------------------|----------------|
| 300                     | 17.18          |
| 500                     | 29.44          |
| 600                     | 34.82          |

Results of Table 3 shows that the greatest amount of salt water had the highest efficiency for the designed desalination set-up. This was due to the fact that the greatest amount of salt water in the experiment had the greater heat requirement. The amount of heat required to vaporize the salt water was dependent on the amount of condensate recovered. The energy required to vaporize the salt water increased because it was directly proportional to the amount of salt water used in the operation.

The low efficiency of the designed set-up implies that the solar powered desalination system was dependent on the solar energy.

4. Conclusions
The design set-up for the solar powered desalination system using Fresnel lens can desalinate saltwater. Fresnel lens made of acrylic plastic can be used as a solar concentrator for a solar powered desalination system. Solar stills inclined at 23° with respect to the ground can optimize the vaporization angle if location of operation is in the Philippines. The shortest time of vaporization was at 293 sec and the optimum angle of position of the lens was 36.42°. The amount of condensate collected was directly proportional to the amount of salt water in the solar still. The design set-up for desalinating the salt water using the Fresnel lens was effective in removing the pollutants. The design set-up for the solar powered desalination system produced a condensate that passed the standards set by WHO for drinking water.

5. References
[1] Hammer M 2007 Water and Waste-Water Technology 3rd ed. (New York : John Wiley & Sons)
[2] Lipa M 2010 Water crisis in Bacolod City Interview TV Patrol Bacolod City
[3] Information on http://www.baciwa.com.ph
[4] Information on http://fuzo.com/science/RadIntro.htm#List
[5] Green D W and Perry R H 2008 Perry’s Chemical Engineer’s Handbook, 8th Ed. (New York : McGraw-Hill International)
[6] List R J 1971 Smithsonian Meteorological Table (Washington : Smithsonian Institution Press)
[7] Information on http://www.sciencedirect.com/science