DEVELOPMENT OF SOLAR POWERED WATER PURIFICATION SYSTEMS

K Dikgale, D.F. Ntobela, BGV Mendes, LK Tartibu, TJ Kunene, E Bakaya-Kyahurwa
Mechanical Engineering Technology Department, University of Johannesburg, Doornfontein Campus, Johannesburg, South Africa
E-mail: ltartibu@uj.ac.za

Abstract

In this paper, we highlight the effects of contaminated water on humans as well as the crisis of water supply and distribution of potable water in many areas of developing countries. Water is the most important substance on earth. While water is a primary human need, contaminated water can cause and spread diseases. It is, therefore, necessary to ensure that water is purified and decontaminated for daily use at a low-cost. Therefore, the design of solar-powered water purification systems is considered to produce clean water. Solar energy poses no polluting effect; thus, has become a dependable energy source for usage. The design of a solar-powered water purification system is based totally on the thermal method by using the thermal heating system principle. This principle converts sunlight rays into heat. The most vital aspect is the absorption of heat to induce evaporation of water. Research shows that flat plate collectors produce heat at relatively low temperatures (27°C to 60°C) and are commonly used to heat liquids. A solar-powered water purification system consists of a solar collector that absorbs sunlight to ensure vaporisation which is the first stage of purifying and a filter that removes contaminants. Four different concepts have been developed. A detailed description of the components and the operation of the systems constitute the main contribution of this paper.

Keywords: Solar photovoltaic, thermal, solar collector, water purification

INTRODUCTION

Water is the most important substance on earth. Humans are fully dependent on water to survive and to live healthily. This makes water to become very scarce since water is used daily. Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids as well as gases from water. Research shows that to maintain a healthy lifestyle, an average male/female consumes approximately 3.7 litres/2.7 litres of water per day (Sawka *et al*, 2005). With many areas not connected to the electricity grid, particularly in developing countries, access to clean de-contaminated water is a crucial problem. Therefore, it is necessary to develop a water purification system that disinfects and cleans biologically contaminated water through the utilization of a readily available energy source, the sun.

The development of a sustainable system that will purify water, which is relatively easier to manufacture, easy to maintain, while relying on a readily available power source (like solar energy) is necessary. Although it is not a permanent solution, such a system will assist to improve the quality of human life. Solar energy poses no polluting effect and has emerged as a dependable energy source for usage. A solar water purification system consists of a solar collector that absorbs sunlight to ensure boiling which is the first stage of purification and a filter that removes contaminants.

LITERATURE REVIEW

A power of approximately $1.8X10^{11}$ MW is intercepted by the earth from the sun (Mohanta *et al*., 2015). This power is greater than the earthly consumption of all commercial energy sources. This makes the solar power source reliable as an energy source. A solar-powered system will alleviate diseases and provide clean water for basic needs. There have been several concepts developed in previous studies. The challenges and opportunities of developing Photovoltaic (PV) powered water purification were discussed by Forstmeier *et al*. (2007). The fluctuation of the PV energy source was identified as the main challenge for the development of such a system. However, the results reported pointed out the potential of this sustainable water purification approach. A Solar-powered portable water purifier was developed by Saraceno (2005). The solar cell was used to supply power to the system. This power was used to operate a pump and facilitate the supply of water to the purifying radiation source. Wright (2011) proposed a water purification apparatus that consists of a purification filter and solar-power system to purify water. A photovoltaic powered reverse osmosis system (PVRO) was designed and tested in the rural community of Mexico (Elasaad *et al*., 2015). This study gives an insight into the designing of PVRO systems and their deployment in rural communities. A solar-powered water purification system comprising a distillation unit able to produce potable water using solar radiation was developed by Joseph *et al*. (2012). The performance evaluation of 16 solar PV-powered drinking water system was performed by Jaskolski *et al*. (2019). While this study shows that the solar PV-powered system removes successfully ion from water, it appears that chlorine levels depend on the location. This literature describes the development of solar-powered water purification systems and provides evidence of the feasibility of such endeavour.
Solar water purification by thermal method uses the thermal heating system principle. This principle converts sunlight rays into heat. Flat plate collectors can produce heat at relatively low temperatures (< 60°C) and are commonly used to heat liquids (Rockenbaugh et al. 2016). The system is powered by the sun to remove contaminants in water. The process consists of boiling water using a solar collector that absorbs heat as a first step of the purification followed by filtration to remove contaminants (Thorat, 2006). A typical illustration of the water solar-powered water purification process is shown in Figure 1.

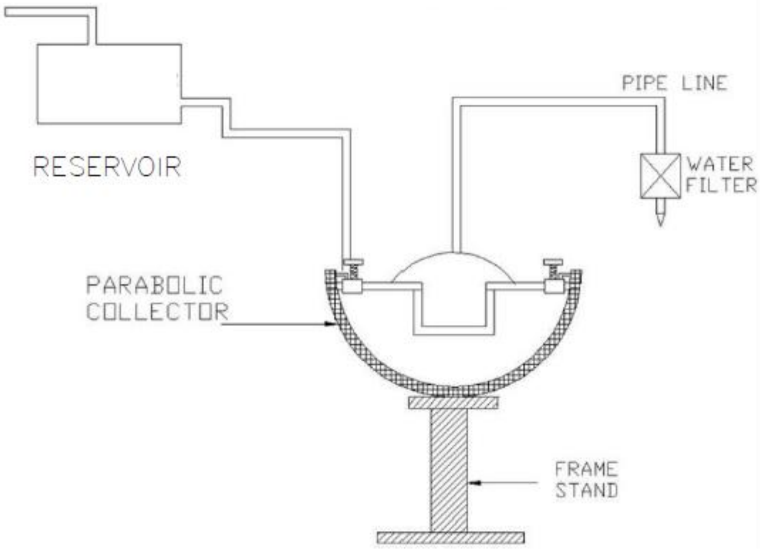


Figure 1*: Typical solar-powered water purification model (Adapted from Thorat, 2006)*

Water purification can happen through solar water distillation processes, solar stills as well as solar water disinfection systems. Solar water disinfection (SODIS) was analysed by Fisher et al. (2016). This study report promising results related to water disinfection. Solar water disinfection system (SODIS) is a water purification system at the household level based on solar radiation treatment and water distillation with the additional use of solar heating. It is a combination of two water purification processes, the Solar Water Disinfection System (SODIS) and the solar distillation process. SODIS has proven to be effective to disinfect small quantities of low turbidity, and micro-biologically contaminated water (Zhang et al. 2018). The provision of additional heat makes such a system suitable to deal with heavily contaminated waters (such as seawater, water with high turbidity, and water contaminated by heavy metal or pathogenic microorganisms).

MOTIVATIONS

Water is described as one of the essential needs for the survival of humans, animals, and plants. Without water, there is no life. The level of water in the major dams and rivers is dropping daily around South Africa. This limits the supply of drinkable water to the users, especially in rural areas. Also, the connection to the electricity grid is challenging in many areas. Hence, the development of a solar-powered water purification system by using the thermal method would be useful.

METHODOLOGY ADOPTED FOR THE DEVELOPMENT OF CONCEPTS

Most of the existing water purification systems are based on the distillation method, chemicals purifying method, condensation method with boilers to aid in fast purification. The "solar water distillation" method is illustrated in Figure 2 (Kumar & Bai, 2008). A similar layout was adopted while developing the design concepts described in this paper.

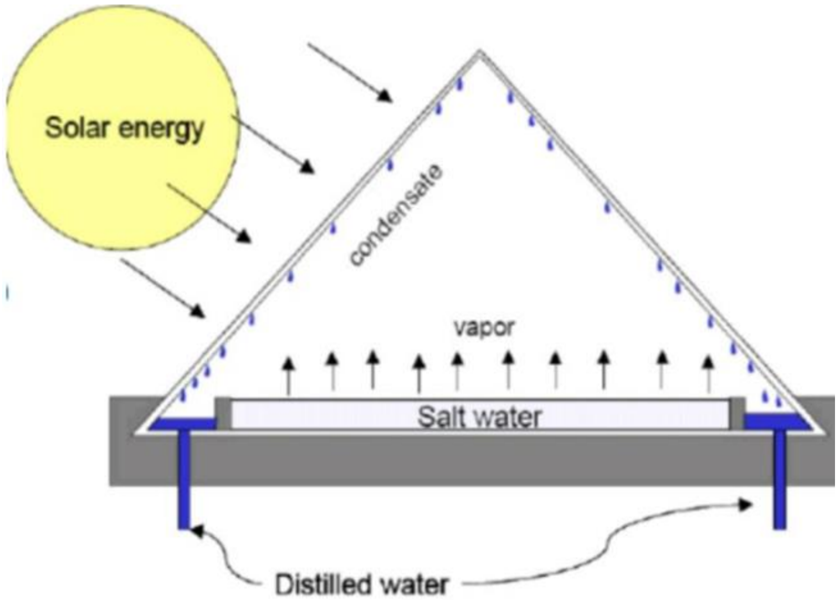


Figure 2: *Solar water distillation method*

The following summarises the disadvantage of the configuration shown in Figure 2 and the features extracted from these existing concepts in the development of our concepts:

Disadvantages of the design shown in Figure 2

- Static or immovable.
- Slow purification process as no boiler or heating coils are installed.

Advantages and features extracted from the design shown in Figure 2

- Condensation method for water purification.

- Triangular shaped cover which is advantageous for the collection of condensed distilled (or purified) water (as it is concentrated in the conical shaped edge of the cover).
- This configuration was adopted for the development of concept 1, 2, and 4 described in this paper.

A “parabolic dish” configuration is illustrated in Figure 3. This configuration was also adopted for the development of concepts described in this paper.

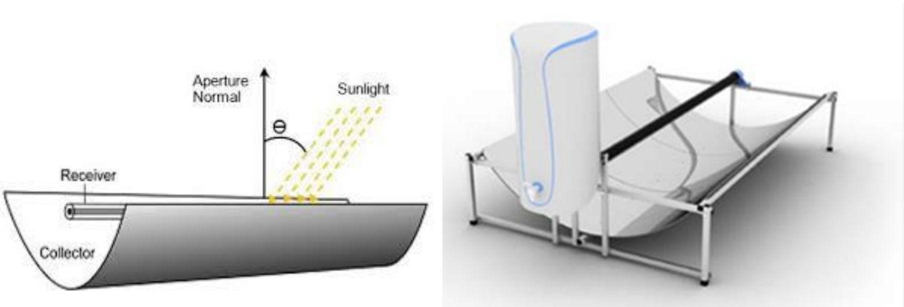


Figure 3: *Parabolic dish configuration (Adapted from Sommer et al., 1997)*

The following summarises the advantages of the configuration shown in Figure 3 and the features extracted from these existing concepts in the development of our concepts:

Advantages and features extracted from the design shown in Figure 3

- Utilization of a boiler as well as the availability of sunlight through the parabolic dish.
- The use of boilers and batteries to ensure heat is retained and stored for proper purification.
- This configuration was adopted for the development of concept 4 described in this paper.

A “heating coils” configuration is illustrated in Figure 4. This configuration was also adopted for the development of concepts described in this paper.

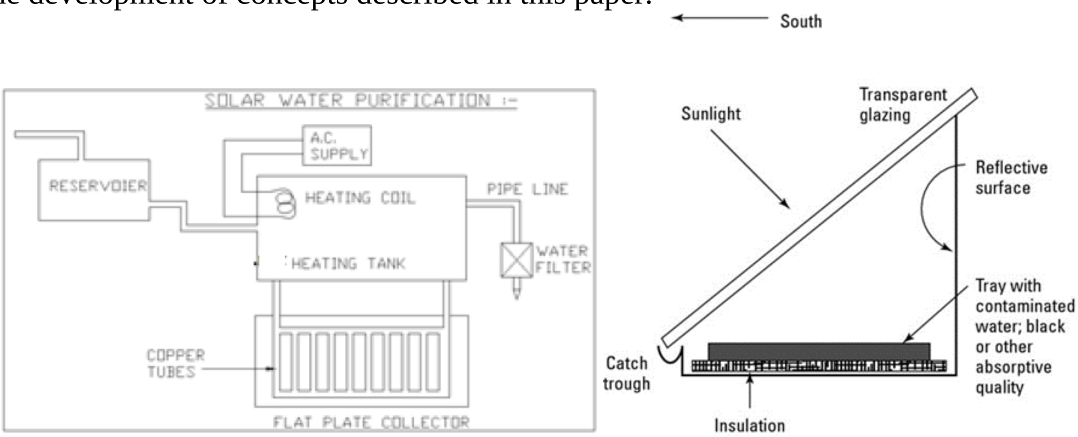


Figure 4: *Heating coils solar water purification system (Adapted from Ghannam et al, 1998)*

The following summarises the advantages of the configuration shown in Figure 4 and the features extracted from these existing concepts in the development of our concepts:

Advantages and features extracted from the design shown in Figure 4

- The design incorporates heating coils within the heating tank which improves the efficiency of heat supply for water purification.
- The heating coil ensures more heat within the process.

- This configuration was adopted for the development of all the concepts described in this paper.

The layout of the systems developed in this paper is based on the three configurations described in this section. Four different concepts have been developed from these existing technologies, and desirable features have been extracted and amalgamated to form new concepts.

The methodology adopted in this study can be summarised as follows:

Step 1 ➔ Problem definition
Step 2 ➔ Literature review: Investigation & observation
Step 3 ➔ Concepts generation: Development of models
Step 4 ➔ Concept evaluation and selection: Design matrix
Step 5 ➔ Final design motivation: Possible promising solution

DESIGN DEVELOPMENT

Specifications and requirements

The following section summarises the specifications and requirements considered for the solar-powered water purification systems (Fahr, 2018):

- The design must comply with SANS 241-2:2015 drinking water quality (DWQ) as the standard (namely durable and weather-resistant solar collector; lower reactive boiler; high heat conductivity for the condenser; high temperature withstanding condenser; high temperature withstanding boiler);
- The durability and lifespan of the design should be a reasonable number of working years.
- The system shall be powered by the sun (solar energy);
- The systems should have a filter or collection tank that can remove contaminants;
- The designs must be user friendly and generate a reasonable amount of purified water;
- Conductivity (Ionic Contaminants) should be ≤ 4.3 µs/cm @ 20˚C for potable water;
- Total Organic Carbon (TOC) should be 500 ppb (target) for potable water;
- pH @ 25˚C should range between 5 – 9.7 for potable water;
- Heavy metals (toxic to humans) should be ≤ 0.1 ppm;

Concept generation

This section provides details about the concepts generated in this paper. These concepts have been developed based on the design configurations described in the previous section. Detailed 3D models and working principles are included. However, details about the sizing, specifications of components/modules, and maintenance requirements are beyond the scope of this paper and will form part of future contributions.

A. Concept 1

i. Description

This concept was built based on the solar water distillation method shown in Figure 2. The following features were incorporated into the development of the design concept (Figure 5 & 6):

- ***Heating coils*** – used for boiling untreated water by solar energy;
- ***Manual water pump*** – used for pumping water from the reservoir into the boiler;

- ***Stepper motor*** – used for automatic pumping water and transportation of slurry,
- ***Double water tank*** – used for separating filtered water and slurry water;
- ***Filtering conveyor*** – used for removing the slurry from the system;
- ***Batteries*** – used for storing the solar energy to supply heating coils;
- ***Battery casing*** – used for holding batteries;
- ***Inlet water pipe clamp*** – used for clamping pipe of inlet water from the reservoir.

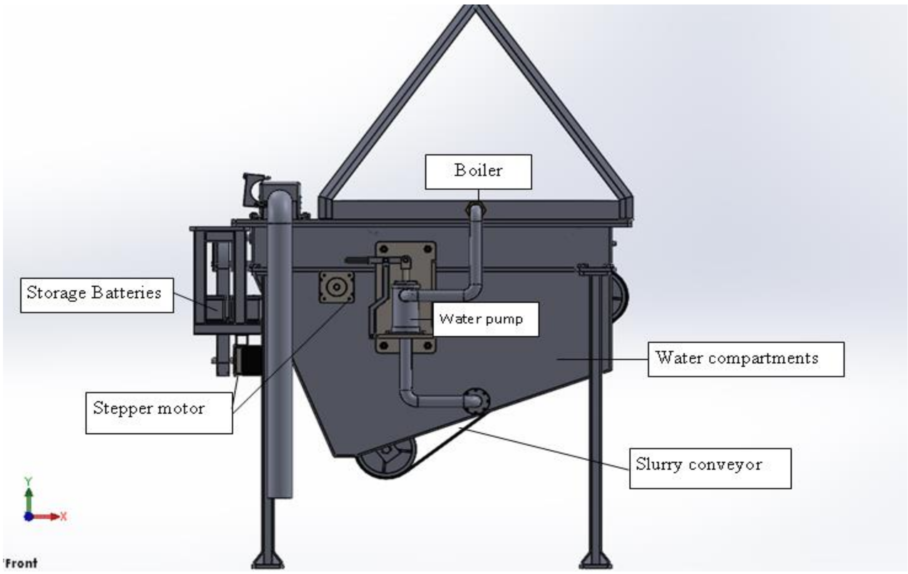


Figure 5*: Design concept 1*

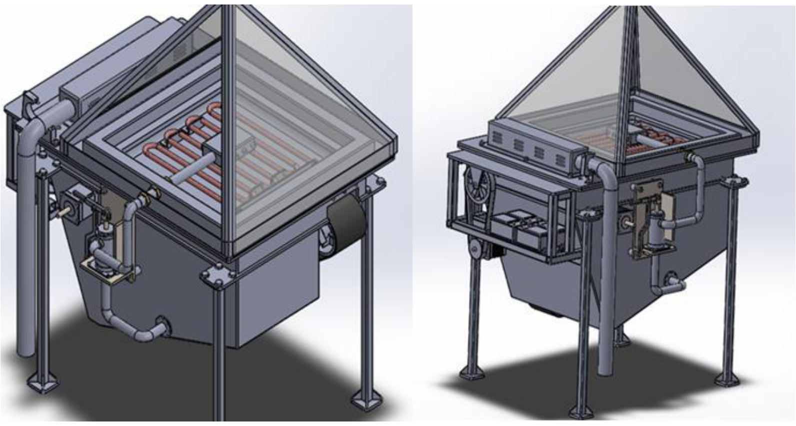
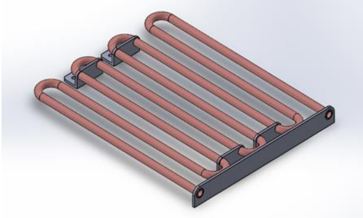
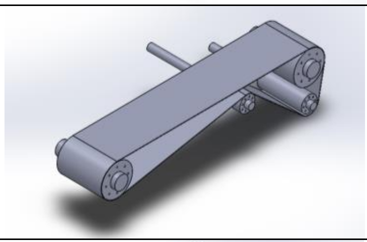
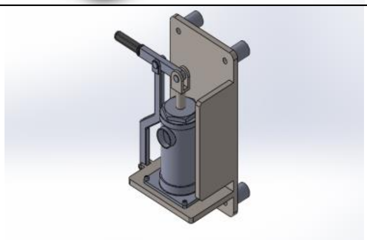
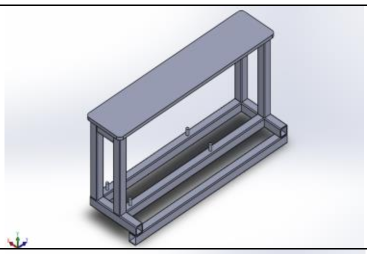
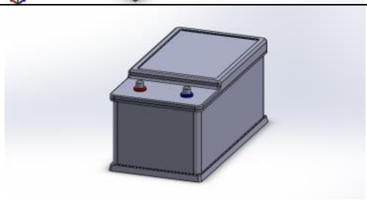
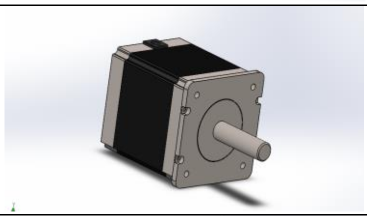
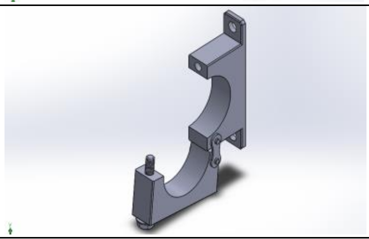


Figure 6: *Design concept 1- side view*

Table 1 provides the details of the main components used for the construction of concept 1.

Table 1: *Main components of design concept 1*

Item	Description	Drawing

Heating coils	• Coil diameter estimated: 10mm • The material selected: Copper	
Filtering conveyor	• 4 Conveyor pulleys • 1 Driving pulley and 3 Driven pulleys • The material selected: Carbon steel, Stainless steel, and Fabric (cloth)	
Manual water pump	• Internal diameter estimated: 450mm • Piston for pumping water estimated: 450mm • The material selected: Mild steel, Stainless steel, Brass, and Rubber.	
Battery casing	• Length estimated: 600mm • The material selected: Mild steel	
Batteries	• Voltage estimated: 24V • Quantity estimated: 4	
Stepper motor	• Voltage estimated: 24V DC • Number of Phases: 3	
Inlet water clamp	• Clamp diameter estimated: 150mm • The material selected: Mild steel	

ii. Working principle

This concept consists of two water compartments namely the filtered water compartment (which is represented by blue colour) and the slurry water compartment (which is represented by red colour) as shown in Figure 8.

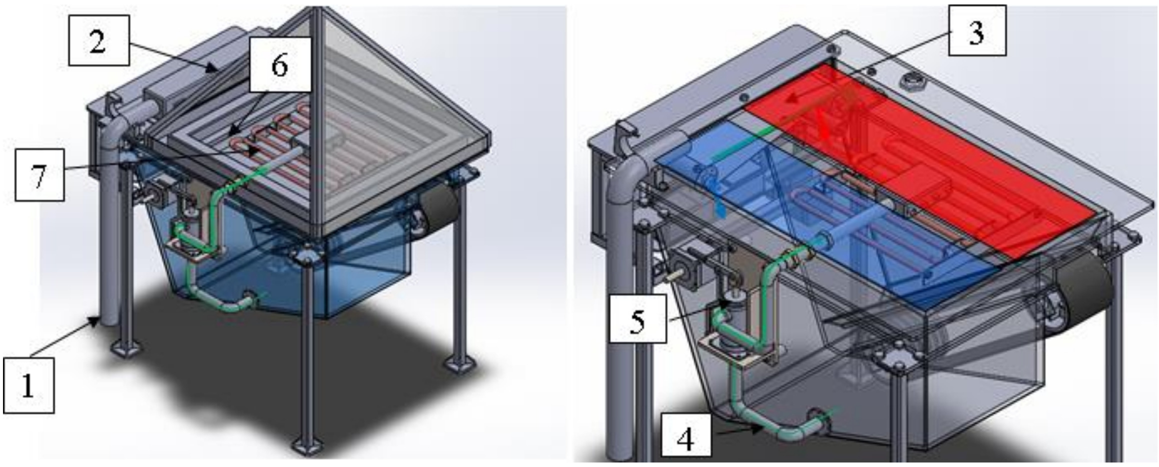


***Figure 7**: Design concept 1- Working principle*

- The contaminated water enters the system through the inlet pipe (1) and is pumped into a fabric conveyor belt (2).
- Water flows over the fabric conveyor belt (2) for filtering and separation of impurities.
- During this process, the conveyor slowly filters the water. Separated impurities are conveyed (3) into the second compartment (red section) while the filtered water is being collected in the first compartment (blue section) for further process.
- The filtered water is pumped from the first compartment (blue section) through PVC pipe (4) with a manual hand pump (5) following the green path line.
- After pumping the filtered water into a boiling container (6), it is heated by an electric heating coil (7) which receives power from the solar-powered batteries.
- As the water evaporates, it condenses on the plastic cone and drips down against the conical-shaped edges as distilled or drinkable water (8) (as shown in Figure 8).

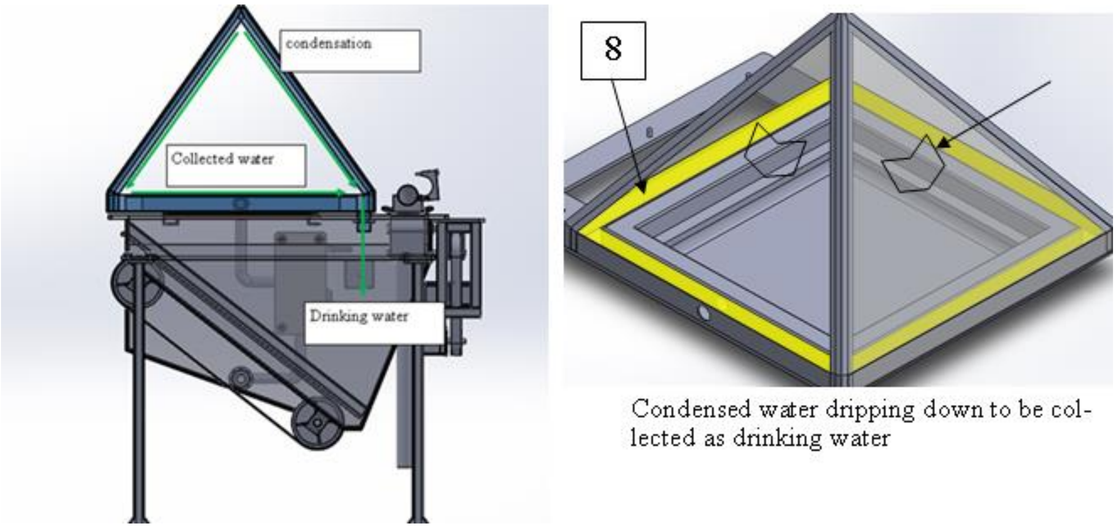


***Figure 8**: Design concept 1- Distillation process*

- The slurry is removed from the second compartment (red section) by using the second conveyor as shown in Figure 9.
- The conveyor design orientation is inclined to remove all the particles (represented by the brown colour) from the system and transferred into the collecting container which is located outside of the system as shown in Figure 9.

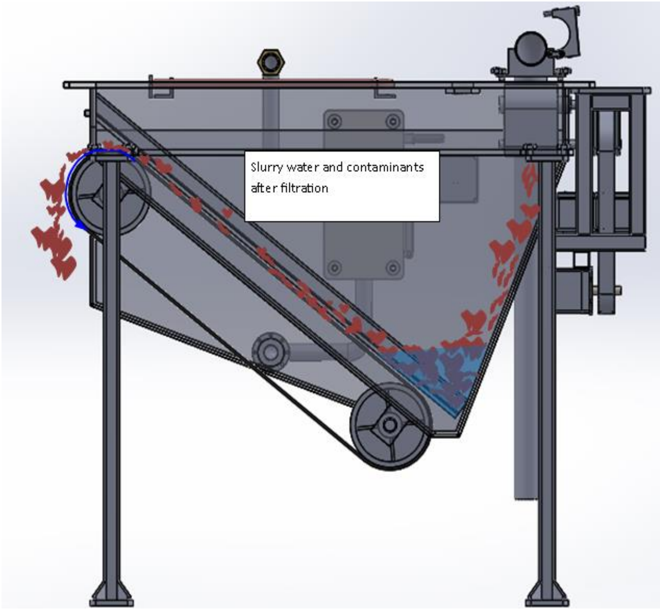
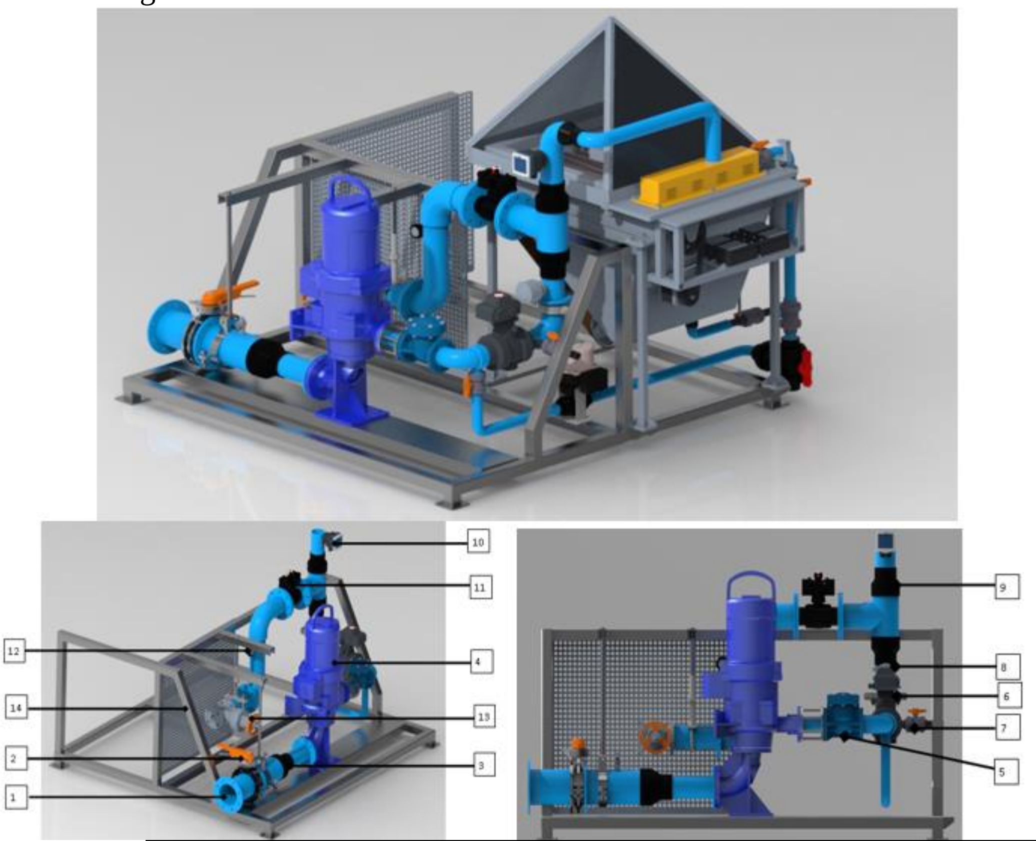


Figure 9: *Design concept 1- removal of the slurry*

Details of the piping system and external modules not included in the previous figures are shown in Figure 10.



1. Raw water inlet from reservoir/ municipality supply	8. Pressure transmitter
2. Butterfly valve	9. Concentric reducer
3. Concentric reducer	10. Flow indicator/ FIT
4. Submersible pump	11. Pneumatic butterfly valve
5. Lift check valve	12. Pressure indicator (PI)
6. Flow transmitter (FT)	13. Manual diaphragm valve (booster line)
7. Drain/ sampling valve	
8. Pressure transmitter	

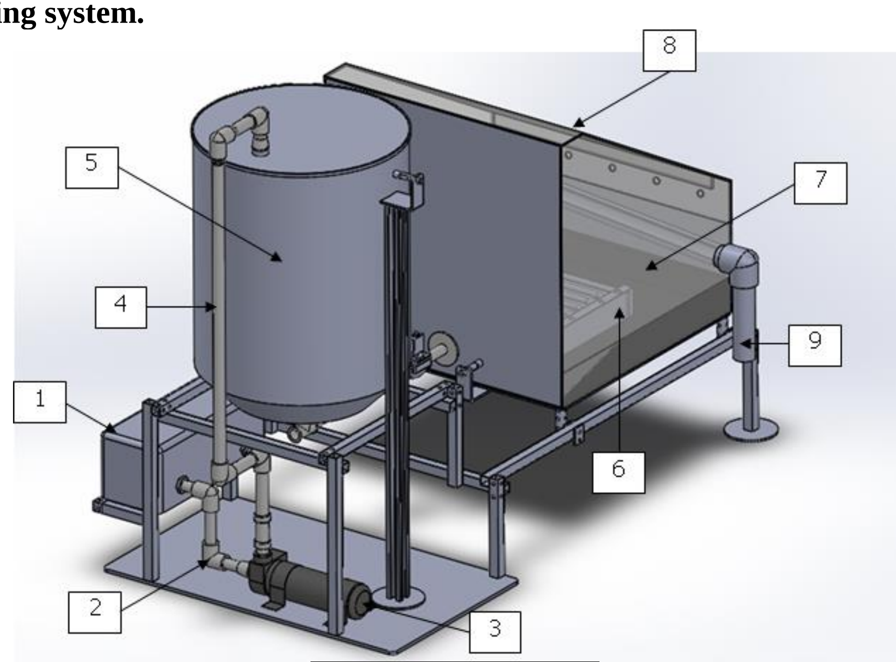
Figure 10*: Final design concept 1 and piping system*

B. *Concept 2*

i. *Description*

This concept was developed based on the parabolic dish shown in Figure 3. The main features incorporated in the development of this design concept are shown in Figure 11. It includes:

- **Electronic water pump;**
- **Inlet water tank;**
- **Perspex clear plastic cover;**
- **Boiler container;**
- **Piping system.**



1. Inlet water tank.	
2. Inlet filtered water pipe.	
3. Electronic water pump.	
4. Filtered water transfer pipe.	
5. Filtered water storage tank.	
6. Heating element.	
7. Boiler container (black).	
8. Perspex clear plastic cover.	
9. Drinking water outlet pipe.	

Figure 11: *Design concept 2 with additional features*

For clarity, the side views, isometric view, and front view of this design concept are shown in Figure 12.

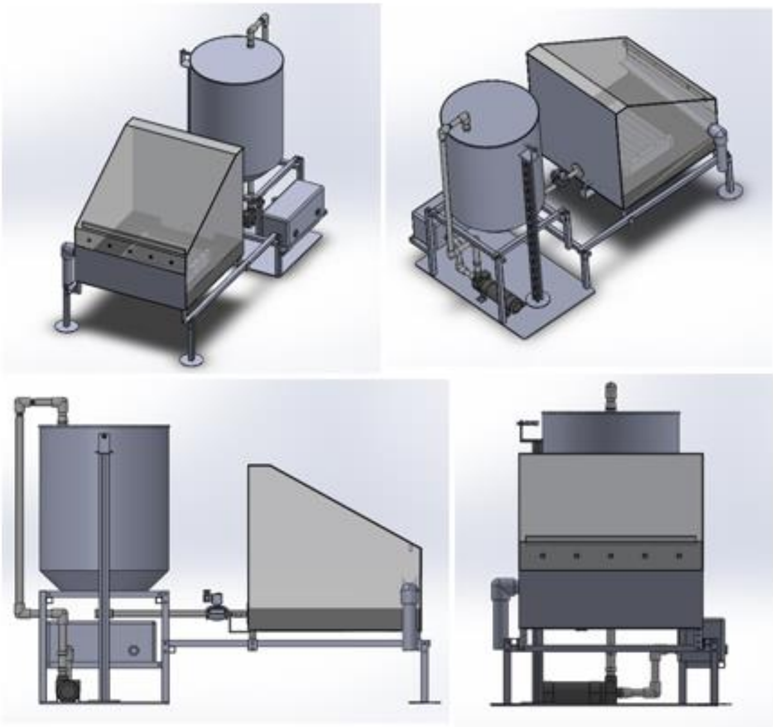


Figure 12*: Final design concept 2 model views*

ii. Working principle

This concept consists of an automatic water refill system to boost the process. When the water in the boiler drops, the sensor (A) triggers an electronic valve (B) to release the flow of water from the water storage tank. When the level of water that is required is reached, the sensor triggers the electronic valve to close the valve as shown in Figure 13. When the level of water in the water storage tank has dropped to a certain level, the electronic valve sends a signal to the pump through a feedback loop. Water will be pumped from the reservoir/ municipal supply into the water storage tank until the level of water that is required is reached. Thus, this process is referred to as a closed feedback loop mechanism.

The purification process is almost the same for all design concepts. When the water reaches the boiling point, it evaporates and condensate is collected from the Perspex plastic cover as shown in Figure 13. As the condensate on the Perspex become dense, it drops into a slating half-open PVC pipe which is connected to the drinking water outlet pipe.

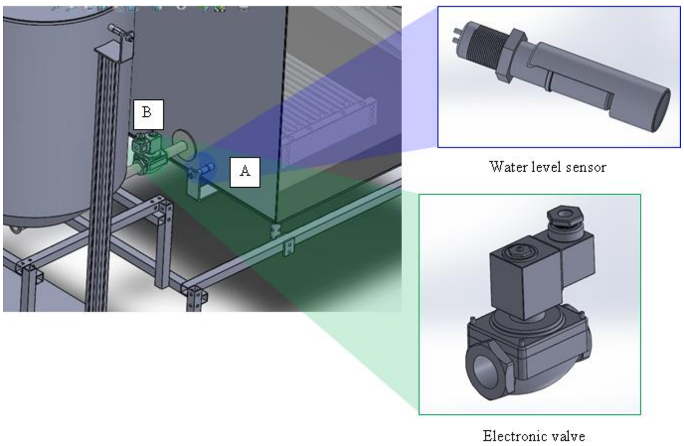


Figure 13: *Water level sensor (A) and Electronic valve (B)*

The contaminated water (water flow-blue line) is transferred by the piping system from two water storage tanks as shown in Figure 14. The first pipe transfers water from the inlet water filter tank (1) to the water pump (2). The second pipe (3) transfers water from the pump into the water storage tank (4). The third pipe (5) takes water from the water storage tank to the boiler (6).

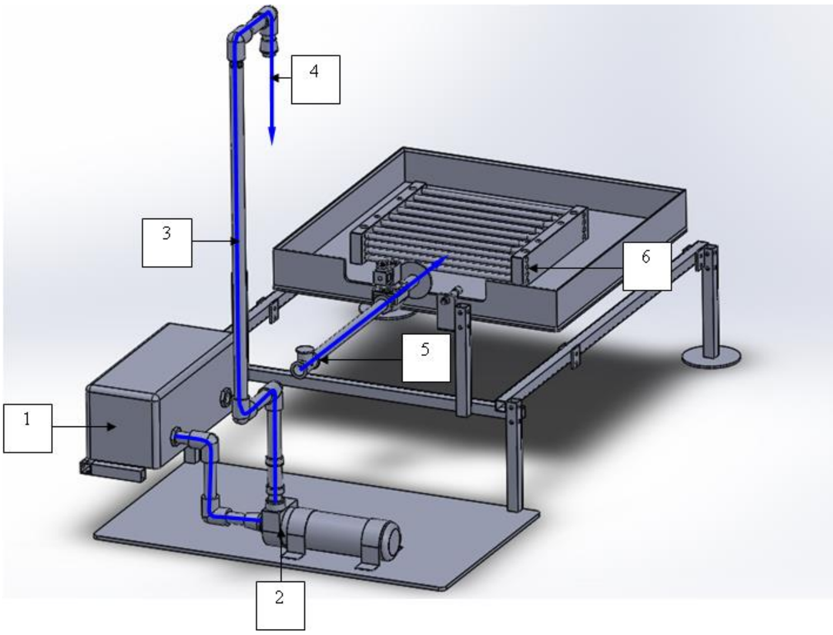


Figure 14: *Piping water system*

C. Concept 3

i. Description

This concept was developed based on the basic principle of solar water purification by distillation method and the heating coils or solar water purification system shown in Figure 2 and Figure 4 respectively. The main features incorporated in the development of this design concept are shown in Figure 15. It includes:

- ***Heating coils*** – to vaporise the water;
- ***Rotating flat solar panels*** – to harness the solar energy from the sun;
- ***Perspex plastic cover*** – to aid with the collection of condensate during the distillation process and transparent glazing;
- ***Batteries*** – to store the power from solar panels through solar energy
- ***The mild steel support structure (plates and square tubes)***.

For clarity, the side views and front view of this design concept are shown in Figure 15.

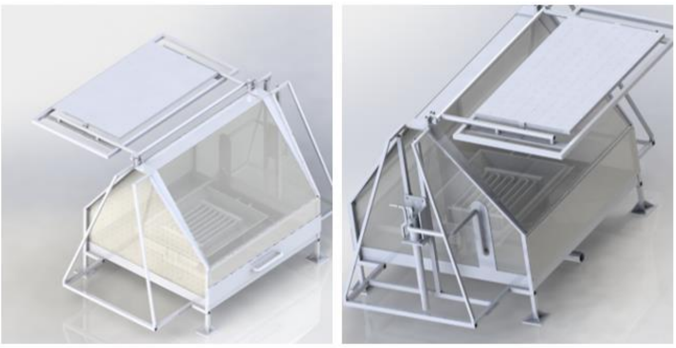


Figure 15*: Design concept 3 - side and front views*

ii.   Working Principle

The untreated water from the reservoir/ municipality enters the system at pipe inlet (1). A pump (2) is used to transfer water to the boiler (3) through a water tube (2). The boiler is equipped with copper heating coils (5) to vaporise the water. The heating coils draw energy from the solar panels (6). As the temperature of water rises, the evaporation occurs (Kumar and Bai, 2008). Ultimately, the droplets of water collected on the convex Perspex plastic and drips down as drinkable water through pipe outlet (7) as shown in Figure 16.

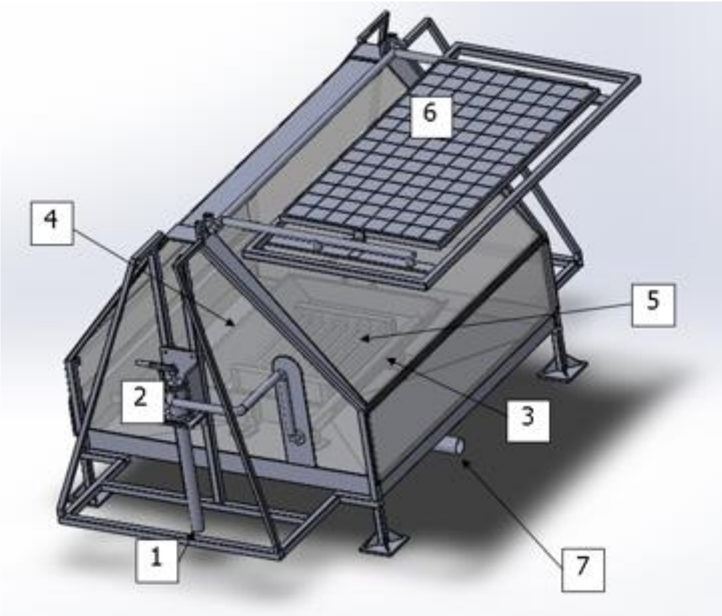


Figure 16: *Design concept 3 - working principle*

The concept incorporates an automatic solar tracker to increase the efficiency of the solar panels by keeping the flat solar panels aligned with the rotation of the sun. The automatic solar tracking is the mechanized system that tracks the sun's rays position to increase the power output of the solar panels. The sun rotates 360˚ on earth in a day, so it rotates 360˚/24 = 15˚ an hour or 3.75˚ in 15 minutes. 2 hours are not considered for tracking because the first hour after the sunrise and last hour before the sunset because the temperature sensor does not have enough light to trigger the system. A stepper motor which gives 3.75˚ rotation in each stepping could be considered. Therefore, approximately (180˚-30˚)/3.75˚ = 40 rotations are required each day to track the sun during daylight (Khan *et al*., 2010). The mechanism works as indicated by the series of a picture in Figure 17.

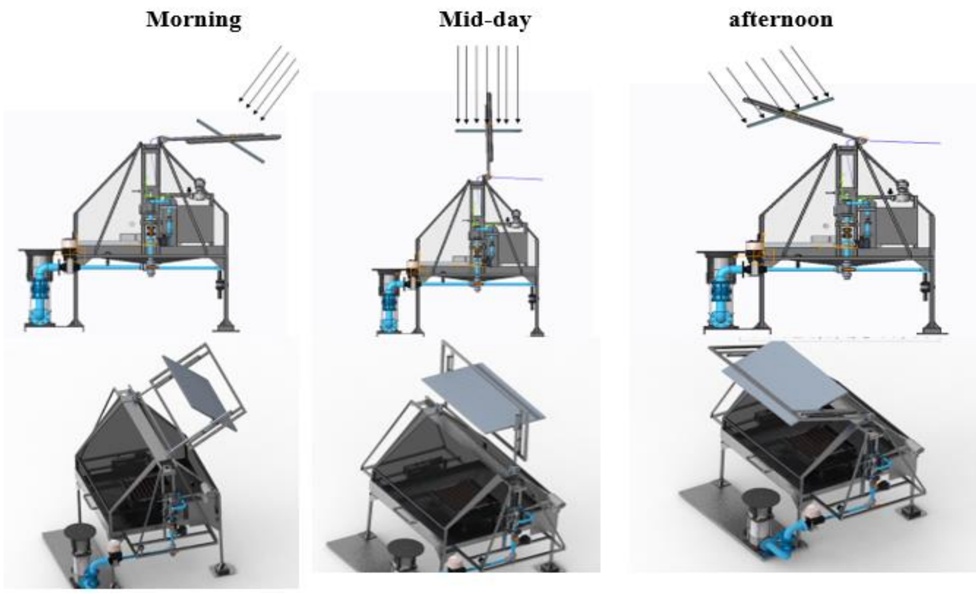


Figure 17*: Automatic solar tracking panels*

The system is equipped with energy storage for backup power to the heating unit in case there is no sunlight due to bad conditions and to supply the boiler with constant power. This storage consists of four 24V solar batteries and a battery charger as shown in Figure 18. The solar batteries are charged by the solar panels and releases the energy when it is needed.

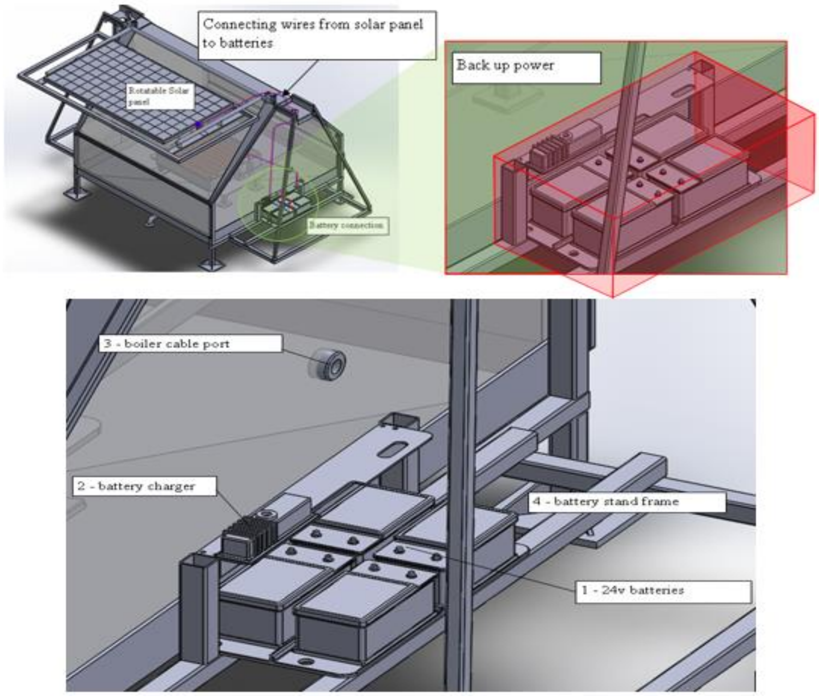
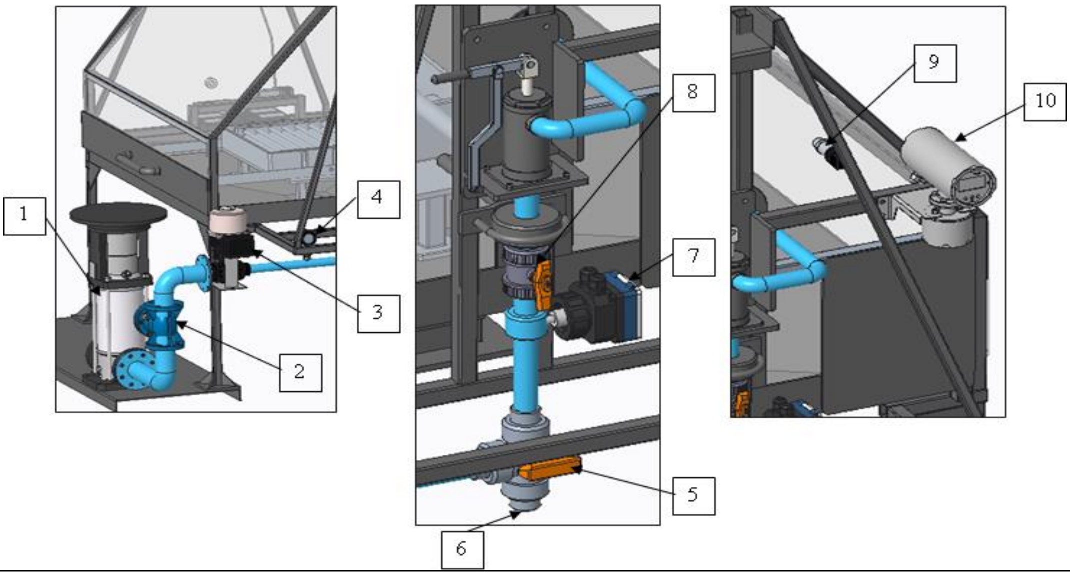


Figure 18: *Energy storage in batteries for back-up power*

The piping system was added to transfer contaminated water from the reservoir to the water tank. The system is designed to make the operation more convenient. Figures 19 & 20 show the details of the final design concept 3 with a piping system and pipe fittings. This includes ball valves, elbows, pressure regulators, flow transmitters, temperature transmitters, and pressure transmitters.

Figure 19: *Final design concept 2 with a piping system and fittings*



1. Submersible pump – connected to municipality/ raw water truck/ borehole.
2. Check valve – allows water to flow in one direction, to prevent backwater/ protect the pump.
3. Pressure reducing valve – to reduce the pressure to protect the PVC pipes with small nominal bores.
4. Pressure indicator – to measure the pressure loss/ current after reducing the valve.
5. 3-Way Ball Valve – acts as a Tee to allow water to pass from the pump or point 6 in case the pump is not functional (manual overwrite).
6. Manual water pump inlet – to pump contaminated water straight from borehole/ dam.
7. Pressure transmitter – to measure and read the pressure before the entrance to the boiler.
8. Non-Return Valve (PVC) – to prevent water from running back down due to gravity, since the pipe orientation is facing up.
9. Temperature sensor – to measure the ambient temperature of the entire boiler house.
10. Temperature indicator – to display temperatures.

Figure 20*: Piping system and fittings*

D. Concept 4

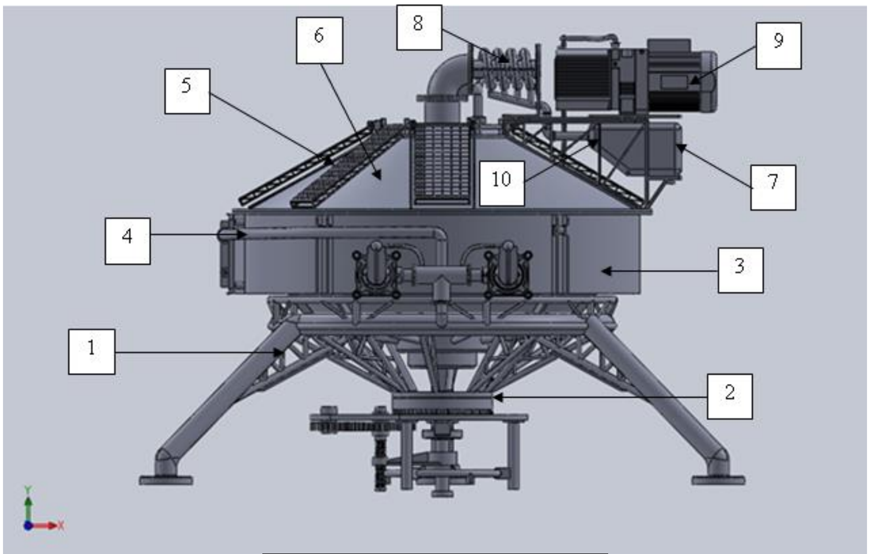
i. Description

This concept was developed based on the heating coils solar water purification system shown in Figure 4. The main features incorporated in the development of this design concept are shown in Figure 21. It includes:

- ***A circular boiler drum*** that is equipped with internal heating coils;
- ***Three-legged trusses*** – to support the system;

- ***A rotating mechanism*** – to convert rotatory motion into linear motion for good performance of the pump;
- ***Cooling coils*** – to cool distilled water;
- ***A metal cover*** – to cover the boiler during the distillation process;
- ***A vacuum pump*** – to vacuum distilled water from the boiler to the water collector and to decrease the boiling temperature by decreasing the pressure within the boiler.

This concept uses concentric aligned solar panels to make the system more compact and minimize spaces. The principle of purification is the same as the other concepts.



1. Three-legged truss frame structure
2. Rotating mechanism
3. Boiler
4. Water supply pipe
5. Solar panels
Metal cover
6. Clean water collector
7. Cooling coil
8. Vacuum pump
9. Vacuum pump support frame

Figure 21: *Design concept 4*

Details of the subsystems of concept 4 are shown in Figure 22.

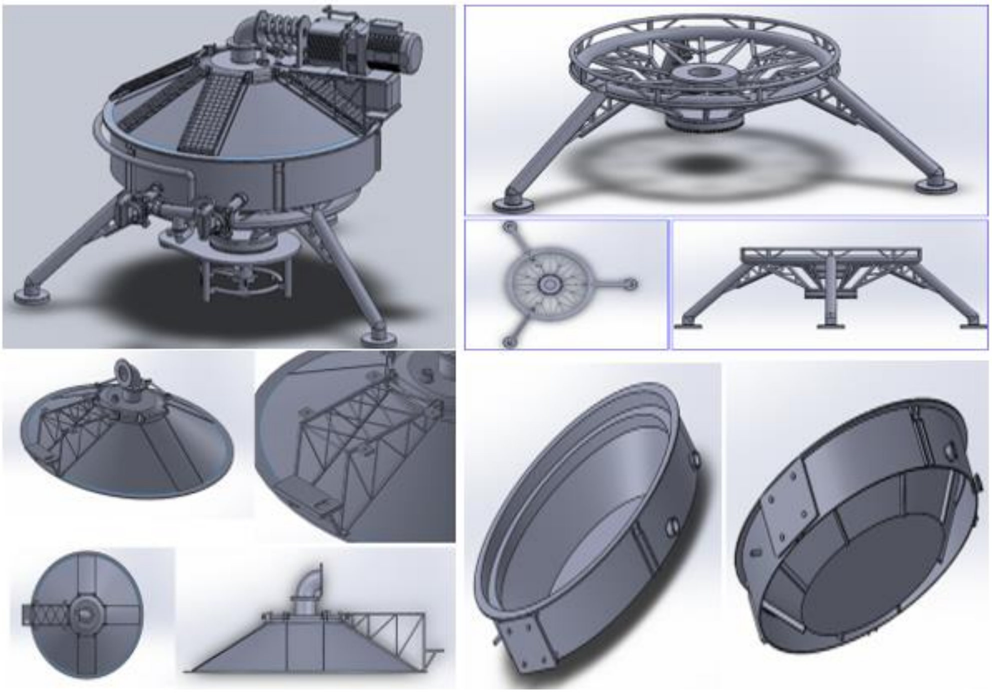


Figure 22: *Final design concept 4 and subsystems*

ii. Working Principle

The working principle of this concept is mostly the same as the previous concepts. The only difference is that this concept will utilize a vacuum pump to reduce the pressure in the heating chamber resulting in the boiling time of the contaminated water. The solar panels are mounted on the top of the boiler and aligned to the direction of the sun. The vacuum pump sucks the water from the reservoir/dam through an inlet water pipe (1) and directs it to the boiler following the blue path line as shown in Figure 23. The heaters (3) increase the temperature of the contaminated water inside the boiler (4). The water evaporates and leaves the system via a cooling coil as illustrated in Figure 23 (in yellow).

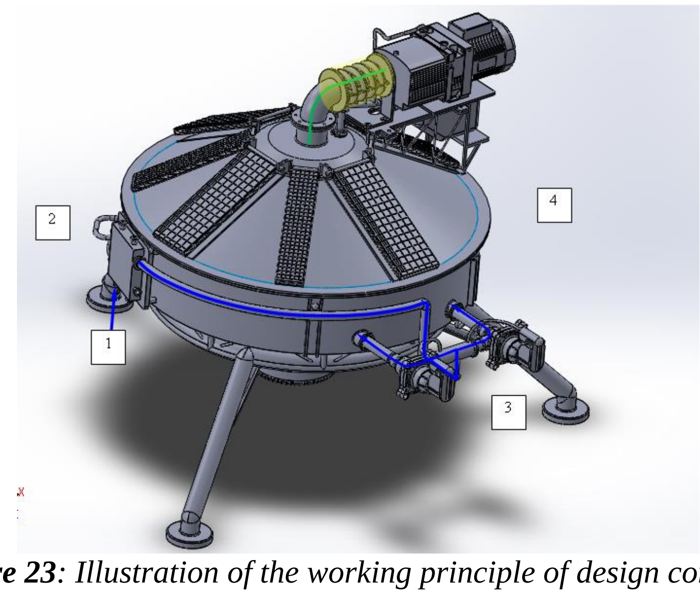


Figure 23*: Illustration of the working principle of design concept 4*

DESIGN SELECTION AND EVALUATION

The concept selection was based on the criterion as illustrated in the decision matrix (Table 2). Scores of 1-5 were allocated to each design concept to identify the most promising solution. Concept 3 has the highest overall score and value of 27 & 4.6. Therefore, this concept was selected for future analysis.

Table 2: *Concept selection and evaluation*

Criterion	**Weighting Factor**	**Parameter**	**Ratings**							
			Concept 1		***Concept 2***		***Concept 3***		***Concept 4***	
			Score	Value	Score	Value	Score	Value	Score	Value
Material Cost	0.10	ZAR	3	0.3	4	0.4	5	0.5	2	0.2
Manufacturing Cost	0.2	ZAR	4	0.8	4	0.8	4	0.8	1	0.2
Manufacturing Time	0.10	Hours	4	0.4	5	0.5	4	0.4	4	0.4
Durability	0.15	Experience	3	0.45	3	0.45	5	0.75	4	0.6
Reliability & Maintenance	0.30	Experience	1	0.3	4	1.2	5	1.5	2	0.6
Reparability	0.15	Experience	3	0.45	4	0.6	4	0.6	3	0.45
Overall Score & Value			18	**2.7**	24	**4**	27	**4.6**	16	**2.5**
*Legend: 5 = Excellent; 4 = Very good; 3 = Good; 2 = Fair; 1 = Poor										

CONCLUSIONS

The purpose of this paper was to develop several solar-powered water purification systems. Through a literature review, several existing concepts have been identified. These existing concepts (namely solar water distillation method, parabolic dish configuration, and heating coils solar water purification system) were used to develop the concepts presented in this paper. The paper focuses on the design systems that could purify biologically contaminated water by using the thermal method. The first concept was developed based on the solar water distillation method. The proposed design incorporates some features such as heating coils, a manual water pump, a stepper motor, a double water tank, a filtering conveyor, batteries, a battery casing, and an inlet water faucet. The second concept was developed based on the parabolic dish. The main features incorporated in the development of this design concept includes an electronic water pump, an inlet water tank, a Perspex clear plastic cover, a boiler container, and piping systems. The third concept was built based on the basic principle of solar water purification by distillation method and the heating coils solar water purification system. The main features incorporated in the development of this design concept include heating coil, rotating flat solar panel, Perspex plastic cover, batteries, and mild steel support structure (plates and square tubes). The fourth concept was developed based on the heating coils solar water purification system. The main features incorporated in the development of this design concept are a circular boiler drum, three-legged trusses, a rotating mechanism, cooling coils, a metal cover, and a vacuum pump. Future work will provide clarity about the materials used, the size of all components/modules, and the maintenance of the proposed systems. Furthermore, the performance of each system could be analysed to improve water purification and minimize design complexity. Based on the concept selection and evaluation, one promising concept will be built.

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REFERENCE

Fahr, A., 2018. *Voigt's Pharmaceutical Technology*. John Wiley & Sons.

Fisher, M.B., Iriarte, M. and Nelson, K.L., 2012. Solar water disinfection (SODIS) of Escherichia coli, Enterococcus spp., and MS2 coliphage: effects of additives and alternative container materials. *Water research*, *46*(6), pp.1745-1754.

Forstmeier, M., Feichter, W. and Mayer, O., 2008. *Photovoltaic powered water purification—challenges and opportunities*. Desalination, 221(1-3), pp.23-28.

Ghannam, J., Ayoub, G.M. and Acra, A., 1998. *A profile of the submarine springs in Lebanon as a potential water resource*. Water international, 23(4), pp.278-286.

Jaskolski, M., Schmitz, L., Otter, P. and Pellegrino, Z., 2019. *Solar-powered drinking water purification in the oases of Egypt's Western Desert*. Journal of Photonics for Energy, 9(4), p.043107.

Joseph III, T.A., Newton, C.C., Wandrie III, H.M. and Carter, M., EPIPHANY SOLAR WATER SYSTEMS, 2012. *Solar-powered water purification system*. U.S. Patent Application 13/496,951.

Khan, M.T.A., Tanzil, S.S., Rahman, R. and Alam, S.S., 2010, December. *Design and construction of an automatic solar tracking system*. In International Conference on Electrical & Computer Engineering (ICECE 2010), pp. 326-329. IEEE.

Kumar, K.V. and Bai, R.K., 2008. *Performance study on solar still with enhanced condensation*. Desalination, 230(1-3), pp.51-61.

Mohanta, P.R., Patel, J., Bhuva, J. and Gandhi, M., 2015. *A Review on Solar Photovoltaics and Roof Top Application of It*. International Journal of Advanced Research in Science, Engineering and Technology, 2, pp.2394-2444.

Rockenbaugh, C., Dean, J., Lovullo, D., Lisell, L., Barker, G., Hanckock, E. and Norton, P., 2016. High Performance Flat Plate Solar Thermal Collector Evaluation (No. NREL/TP-7A40-66215). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Saraceno, D., 2005. *Solar powered portable water purifier*. U.S. Patent 6,863,827.

Sawka, M.N., Cheuvront, S.N. and Carter, R., 2005. *Human water needs.* Nutrition reviews, 63(suppl_1), pp.S30-S39.

Sommer, B., Marino, A., Solarte, Y., Salas, M.L., Dierolf, C., Valiente, C., Mora, D., Rechsteiner, R., Setter, P., Wirojanagud, W. and Ajarmeh, H., 1997. *SODIS- an emerging water treatment process*. AQUA (OXFORD), 46(3), pp.127-137.

Thorat, S. 2006. Solar water purification by using thermal method. Final year design project. Pune University, India.

Wright, A.V., 2011. *Solar-powered water purification system*. U.S. Patent Application 13/010,676.

Zhang, Y., Sivakumar, M., Yang, S., Enever, K. and Ramezanianpour, M., 2018. Application of solar energy in water treatment processes: A review. *Desalination*, *428*, pp.116-145.