ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

EXPERIMENTAL ASSESSMENT OF A GEOTHERMAL STILL FOR HOT SPRING WATER PURIFICATION

(A CASE ON FILWOHA HOT SPRINGS – ADDIS ABABA, ETHIOPIA)

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the award of the Degree of Master of Science in Thermal Engineering

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Thesis Advisor: Yilma Tadesse (PhD)

Addis Ababa, Ethiopia

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DECLARATION

I hereby declare that this M.Sc. thesis entitled, "**Experimental assessment of a geothermal still for hot spring water purification**," is my original work, completed under the supervision of Dr. Yilma Tadesse Birhane (PhD), Associate Professor in Mechanical Engineering (Thermal and Energy Systems Engineering) at Addis Ababa Institute of Technology, School of Mechanical and Industrial Engineering. This thesis content has not been submitted in whole or in part for a degree, diploma, or certificate at any university/institution. All relevant resources and materials used for this thesis have been properly acknowledged, and a reference list is provided.

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Student	Signature	Date

This is to certify that the candidate's above statement is correct to the best of my knowledge and belief. With my approval, this has been submitted for review.

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SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING (SMIE)

Thermal system and energy conversion chair

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By: KALKIDAN MINWYELET WENDMENEH

Submitted in accordance with the requirements for the degree of Master of Science (M.Sc.)

Approved by Board of Examiners

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ABSTRACT

The filwoha hot spring water is used for shower, hydro-therapy massage, sauna bath and steam bath services. Although the natural hot spring water provides such services it is not used as a drinking water. This is as a result of the concentration of parameters such as the total dissolved solid (TDS), the total alkalinity and the fluoride being above the standard requirements for a drinking water. In this research a geothermal still was manufactured and experimental tests were carried out at the Filwoha Spa Service Enterprise, Addis Ababa, Ethiopia. Geothermal still is an apparatus that uses the hot spring water both as a water to be treated and as an energy source that drive the geothermal still operation. The basin area of the geothermal still was $1\ \mathrm{m}^2$ and the glass cover tilt angle was fixed at $20°$. An L shaped condensate channel of $40\mathrm{mm} \times 120\mathrm{mm}$ is made to collect the distillate running down the inner surface of the inclined glass cover. To prevent any heat lose, the bottom and sides of the geothermal still was insulated with 50 mm thick glass wool. The geothermal still construction was contained in a wooden frame of a trapezoidal shape. The geothermal still had an outlet pipe at the front, an inlet pipe at the back and another outlet pipe on the right side for the output discharge with each pipe having a diameter of 20 mm. The experiment was performed at a water depth of 2 cm. The operating flow rate for the geothermal still was between $0.05 - 0.07$ L/sec. The continues flow of the hot water across the geothermal still serves the purpose of maintaining the temperature of the water stored on the basin. Temperature readings of the parameters such as the basin water and the water vapor were recorded. The geothermal still was estimated to produce 8 liters of distillate output per day. Finally, the water quality analysis reports were prepared by Addis Ababa Water and Sewerage Authority (AAWSA) and Ethiopian Conformity Assessment Enterprise (ECAE) for the distillate samples collected from the geothermal still. The laboratory results showed that the concentration of the total dissolved solid (TDS), the total alkalinity and the fluoride was reduced to the acceptable level for a drinking water.

Keywords: Filwoha hot spring water, Geothermal still, Distillate output

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CHAPTER ONE

INTRODUCTION

1.1 Background

The filwoha hot spring water played an important role for the establishment of Addis Ababa as the capital city of Ethiopia. If it was not for filwoha the capital might be situated at Entoto, the northern most neighborhood of Addis Ababa, where Emperor Menelik II built his palace. Perhaps due to the cold elevation of the palace or simply because Empress Taytu used to like hot springs, she built a house downhill at the hot springs. The other nobles followed, building their houses nearby, and Menelik II founded the capital down there as Addis Ababa [1].

By the order of emperor Menelik II in 1897 E.C the first filwoha shower rooms were constructed and in 1956 E.C Emperor Haile Selassie established the Filwoha Service Enterprise in a modern way [1]. The Spa Service Enterprise is the only institution in Addis Ababa which provides natural hot spring services to the community. The Spa Service Enterprise has also two major branch hotels and one resort hotel, namely as the New Filwoha Hotel, the Finfine Cultural Hotel and Langano Resort Hotel.

The Filwoha Spa Service Enterprise healing services include massage, sauna bath, hot spring bath and steam bath. This center has 338 bathing rooms, 27 massage rooms, 17 sauna bathes and 4 steam bathes that are currently giving services to the community [2]. The natural healing powers provided by the hot spring water (filwoha) are listed below [2]:

- ✓ By increasing the body temperature, it kills harmful germs and viruses.
- ✓ By facilitating oxygen rich blood circulation, it removes poisonous elements from the body.
- ✓ It activates intestine chemical production used for food digestion.
- ✓ It helps to improve the function of the endocrine gland and it activates the nervous system.
- ✓ Minerals such as sulfur, calcium, magnesium, lithium will be balanced in the body which benefits the organs activities.

- ✓ Hot spring water containing sulfur is a cure for skin diseases such as fungus.
- ✓ Recent studies show that bathing with hot spring water reduce heart attack and facilitates the rapid distribution of hot blood to various body parts. By dissolving the fats around blood distributing pipes, it helps to reduce blood pressure.
- ✓ Some medical experts state that soaking in 39 ℃ water for 15 minutes before sleep helps to avoid loss of sleep.
- ✓ People suffering from arthritis can get a relief from the natural hot spring water. Especially it is helps for freedom of movement of joint and muscles.
- ✓ Bathing or soaking the body in hot spring water produces a lot of sweat which results in the removal of poisonous substances from the body.
- ✓ The high sulfur content in the hot spring water is a solution for sinus and nasal congestion.
- ✓ In the mineral rich hot spring water, high level of sodium bicarbonate and calcium exists that facilitate blood and fluid flow in the body.
- ✓ The saltiness of the natural hot spring water has a positive impact on the food digestion system.

The Enterprise hot water supply is from five bore holes located at Finfine compound, each bore hole having a temperature range of 68 – 79 ℃ and these bore holes in total have the capacity to provide 14.08 L/sec [2]. Currently the hot water supply capacity is 65 m^3/hr, each bore hole producing 13 m^3/hr [2]. The hot water from these bore holes is fed into the collection chamber by using water pumps.

Figure 1. 1 : The collection chamber at the Finfine compound

1.2 Problem statement

The filwoha hot spring water is used for shower, hydro-therapy massage, sauna bath and steam bath services [2]. Although the natural hot spring water provides such services it is not used as a drinking water.

This is as a result of the concentration of some parameters in the hot spring water being above the standard requirements for a drinking water. The Physico-chemical water quality analysis reports for the filwoha hot spring water by Addis Ababa Water and Sewerage Authority (AAWSA) and by Ethiopian Conformity Assessment Enterprise (ECAE) are presented below.

Table 1. 1 : Physico-chemical water quality analysis report by Addis Ababa Water and Sewerage Authority (AAWSA) **[Appendix A]**

Parameters	**Unit**	**Filwoha water**	**WHO**
Turbidity	NTU	0.485	<5
Odor	Non obj.	Non obj.	Non obj.
Taste	Non obj.	Non obj.	Non obj.
PH	-	8.12	6.5-8
Total dissolved solid (TDS)	mg/l	**1640**	600
Ammonia as N	mg/l	0.15	1.5
Nitrite as N	mg/l	0.016	1
Nitrate as N	mg/l	0.1	11
Fluoride as F	mg/l	**23.5**	1.5
Total iron as Fe	mg/l	0.1	0.3
Chloride as Cl	mg/l	3.3	250

Table 1. 2: Ethiopian Conformity Assessment Enterprise test report **[Appendix B]**

Characteristics tested	**Unit**	**Filwoha water**	**Standard requirements**
Total hardness as $CaCO_3$	mg/l	224	400
Total alkalinity as $CaCO_3$	mg/l	**2148**	1100
PH value	-	8.12	6.5-8.5
Chloride as Cl	mg/l	3.3	250
Fluoride as F	mg/l	**23.5**	1.5
Nitrate as NO_3	mg/l	0.1	50
Nitrite as ${NO_2}^-$	mg/l	0.016	0.1

Among the parameters listed above, the total dissolved solid (TDS), the total alkalinity and the fluoride exceeded the concentration level of the World Health Organization (WHO) and the Ethiopian Conformity Assessment Enterprise for a drinking water.

1.3 Objectives

1.3.1 General objective

The general objective of this research is to manufacture and carry out experimental investigation on the performance of a geothermal still for purification of the hot spring water found in Addis Ababa, Ethiopia.

1.3.2 Specific objectives

The specific objectives are:

- To manufacture a geothermal still using appropriate local materials.
- To experimentally investigate the performance of the geothermal still.
- To investigate the production rate of the geothermal still.
- To analyze the physicochemical characteristics of the collected water samples.

1.4 Significance of the research

- Purifying the hot spring water for drinking purpose helps to avoid expenses spent for purchasing bottled drinking water for the spa service enterprise consumption.
- In addition to the services the enterprise provides to community using the filwoha hot spring water, by further treating the water for the purpose of drinking the institution can commercialize it as an alternative bottled drinking water.
- It helps to create new job opportunities.

1.5 Delimitation

A geothermal still is manufactured for the purpose of treating only hot spring water. Although the geothermal still can be used to treat hot spring water from different sources, this research will particularly study its performance on filwoha hot springs located in Addis Ababa, Ethiopia. The geothermal still will operate only using the geothermal energy contained in the hot spring water.

CHAPTER TWO

LITERATURE REVIEW

2.1 Desalination technologies

Desalination is by definition a process of removing minerals and salts from sea water to produce fresh water. According to the world health organization (WHO), the permissible limit of salinity in water is 500 parts per million (ppm) and for special cases up to 1000 ppm [3]. Most of the water available on earth has salinity up to 10,000 ppm, and sea water normally has salinity in the range of 35,000-45,000 ppm in the form of total dissolved salts [3].

Table 2. 1 : Level of water salinity in different water solutions [3]

Water salinity based on dissolved salts			
Fresh water	Brackish water	Saline water	Brine
<0.05%	0.05 - 3%	3 - 5%	>5%

Desalination techniques may be classified into phase change or thermal processes and membrane or single-phase processes. In the phase change or thermal processes, the distillation of sea water is achieved by utilizing a thermal energy source. The thermal energy may be obtained from a conventional fossil fuel source, nuclear energy, or a non-conventional solar energy source or geothermal energy. In the membrane processes, electricity is used for either driving high-pressure pumps or ionization of salts contained in the sea water. Solar energy can be used for sea water desalination by producing either the thermal energy required to drive the phase change processes or the electricity required to drive the membrane processes.

Table 2. 2 : Desalination processes [3]

Phase change processes	**Membrane processes**
Multi-stage flash process (MSF)	Reverse osmosis (RO)
Multiple effect boiling (MEB)	Reverse osmosis (RO) without energy recovery
Vapor compression process (VC)	Reverse osmosis (RO) with energy recovery (ER-RO)
Freezing	Electro dialysis (ED)
Humidification-dehumidification	
Solar stills	

2.1.1 The multi-stage flash (MSF) process

The MSF process is composed of a series of elements, called stages. In each stage, condensing steam is used to pre-heat the sea water feed. By fractionating the overall temperature differential between the warm source and sea water into a large number of stages, the system approaches ideal total latent heat recovery operation of this system requires pressure gradients in the plant. The principle of operation is shown in Figure 2.1 [3]. Current commercial installations are designed with 10-30 stages (2 ℃ temperature drop per stage) [3].

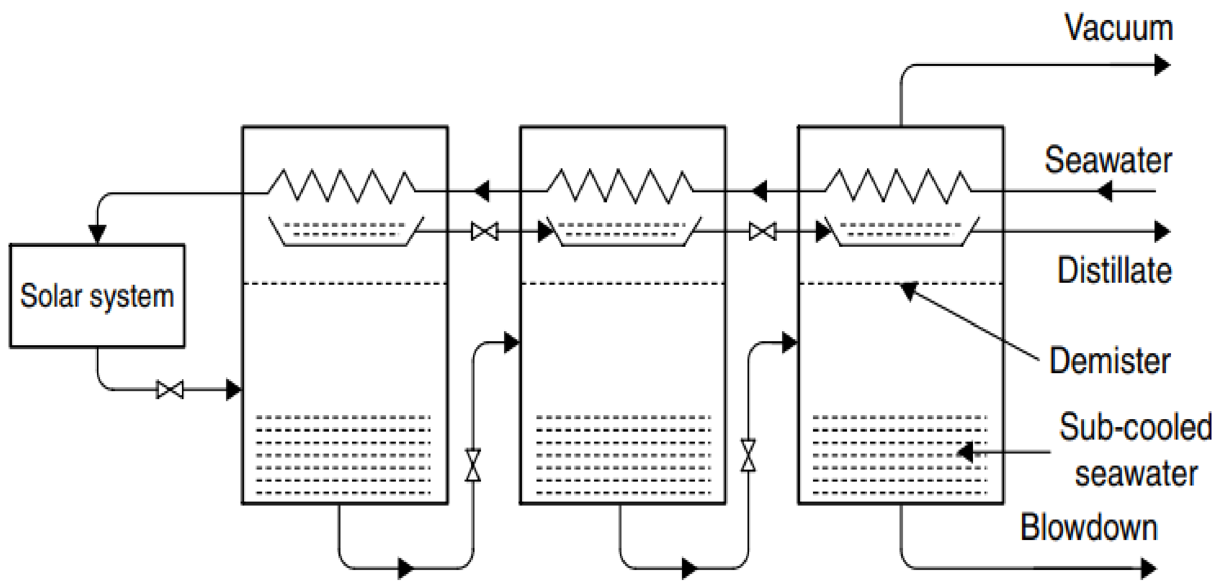


Figure 2. 1: Principle of operation of the multi-stage flash (MSF) system [3]

A practical cycle representing the MSF process is shown in Figure 2.2 [3]. The system is divided into heat recovery and heat rejection sections. Sea water is fed through the heat rejection section, which rejects thermal energy from the plant and discharges the product and brine at the lowest possible temperature.

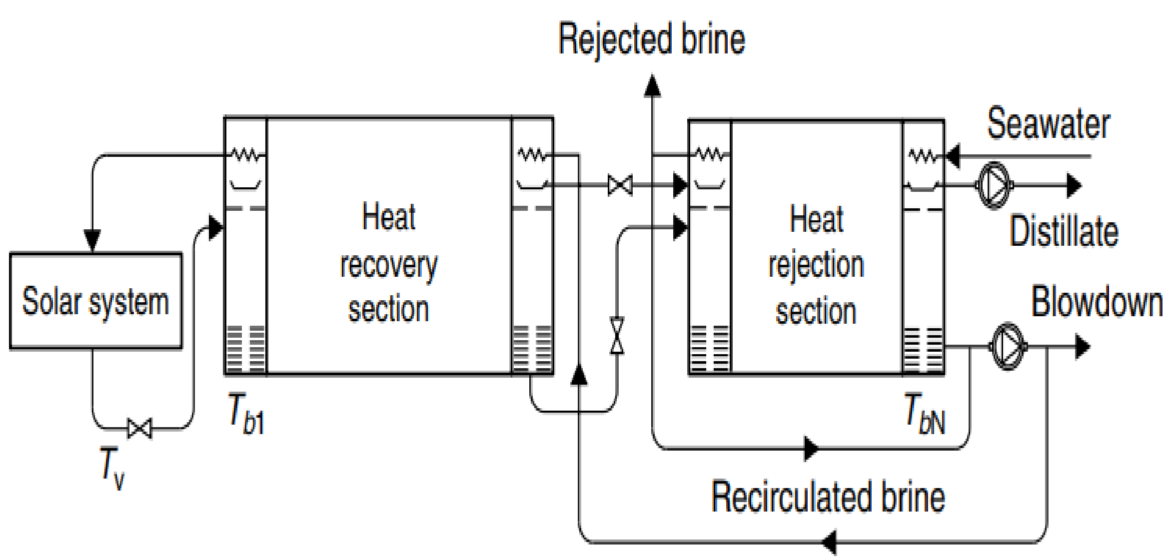


Figure 2. 2: A multi-stage flash (MSF) process plant [3]

The feed is then mixed with a large mass of water, which is re-circulated around the plant. This water then passes through a series of heat exchangers to raise its temperature. The water next enters the solar collector array or a conventional brine heater to raise its temperature to nearly the saturation temperature at the maximum system pressure. The water then enters the first stage through an orifice and, in so doing, has its pressure reduced. Since the water was at the saturation temperature for a higher pressure, it becomes super-heated and flashes into steam. The vapor produced passes through a wire mesh (demister) to remove any entrained brine droplets and then into the heat exchanger, where it is condensed and drips into a distillate tray. This process is repeated through the plant because both brine and distillate streams flash as they enter subsequent stages that are at successively lower pressures.

2.1.2 The multiple effect boiling (MEB) process

The MEB process shown in Figure 2.3 [3] is also composed of a number of elements, which are called effects. The steam from one effect is used as heating fluid in another effect, which, while condensing, causes evaporation of a part of the salty solution. The produced steam goes through the following effect, where, while condensing, it makes some of the other solution evaporate, and so on. For this procedure to be possible, the heated effect must be kept at a pressure lower than that of the effect from which the heating steam originates.

The solutions condensed by all effects are used to pre-heat the feed. In this process, vapor is produced by flashing and by boiling, but the majority of the distillate is produced by boiling. Unlike the multi-stage flash (MSF) plant, the MEB process usually operates as a once-through system without a large mass of brine re-circulating around the plant. This design reduces both pumping requirements and scaling tendencies.

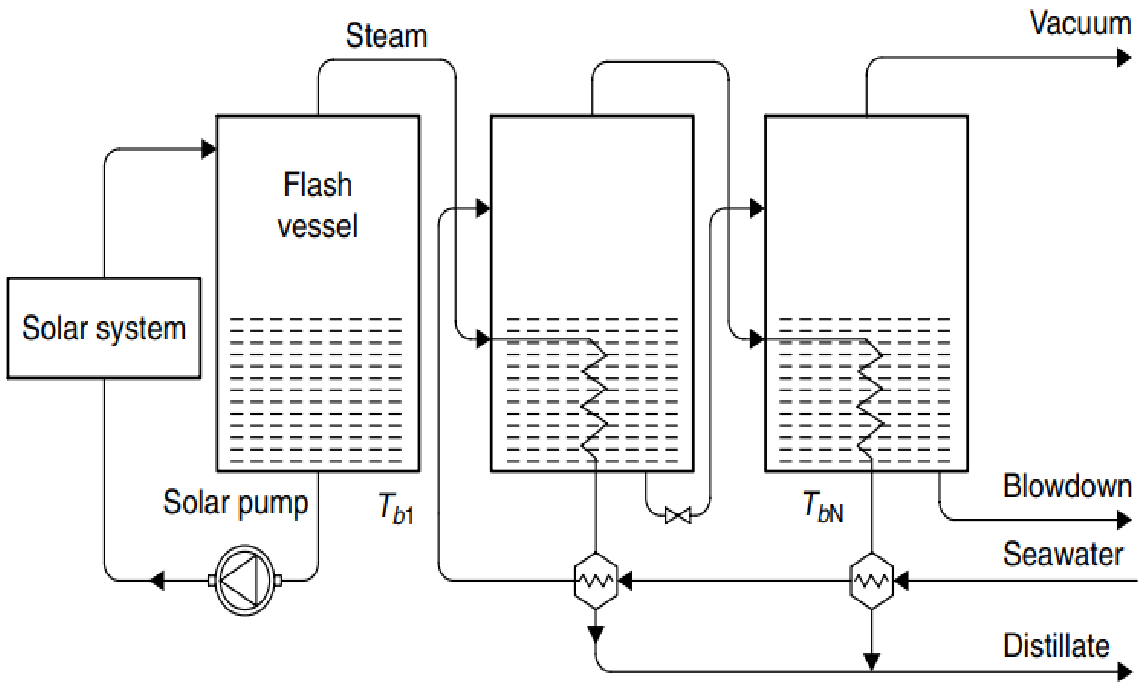


Figure 2. 3: Principle of operation of a multiple effect boiling (MEB) system [3]

As with the MSF plant, the incoming brine in the MEB process passes through a series of heaters, but after passing through the last of these, instead of entering the brine heater, the feed enters the top effect, where the heating steam raises its temperature to the saturation temperature for the effect pressure. Further amounts of steam, from either a solar collector system or a conventional boiler, are used to produce evaporation in this effect. The vapor then goes, in part, to heat the incoming feed and in part, which is at a lower pressure and receives its feed from the brine of the first effect. This process is repeated all the way through (down) the plant. The distillate also passes down the plant. Both the brine and distillate flash as they travel down the plant due to progressive reduction in pressure.

2.1.3 The vapor compression (VC) process

In a VC plant, heat recovery is based on raising the pressure of the steam from a stage by means of a compressor. The condensation temperature is thus increased and the steam can be used to provide energy to the same stage it came from or to other stages.

As in a conventional multiple effect boiling (MEB) system, the vapor produced in the first effect is used as the heat input to the second effect, which is at a lower pressure. The vapor produced in the last effect is then passed to the vapor compressor, where it is compressed and its saturation temperature is raised before it is returned to the first effect.

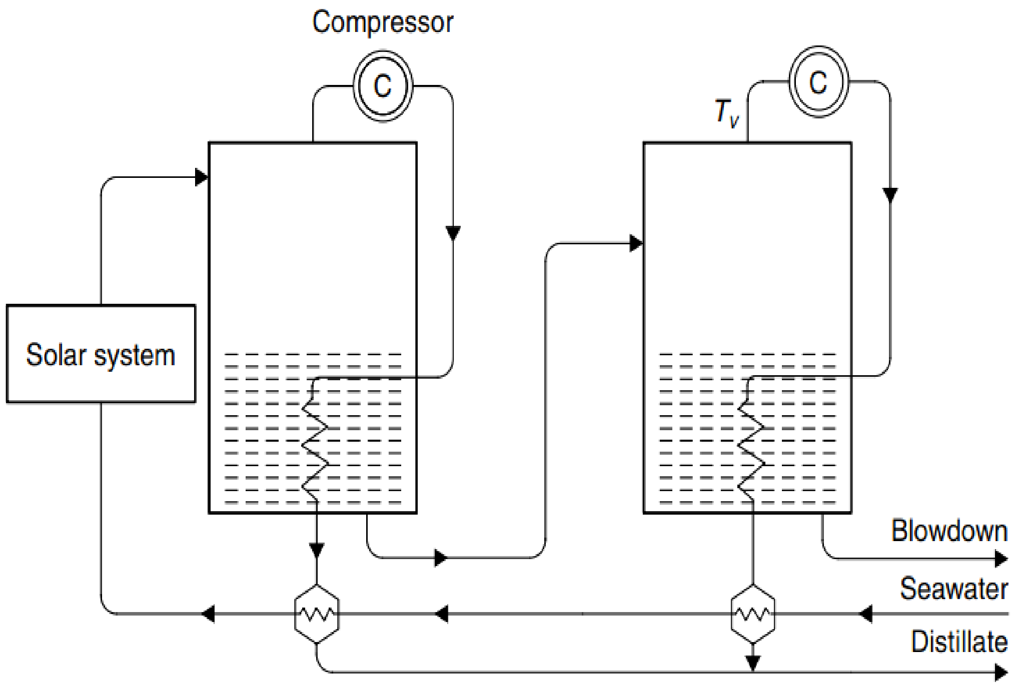


Figure 2. 4: Principle of operation of a vapor compression (VC) system [3]

Vapor compression systems are subdivided into two main categories: mechanical vapor compression (MVC) and thermal vapor compression (TVC) systems. Mechanical vapor compression systems employ a mechanical compressor to compress the vapor, whereas thermal ones utilize a steam jet compressor.

2.1.4 Reverse osmosis (RO)

The RO system depends on the properties of semi-permeable membranes, which, when used to separate water from a salt solution, allow freshwater to pass into the brine compartment under the influence of osmotic pressure. If a pressure in excess of this value is applied to the salty solution, fresh water will pass from the brine into the water compartment.

Theoretically, the only energy requirement is to pump the feed water at a pressure above the osmotic pressure. In practice, higher pressures must be used, typically 50-80 atm, to have a sufficient amount of water pass through a unit area of membrane [3].

With reference to Figure 2.5 [3], the feed is pressurized by a high pressure pump and made to flow across the membrane surface. Part of this feed passes through the membrane, where the majority of the dissolved solids are removed.

The remainder, together with the remaining salts, is rejected at high pressure. In larger plants, it is economically viable to recover the rejected brine energy with a suitable brine turbine such systems are called energy recovery reverse osmosis (ER-RO) systems.

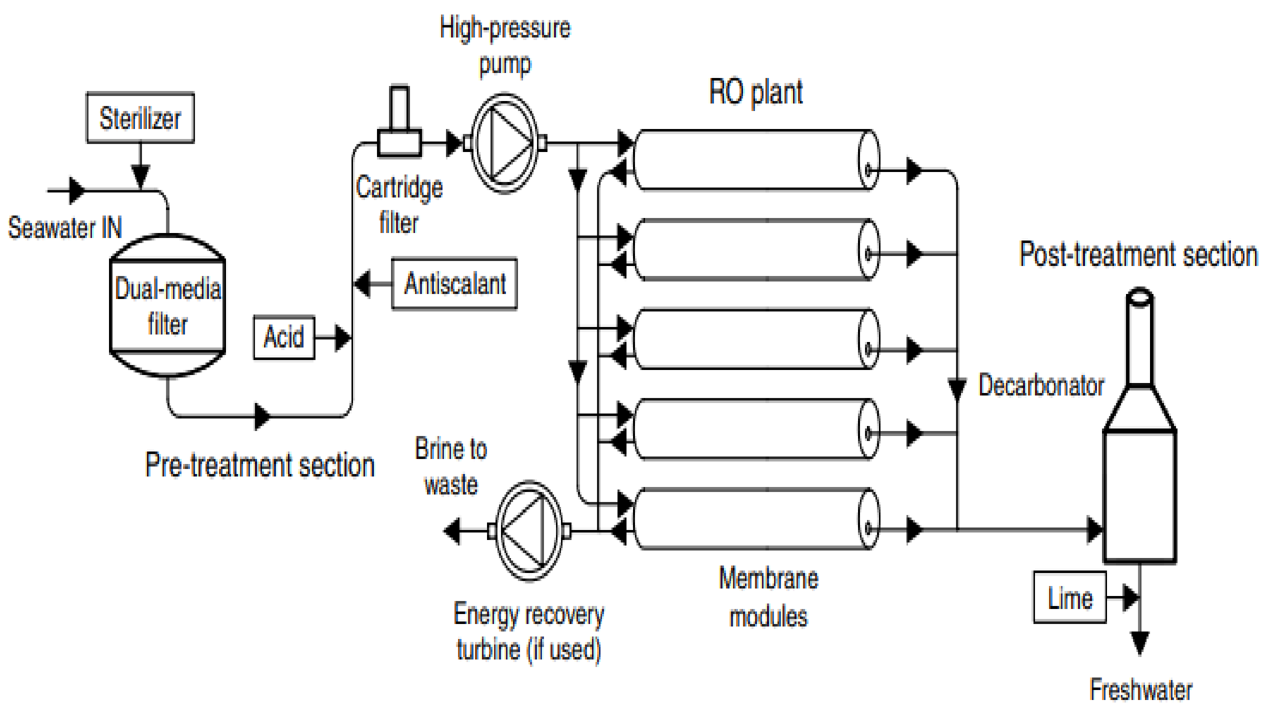


Figure 2. 5 : Principle of operation of a reverse osmosis (RO) system [3]

The membranes are in effect, very fine filters and very sensitive to both biological and non-biological fouling. To avoid fouling, careful pre-treatment of the feed is necessary before it is allowed to come in contact with the membrane surface. One method used recently for the pre-treatment of sea water before directed to RO modules is nanofiltration (NF). NF was developed primarily as a membrane softening process, which offers an alternative to chemical softening.

The main objectives of NF pre-treatment are

1. Minimize particulate and microbial fouling of the RO membranes by removal of turbidity and bacteria.
2. Prevent scaling by removal of the hardness ions.
3. Lower the operating pressure of the RO process by reducing the feed water total dissolved solids (TDS) concentration.

2.1.5 Electro dialysis (ED)

The electro dialysis system, shown schematically in Figure 2.6 [3], works by reducing salinity by transferring ions from the feed water compartment, through membranes, under the influence of an electrical potential difference. The process utilizes a direct current (DC) electric field to remove salt ions in the brackish water. Saline feed water contains dissolved salts separated into positively charged sodium and negatively charged chlorine ions. These ions move toward an oppositely charged electrode immersed in the solution, that is, positive ions (cation) go to the negative electrode (cathode) and negative ions (anions) to the positive electrode (anode). If special membranes, alternatively cation permeable and anion permeable, separate the electrodes, the center gap between these membranes is depleted of salts. In an actual process, a large number of alternating cation and anion membranes are stacked together, separated by plastic flow spacers that allow the passage of water. The streams of alternating flow spacers are a sequence of diluted and concentrated water, which flow parallel to each other. To prevent scaling, inverters are used that reverse the polarity of the electric field every 20 minutes [3]. Because the energy requirements of the system are proportional to the water's salinity, ED is more feasible when the salinity of the feed water is no more than about 6000 parts per million (ppm) of dissolved solids [3].

Similarly, due to the low conductivity, which increases the energy requirements of very pure water, the process is not suitable for water of less than about 400 ppm of dissolved solids [3]. Because the process operates with DC power, solar energy can be used with electro dialysis by directly producing the voltage difference required with photovoltaic panels.

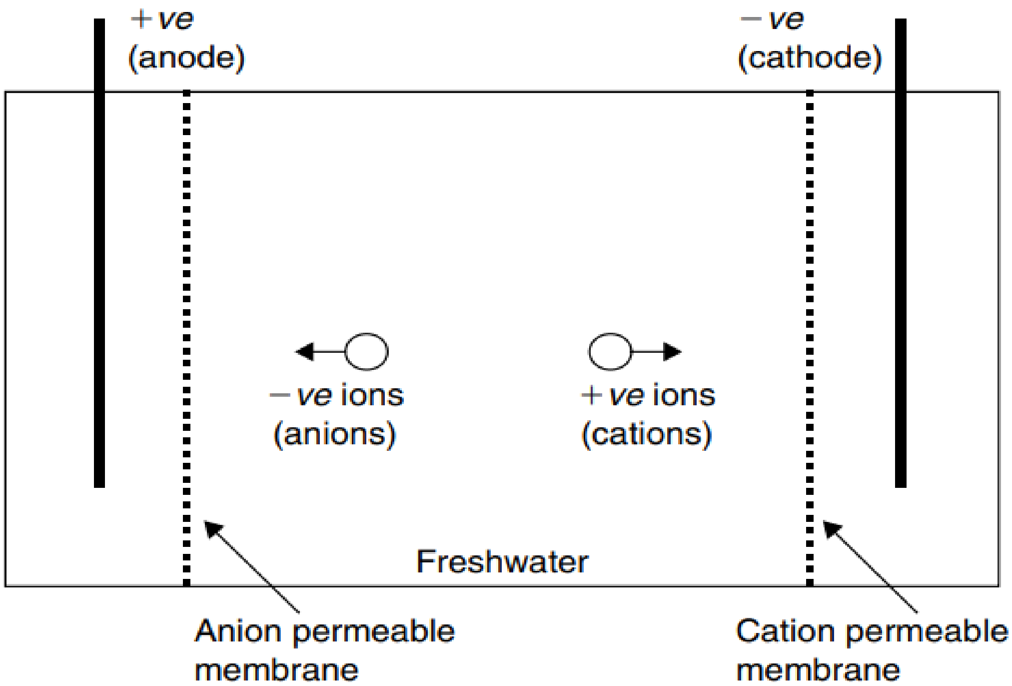


Figure 2. 6: Principle of operation of electro dialysis (ED) [3]

2.1.6 Freezing

In desalination of water by freezing, fresh water is removed and leaves behind concentrated brine. It is a separation process related to the solid-liquid phase change phenomenon. Therefore the basic energy input for this method is the refrigeration system.

2.1.7 Humidification-dehumidification

The humidification-dehumidification method also uses a refrigeration system, but the principle of operation is different. The humidification-dehumidification process is based on the fact that air can be mixed with large quantities of water vapor.

2.2 Solar still

Solar still is a direct solar desalination process in which the collection of heat and distillation occurs in the same unit. A solar still operates using the basic principles of evaporation and condensation.

The impure saline feed water goes into the solar still and the solar radiation penetrate a glass surface causing the water to heat up through the greenhouse effect and consequently evaporate. When the water evaporates inside the solar still, it leaves all contaminants and microbes behind in the basin. The evaporated and now purified water condenses on the underside of the glass and runs into a collection trough and then into an enclosed container.

A solar still effectively eliminates all water-borne pathogens, salts and heavy metals that other huge methods cannot do. Solar still technologies bring immediate benefits to users by reducing health problems associated with water-borne diseases.

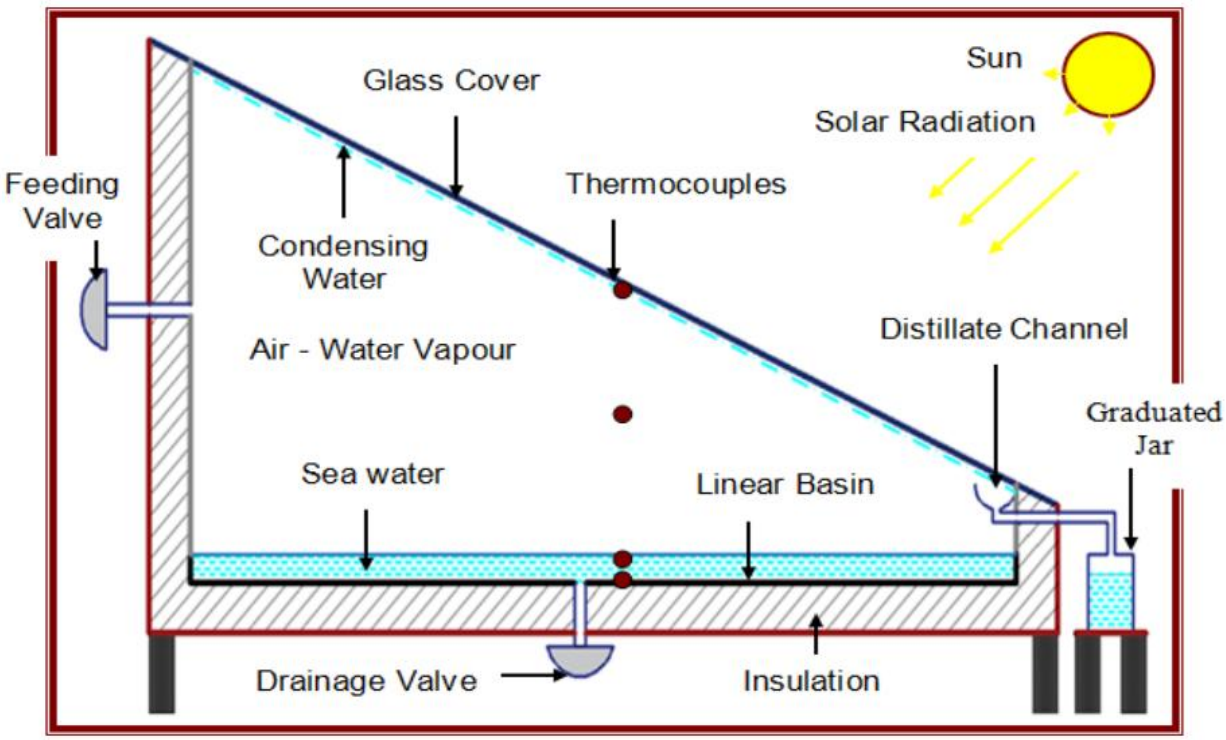


Figure 2. 7: Schematic diagram of a solar still [4]

2.3 Reviews on solar stills

Bhupendra Gupta et al [5] modified, developed and tested existing design of single slope solar still. The modifications in conventional single slope solar still include (i) painting the sidewalls with white color and (ii) attachment of water sprinkler with constant water flow rate of 0.0001 kg/s on the glass cover. The performance of modified single slope solar still has been evaluated and compared with conventional solar still. Experiments have been carried out on both the modified and the conventional single slope solar stills for 5 cm water depth in the month of April at Jabalpur (Latitude 23˚18 N; Longitude 79˚95 E) India.

The distilled water output was recorded 2940 ml and 3541 ml from the conventional and the modified solar stills respectively. Water productivity or yield of the single slope solar still was increased by 20% as a result of the modifications. The overall efficiency was increased by 21% over the conventional solar still.

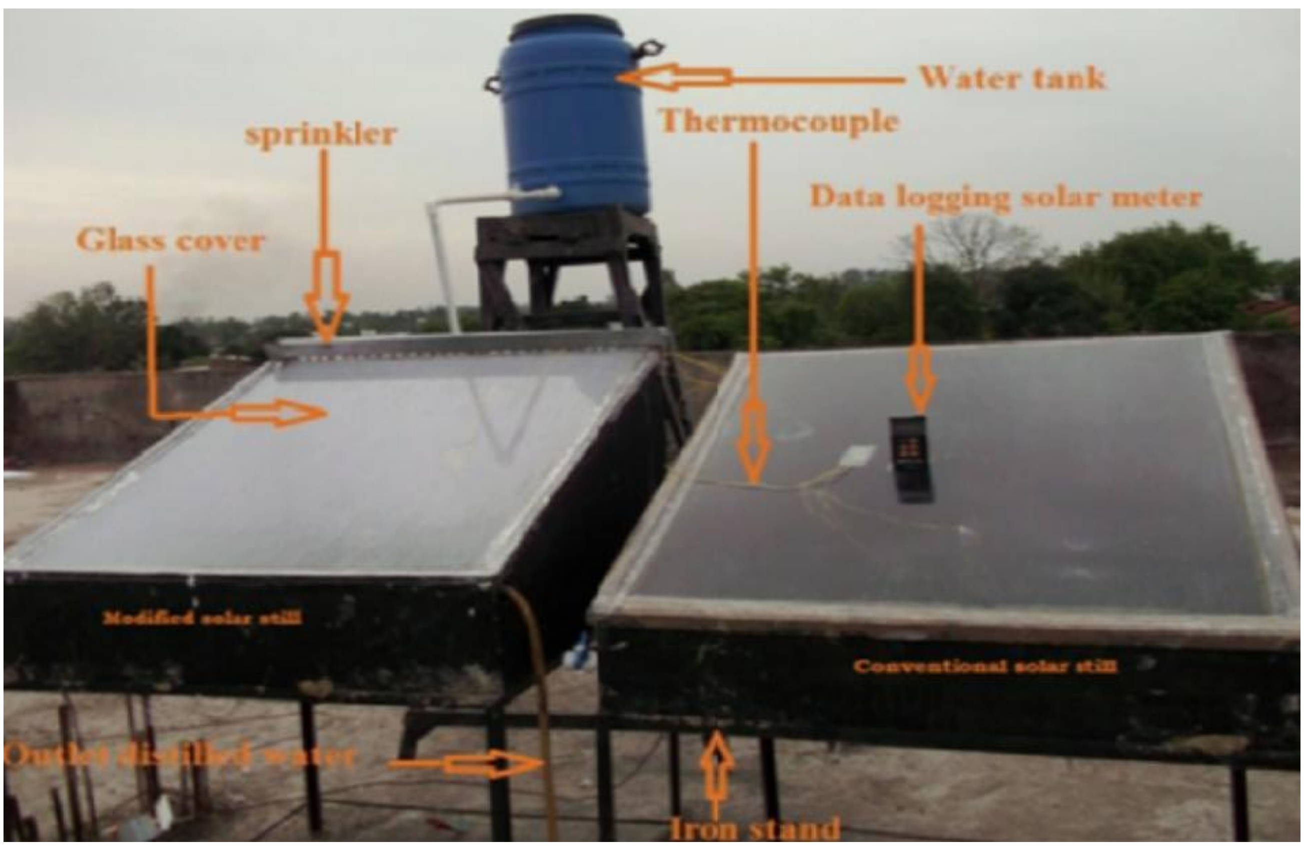


Figure 2. 8: Experimental setup of the modified and the conventional solar stills [5]

Anshika Rani et al [6] performed the experimental study at the M.A.N.I.T, Bhopal M.P, India (latitude: 23°12′ 51″ N, longitude: 77° 25′ E) in the month of January 2018. The investigation has been performed on single slope solar still coupled with a flat plate solar collector to examine the thermal behavior of the solar system and results have been presented for the natural and the forced convection modes.

The solar desalination (SD) system was fabricated to investigate the effect of different operating parameters under similar seasonal effect of the central part of India at Bhopal. The single slope solar still was attached with flat plate collector (FPC) directly in the natural convection mode while in the forced convection mode, there was a pump used between the outlet of the solar still and inlet of the collector and the flow rate from the pump was 3.5 L/min.

The SD system was wrapped by black color polythene to prevent heat loses and the pumping system was stopped at night hours to reduce heat loses. The basin of the solar still was painted black for acquiring more absorptivity and a glass cover of 3 mm thick was used. The area of the solar still and FPC was 1 and 2 m^2, respectively. The depth of solar still was 5.08 cm. Glass was fixed on the side of the Fiber-Reinforced Plastic (FRP) frame, and an inclination of 23^0 is given to the glass cover, which is same as the latitude of Bhopal. To avoid vapor leakage, glass putty was used as a sealing material for filling the gap between the solar still and glass cover. Plastic vessels were used to collect the distillate yield. The overall efficiency reached up to 9.86% in the natural mode where as 16.70% in the forced mode. Therefore, the forced mode solar still was preferred.

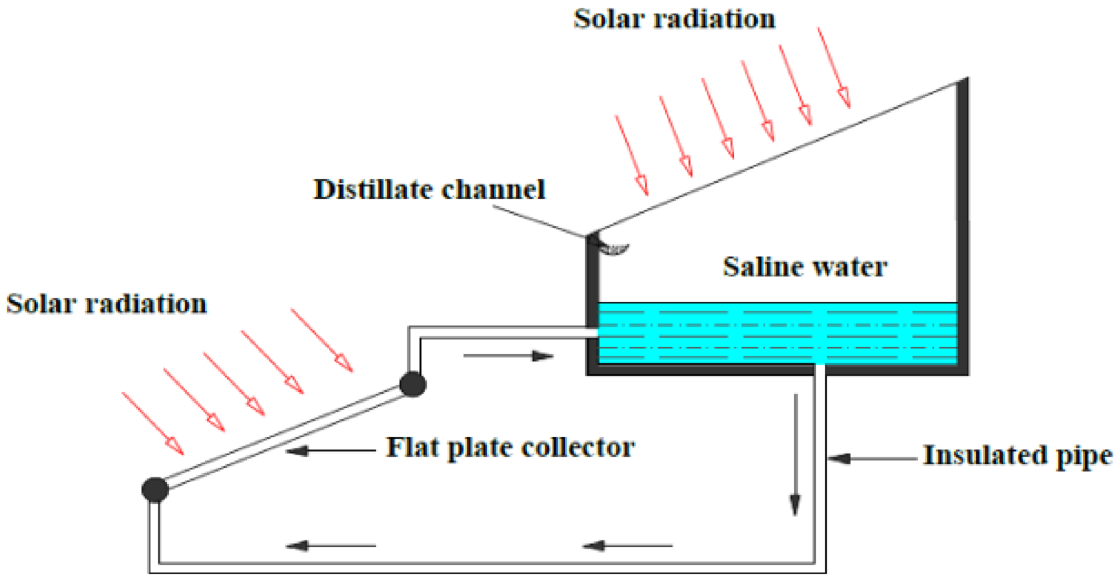


Figure 2. 9: Cross-sectional view of the single slope natural convection solar still [6]

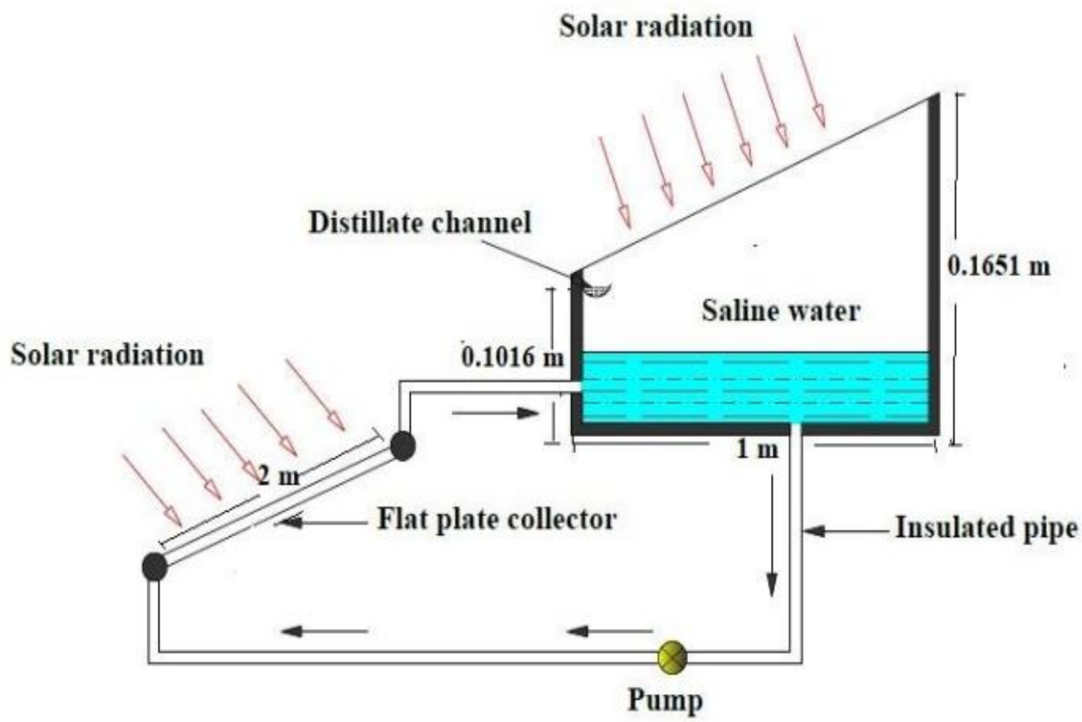


Figure 2. 10: Cross-sectional view of the single slope forced convection solar still [6]

B.B. Sahoo et al [7] aimed to improve the productivity of an existing conventional single slope solar still with modifications. The conventional solar still was modified by using reflectors, jute cloth and improved glass angle. The glass of the conventional solar still was placed at 8° inclination to the horizontal. The modified still productivity and performance were investigated experimentally and compared to that of the conventional solar still.

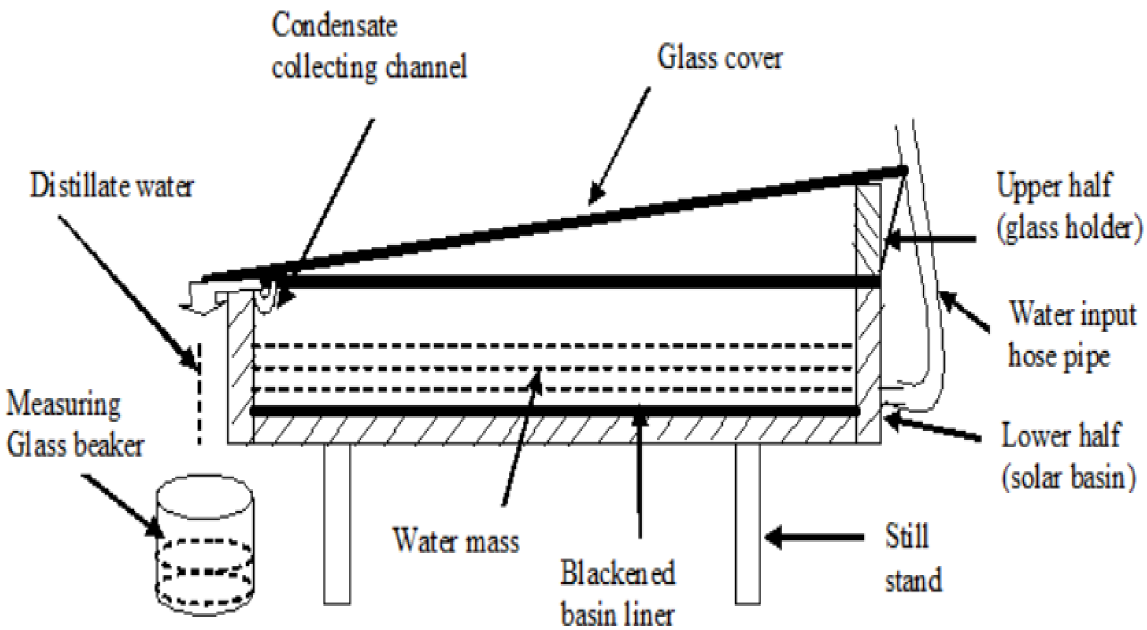


Figure 2. 11: Schematic Diagram of the conventional solar still [7]

The results demonstrated that the solar still performance was improved with 10° glass angle due to better water flow properties and higher solar radiation falling on the solar still. The results revealed that, with all the combined modifications, the water productivity and efficiency of the modified solar still increased by 72.18% and 41.51% respectively more than the conventional one. This implied that the modified solar still could be adopted for higher water productivity at a lower additional cost.

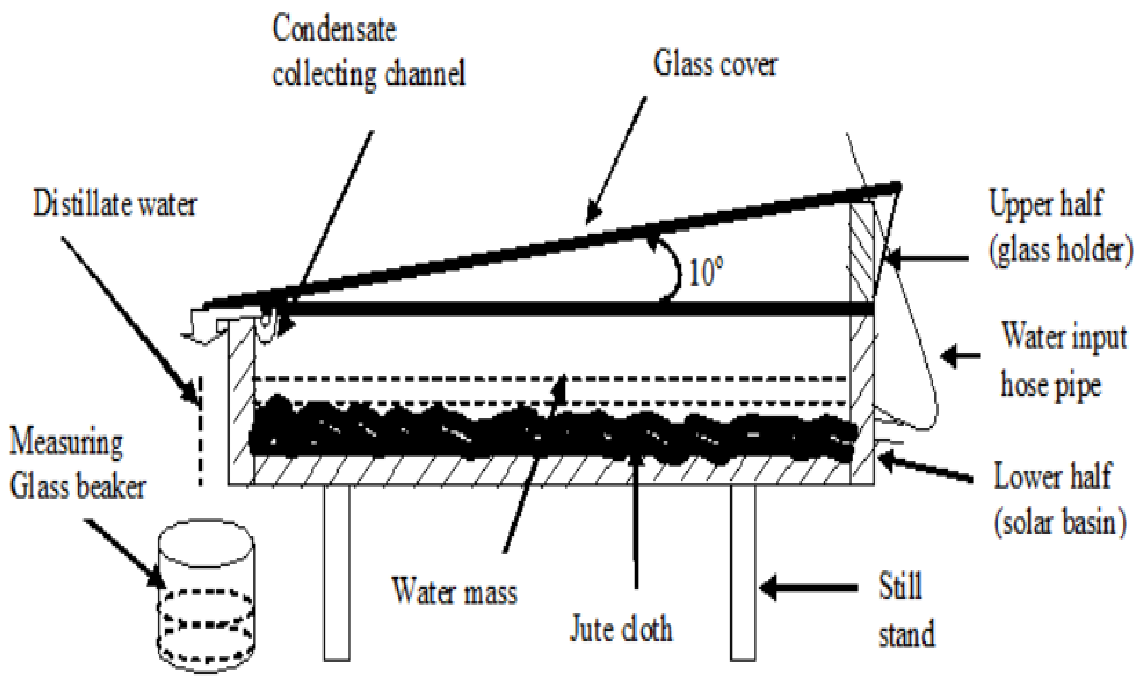


Figure 2. 12: Schematic diagram of the modified solar still [7]

G. S. Dhindsa et al [8] modified the conventional single effect basin type solar still by incorporating floating wicks inside the basin to augment its daily distillate output. The solar still with floating wicks in the basin water was referred as a modified solar still. Both of the solar stills were fabricated with the same material and dimension for comparison purpose. The performance of the modified and the conventional solar stills has been compared under similar operating and weather conditions.

The schematic diagram of the modified solar still is shown in. The single basin single slope solar still frame was made of up of mild steel having high tensile strength. The top of the solar still has been covered with transparent glass and the basin was made up of stainless steel due to high ductility and resilience.

The glass of the solar still was inclined at an angle of 30º and the surface of the basin was covered with black material. The basin tray was made up of stainless steel having a surface area of 1.2 m^2. The wicks were made up of light weight thermocol and covered with blackened porous cloth.

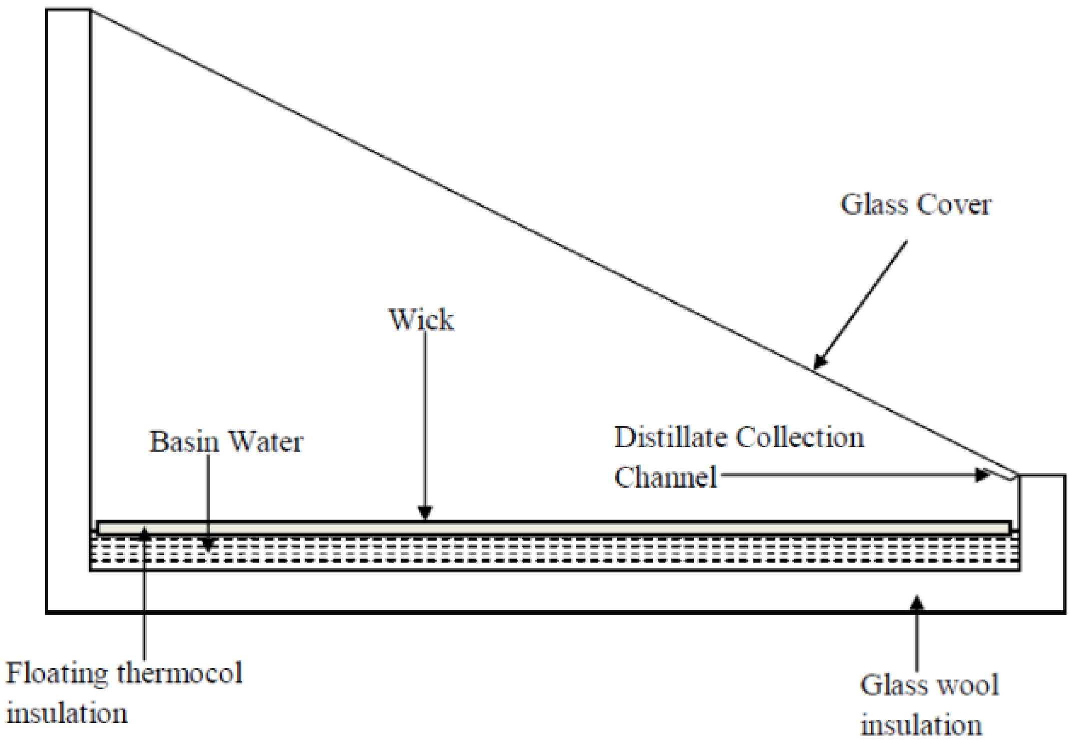


Figure 2. 13: Schematic diagram of the solar still with floating wicks [8]

Thermocol was used as a floating material. Thermocol sheet was cut into various sizes of floats. The width of floating wicks was 1 inch and having fixed length of 28 inches. The floating wicks were arranged adjacent to each other and sufficient distance was maintained between float and sidewalls of the basin. Due to this the floating wicks were unable to displace as the level of water changes.

The use of float wicks reduced thermal inertia of the basin leading to early response and higher operating temperatures which resulted in enhanced distillate outputs of the modified solar still as compared to the conventional solar still.

In this work, the area ratio of floating wicks and basin surface was varied so that the solar still can produce sufficient amount of distillate also during night. The gain in day productivity of the modified solar still was found be increased from 16.9% to 59.5 % while the gain in night productivity decreased from 20% to -33.33% as the area ratio of wick to basin increased from 0.4 to 1.

The maximum overall gain in productivity of the modified solar still over the conventional solar still was found to be 21 % at 0.6 area ratio. The overall productivity of the modified and the conventional solar still for 0.6 area ratio was found to be 4.24 kg/m^2 and 3.48 kg/m^2 respectively, at 3 cm basin water depth and 22.79 MJ/m^2 solar intensity.

A. A. Ibrahim et al [9] conceptualized and developed two designs of solar stills and experimentally investigated their effects on the productivity process. A solar still using a submerged flat absorber plate and another solar still without any submerged absorber plate were designed and constructed. The designs were developed by virtue of the comparative analysis to be carried out. The two solar still designs were tested under the same conditions. Comparatively, more distilled water was obtained from the solar still without submerged plate at 10 liters of inlet raw water during the first day of experiment while the still with submerged flat absorber had more distillate during the second and third day of the experiment with 20 and 30 liters inlet raw water respectively.

Figure 2. 14: The submerged flat absorber plate [9]

It is necessary that the material for both the basin and the submerged absorber plate have high absorptivity or very less reflectivity and tansmissivity. In this work a blackened aluminum sheet having a thermal conductivity of 205 W/m℃ was used. The length of the submerged absorber plate was a little bit less than the length of the solar still basin so that it could fit easily.

The efficiencies were 82.35 % and 82.35 % on the first day of experiment, 82.99% and 82.56% on the second day of experiment and 83.82% and 81.98% on the third day of experiment for the solar still with submerged flat plate absorber and the solar still without submerged flat plate absorber respectively.

J. O. Ozuomba et al [10] fabricated and tested a slanting-type solar water distillation kit outdoor under the meteorological conditions of Imo State University, Owerri, Nigeria. The system consist of four major components; a wooden basin of surface area 0.16 m^2, an absorber surface, a slanting glass roof and a condensate channel. Locally available materials were used to fabricate the solar still. The solar still produced an average of 0.09 m^3 of distilled water per day, and this study was performed in the month of November, 2015. Daily efficiencies of the distillation kit were estimated and the average efficiency of the kit was found to be 7.7%.

C. Tenthani et al [11] designed two conventional solar stills with an identical geometry but the internal surfaces of their walls were painted white and black. These solar stills were tested outdoors under the same meteorological conditions at the Malawi Polytechnic (15° 42' S, 35°02' E).

Distillate output was measured during experimentation. It was found that the average daily distillate outputs were 2.55 kgm^{-2} and 2.38 kgm^{-2} for the experimental solar still and the conventional solar still (whose internal surface was painted black) respectively.

In addition, the efficiency of the experimental solar still was 6.8% more than that of the conventional solar still. It can therefore be concluded that painting the internal surfaces of the walls of the solar still white improve the distillate output.

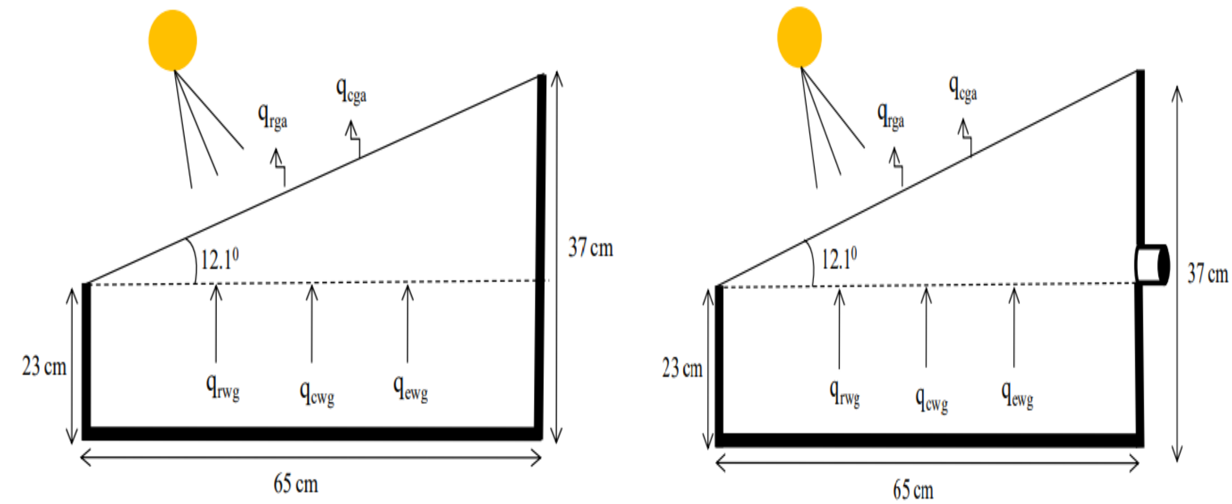
J. D. Obayemi et al [12] carried out experimental investigations on two single slope solar stills: a modified solar still with variable collector/inclination angle (still A), and a conventional solar still with rigid angle of collector/inclination (still B).

The significance of the design was its ability to be able to optimally function properly by variation of the angle at which solar radiation is optimally incident on the system at different locations and time.

Also, the experiment was carried out at latitude of 11º 20′ in Samaru, Zaria – Nigeria, during an average period of solar radiation. Experimental results between the hours of 8:00 am and 5:00 pm for a period of 5 days were carefully obtained and analyzed. The results clearly showed that distillate peak yield occurred between 2:00 pm and 3:00 pm while minimum yield was obtained between 8:00 am and 9:00 am during the period of experiment. It was observed that, still B had an average yield of 1.366 liter/day/m^2 as compared to still A, 1.407 liter/day/m^2.

Furthermore, the results obtained for the two single slope solar stills were analyzed using a statistical model (a paired T-test). The outcomes clearly suggest that, there is no significant difference between the distillate of solar still A (efficiency of 42%) and solar still B (efficiency of 39%).

S Umar et al [13] presented an experimental investigation and performance analysis of single slope solar stills of identical basin area of 0.35 m^2. The stills include; solar still D1, (conventional with galvanized iron basin), solar still D2, (galvanized iron basin with 4inch hand hole attached at the side), solar still D3, (conventional with blacked ceramic basin), and solar still D4, (Ceramic basin with 4 inch hand hole attached at the side).



(a) (b)

Figure 2. 15 : Schematic diagram of (a) The conventional solar still (b) The modified solar still [13]

The results obtained showed that the solar stills D1, and D2 with galvanized iron (GI) basin revealed higher productivity of 580 ml/day and 510 ml/day respectively, compared to the solar stills D3, and D4, which have 340 ml/day and 315 ml/day respectively.

Further results indicated that solar still D1 with galvanized iron at the basin has greater efficiency and distillate productivity of 54.06 % compared to the other solar stills D2, D3 and D4 which have daily efficiency and productivity of 50.91 %, 28.20 %, and 27.97 % respectively. This however, indicated that the adoption of 4 inch hand hole in the solar still design can help in reducing the particles deposited at the basin to minimize basin corrosion.

Phillips O. Agboola et al [14] designed, fabricated and tested an inclined solar water distillation system under the climatic condition of Riyadh. The study investigated the effect of cooling the glass cover of an inclined solar water distillation system.

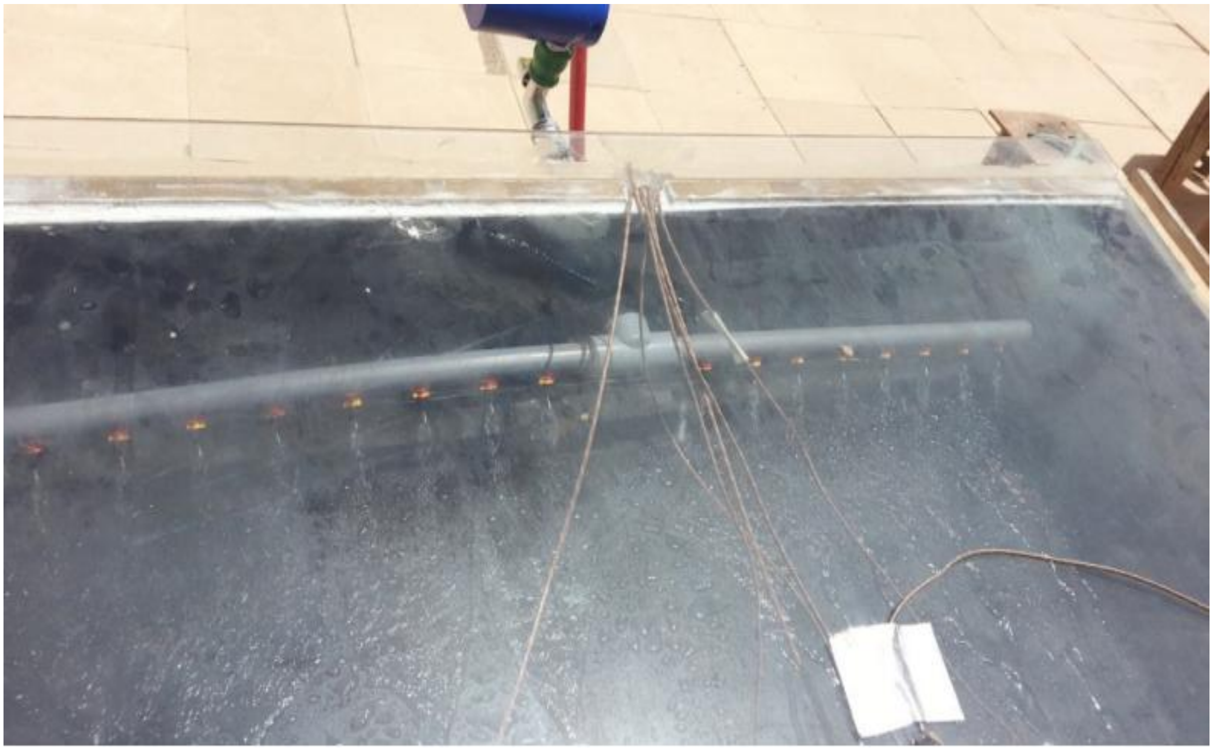


Figure 2. 16: Water film cooling of the glass cover [14]

The system was tested with three modifications: a system without glass cooling, a system with part of the glass shaded with silver shade mesh, and a system with intermittent water film cooling of the glass cover. Experimental results showed that the use of shade and water film cooling increased the yield by 10.77% and 58.98%, respectively.

Bhupendra Gupta et al [15] carried out an experimental investigation in the month of April 2015 for climate condition of Jabalpur, Madhya Pradesh, India (latitude 23° 18′ N; longitude 79° 95′ E) during full day, 6:00 a.m. to 6:00 p.m. The performance of the solar still with modification of water flow over the glass cover (sprinkler attachment) and nanoparticles (cuprous oxide) in basin water has been observed, recorded, and compared with the conventional solar still.

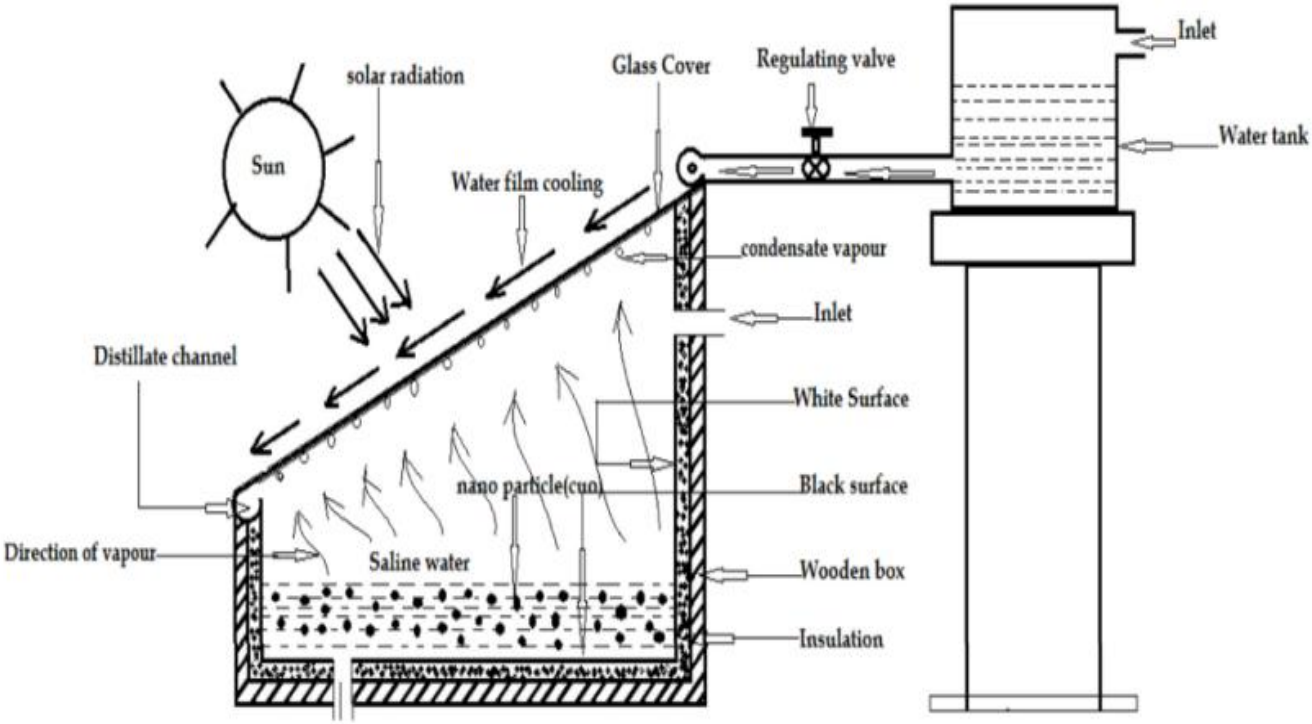


Figure 2. 17 : Schematic view of the modified solar still [15]

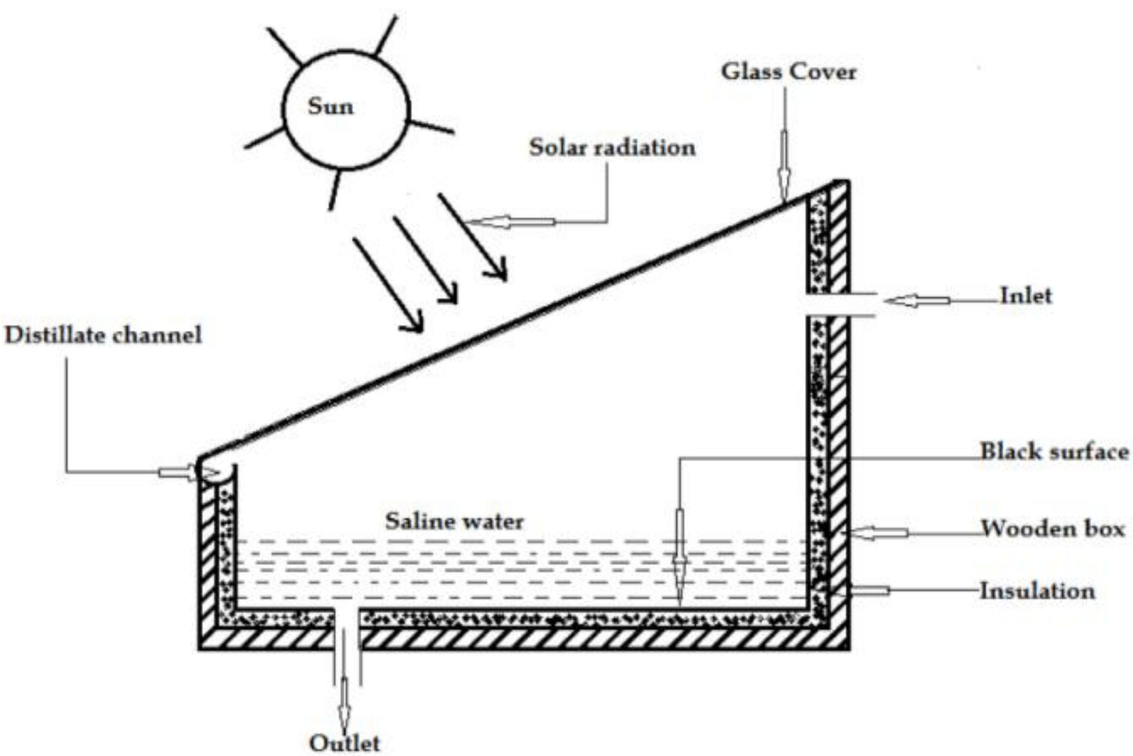


Figure 2. 18: Schematic view of the conventional solar still [15]

It has been found that the collection of pure water in the modified solar still was 4 L/m^2/day as compared to 2.9 L/m^2/day in the conventional solar still. Efficiency of 34% and 22% has been obtained for the modified solar still and the conventional still, respectively. With design amendments, increase in overall effectiveness was found to be 54.54%.

Abhay Agrawal et al [16] conducted an experimental study in Rewa, India for improving the performance of single slope basin type solar still. For this purpose, multiple spherical floating jute cloth absorbers were floated over the surface of the basin water. Due to low thermal capacity and capillary property of porous absorbers, a high rate of evaporation of water was obtained, resulting in more productivity. The effect of solar radiation, ambient temperature, absorber temperature, glass cover temperature, basin water temperature, hourly and daily distillate output and daily efficiency of the modified and the conventional solar stills were studied. It was observed that the modified solar still gave 46.33% higher distillate output over the conventional solar still. The daily efficiency of the modified solar still was 55.73%, which was higher than that of the conventional solar still.

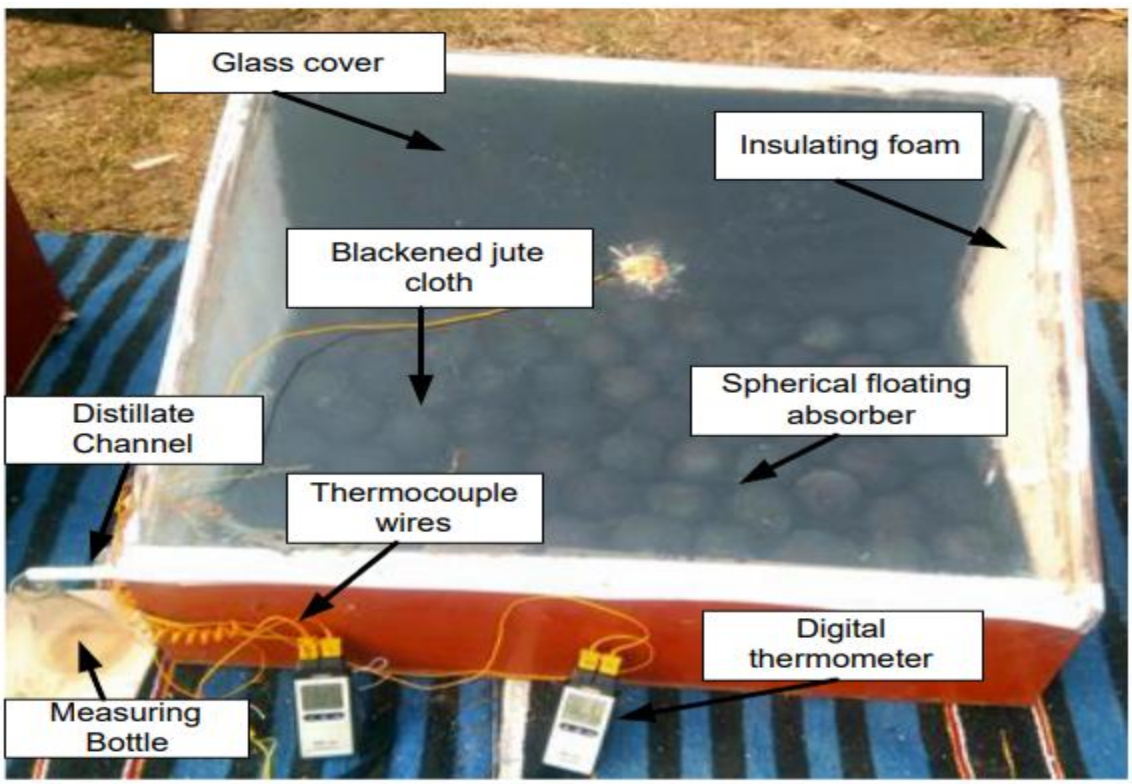


Figure 2. 19: The experimental setup of the modified solar still [16]

Mulyanef et al [17] presented a study of experimental performance of a solar still using reflector to produce fresh water and salt in the climate of Padang city, Indonesia. The solar collector was equipped with a reflector placed on the top of the cover with slope of 30º. The test results showed that using a reflector can increase the temperature of the basin. Average daily freshwater productivity increased by 16.8% during the testing period by adding reflector compared to the solar still without a reflector.

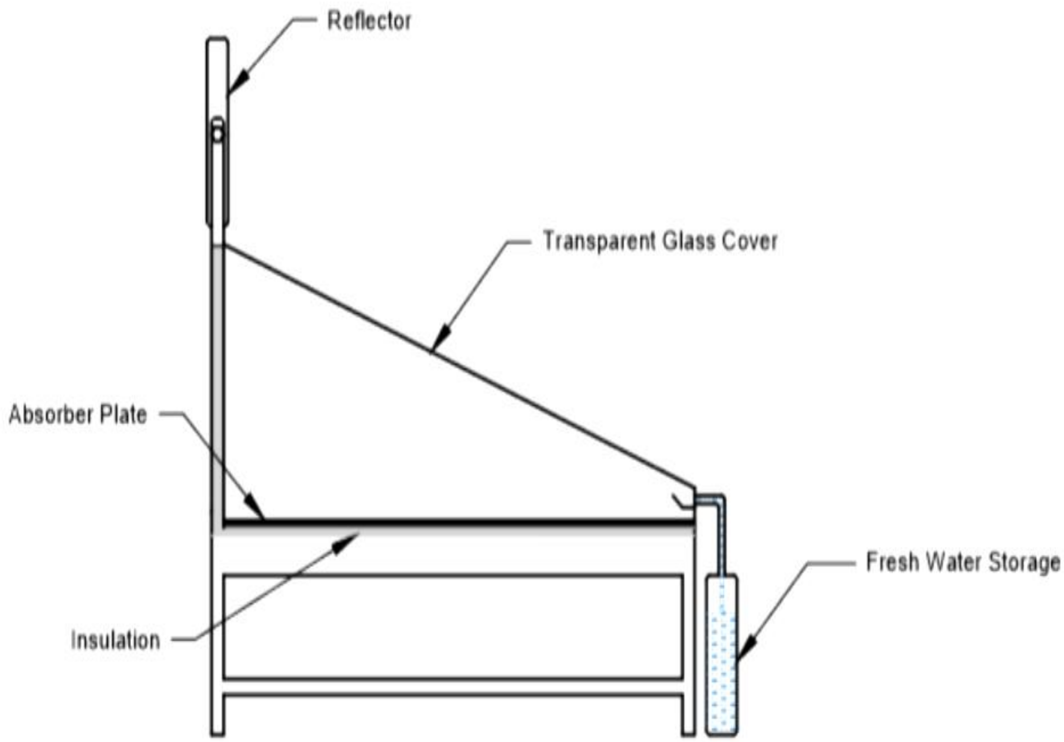
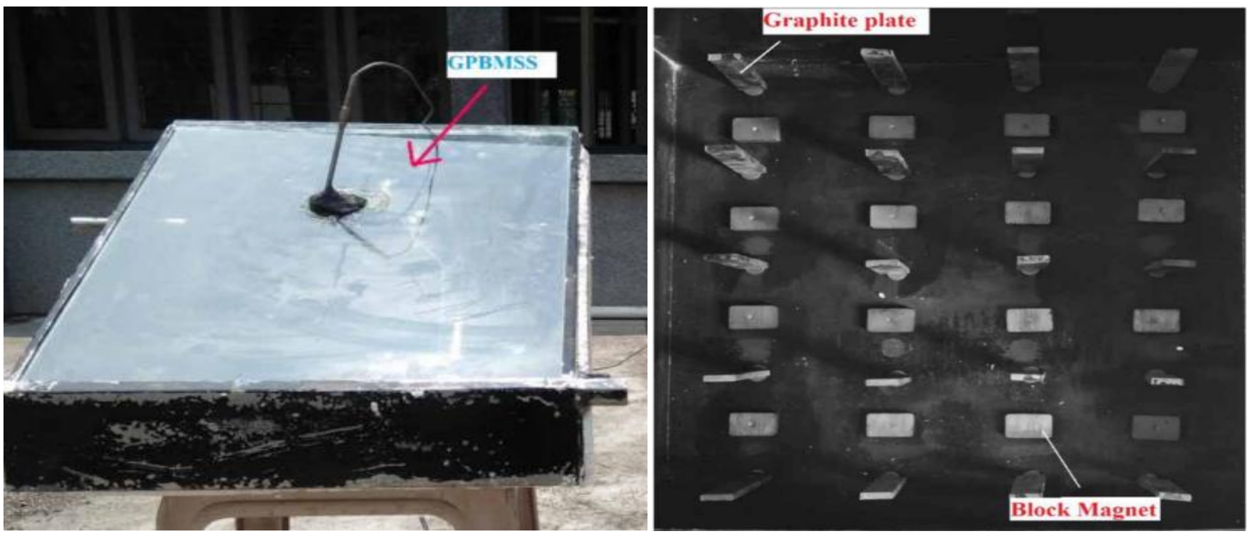


Figure 2. 20: Schematic diagram of the solar still [17]

R. Dhivagar et al [18] investigated the thermodynamic (energy and exergy) analysis of a single slope solar still using graphite plates and block magnets (GPBMSS) during summer and winter climatic conditions of Coimbatore city, India. The results observed in GPBMSS were compared with a conventional solar still (CSS) under the same climatic conditions. The outcomes observed showed that the hourly productivity in GPBMSS was 19.6% and 22.8% higher in summer and winter days, respectively, when compared to CSS. The cumulative productivity in GPBMSS was found to be about 3.93 kg/m^2 and 3.56 kg/m^2 respectively, for 12 hours observations during summer and winter days.

Furthermore, the energy and exergy efficiencies of GPBMSS were substantially improved by 20.6% and 18.1% when compared to CSS during summer days. Similarly, the energy and exergy efficiencies of GPBMSS were increased by 18 and 19% compared to CSS in winter days.

In addition, the maximum basin exergy destruction was observed in CSS compared to other solar still components. The results observed that the heat storage ability of the graphite plates and water magnetization in GPBMSS greatly decreased the exergy destructions. Finally, the water quality analysis proved that the distillate collected from both GPBMSS and CSS satisfied the requirements recommended by the Bureau of Indian Standards.



(a) (b)

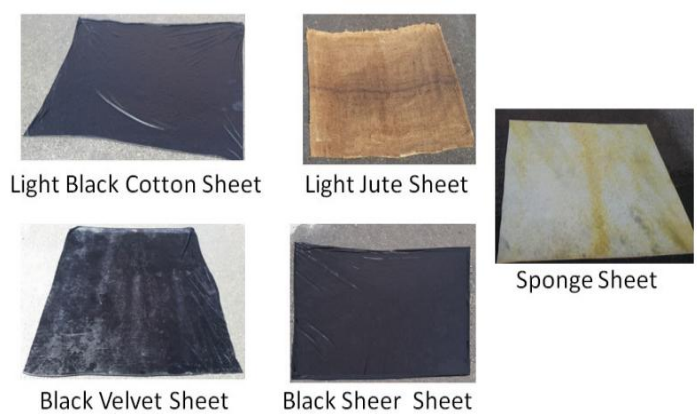
Figure 2. 21: Photographic view of (a) The single slope solar still (b) The block magnets arrangement [18]

Husham M. et al [19] designed and constructed three identical conventional basin type solar stills in order to experimentally investigate the effect of using different wick materials in two different layout arrangements. The first solar still was used as a reference still for comparison. The second solar still was used for uniformly spreading the wick material sheets in the saline water. In this case, the wick materials sheets were completely immersed in the saline water covering the total still basin area. The third solar still had a specially designed set up of steel mesh wires. In this case, the wick materials were partially immersed in the saline water. The net basin horizontal effective area of each solar still was 1 m^2, and the glass cover tilt angle was fixed at 32.5º.

Five types of wick materials in the form of material sheets were used. They were light black cotton fabric, light jute fabric, black velvet fabric, black sheer mesh fabric, and a 4 mm thick sponge sheet. Spreading the wick material sheet to cover the basin area had the effect of preventing the sunrays from reaching the solar still basin and consequently absorbed by the saline water and the wick material resulting in enhancement of the yields of solar stills. The aim of adding mesh wire layout arrangement was to increase the surface area of evaporation for the saline water.

The first solar still (reference conventional bare solar still without wick materials) was found to produce an average value of 3.261 liters/day. The second solar still with wick materials was found to enhance the solar still productivity by 36.9%, 23%, 20%, 16.8%, and 11.5% for the light black cotton fabric, light jute fabric, black velvet fabric, black sheer mesh fabric, and a 4 mm thick sponge sheet respectively. The light black cotton fabric is the most effective and the sponge sheet is the least effective materials in enhancing the solar still productivity.

The third still with wick materials and mesh layout arrangements found also to enhance the productivity by 26.3%, 16.9%, 14.8%, 12.5%, and 9.9% respectively for the same sequence of materials. It can be seen that immersing the wick materials has more positive effect in enhancing the solar still productivity than the still with mesh arrangements and partially immersed wick materials.



(a) (b)

Figure 2. 22: Photographs of (a) The three identical conventional basin type solar stills (b) The five types of wick materials [19]

Table 2. 3 : The modifications introduced by researchers to enhance the productivity of solar stills

No.	Authors	Title	Modifications
1	Bhupendra Gupta et al [5]	Performance enhancement of modified solar still using water sprinkler: An experimental approach	The modifications in conventional single slope solar still include (i) inside walls painted with white color and (ii) attachment of water sprinkler with constant water flow rate of 0.0001 kg/s on the glass cover.
2	Anshika Rani et al [6]	Experimental investigation on thermal behavior of hybrid single slope solar still	Single slope solar still is attached with flat plate collector directly in natural convection mode while in forced convection mode, a pump was used between the outlet of the solar still and the inlet of the collector.
3	B.B. Sahoo et al [7]	Performance enhancement of solar still by using reflectors-jute cloth-improved glass angle	The conventional solar still was modified by using reflectors, jute cloth and improved glass cover angle.
4	G. S. Dhindsa et al [8]	Augmentation of the diurnal productivity of basin type single slope solar still using	The conventional single effect basin type solar still was modified by

		floating wicks in the basin	incorporating floating wicks inside the basin. Thermocol was used as a floating material.
5	A. A. Ibrahim et al [9]	Design, construction and performance comparison of two solar stills having different absorber design	A solar still using a submerged flat absorber plate was designed and constructed.
6	J. O. Ozuomba et al [10]	Design and determination of the efficiency of a slanting-type solar water distillation kit	-
7	C. Tenthani et al [11]	Improved solar still for water purification	Two conventional stills were designed with an identical geometry but the internal surfaces of their walls were painted white and black.
8	J. D. Obayemi et al [12]	Design and fabrication of a single slope solar Still with variable collector angle	An experimental investigation was carried out on a modified solar still with variable collector/inclination angle.
9	S. Umar et al [13]	Experimental investigation and performance analysis of single slope solar still	Experimental investigation was performed on single slope solar stills having identical basin area. The solar stills include; solar still D1, (conventional with galvanized iron basin), solar still D2, (galvanized

			iron basin with 4inch hand hole attached at the side), solar still D3, (conventional with blacked ceramic basin), and solar still D4, (Ceramic basin with 4 inch hand hole attached at the side).
10	Phillips O. Agboola et al [14]	Effect of cooling the glass cover of an inclined solar water distillation system under the climatic condition of Riyadh, Saudi Arabia	The system was tested with three modifications: a system without glass cooling, a system with part of the glass shaded with silver shade mesh, and a system with intermittent water film cooling of the glass cover.
11	Bhupendra Gupta et al [15]	Experimental investigation on modified solar still using nanoparticles and water Sprinkler attachment	The performance of the solar still with modification of water flow over the glass cover (sprinkler attachment) and nanoparticles (cuprous oxide) in basin water has been observed.
12	Abhay Agrawal et al [16]	An experimental investigation of single sloped basin type spherical floating jute cloth absorbers solar still	Experimental study was conducted using multiple spherical floating jute cloth absorbers over the surface of basin water.
13	Mulyanef et al [17]	Performance experimental	Experimental performance

		study of solar still with reflector to produce fresh water and salt	of solar still using reflector was carried out. The solar collector was equipped with a reflector placed on the top of the cover with slope of 30º.
14	R. Dhivagar et al [18]	Thermodynamic analysis of single slope solar still using graphite plates and block magnets at seasonal climatic conditions	The thermodynamic (energy and exergy) analysis of a single slope solar still was investigated using graphite plates and block magnets.
15	Husham M. et al [19]	Performance evaluation of a conventional solar still with different types and layouts of wick materials.	Three identical conventional basin type solar stills were designed and constructed in order to experimentally investigate the effect of using different wick materials. They were light black cotton fabric, light jute fabric, black velvet fabric, black sheer mesh fabric, and a 4 mm thick sponge sheet.

2.4 Literature review summary

There are a number of advantages of solar stills. Some of them are:

- Solar energy can be well utilized, thus the use of fossil fuels will be reduced to a great extent.
- Solar still does not involve any moving part, thus no electricity is required.
- Solar energy source is pollution free and eco-friendly.
- Distilled water can be generated with a small investment for domestic and commercial purposes.
- Low maintenance cost

Some of the disadvantages of solar stills are

- Occupies a large space.
- Less distillate output per unit time.
- The output will be affected during winter days.
- It needs to be inclined towards the sun's orientation.
- It needs to be protected during adverse conditions like rain and high wind blowing.

Solar stills have the advantage of being eco-friendly, zero fuel cost and low maintenance cost. But on the other hand, it has the disadvantage of occupying a large space and being a slow process leading to less distillate output per unit time.

A Number of performance parameters such as water depth, cover tilt angle, condensing cover cooling, dyes, wicks, reflectors, sun tracking system, thermal and energy storing materials, etc. greatly affect the output of the solar still. Proper combination and utilization of these parameters helps to meet the water demand effectively and economically.

From the literature review it can be concluded that all the solar still designs, which are available, were used for the desalination of sea water. No research has been done regarding the purification of hot spring water using a solar still.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the proposed system

The proposed system can be named as a geothermal still. Geothermal still is an apparatus that uses geothermal energy to separate fresh water from salts or other contaminants. Geothermal still condenses pure water vapor and settles out harmful substances.

At the back of the geothermal still there is an inlet pipe through which the hot water enters the basin. Some water volume is stored inside the geothermal still basin. When the water reaches the intended level, the hot water leaves the basin through the outlet pipe located at the front of the geothermal still. The continues flow of the hot water across the geothermal still serves the purpose of maintaining the temperature of the water stored on the basin.

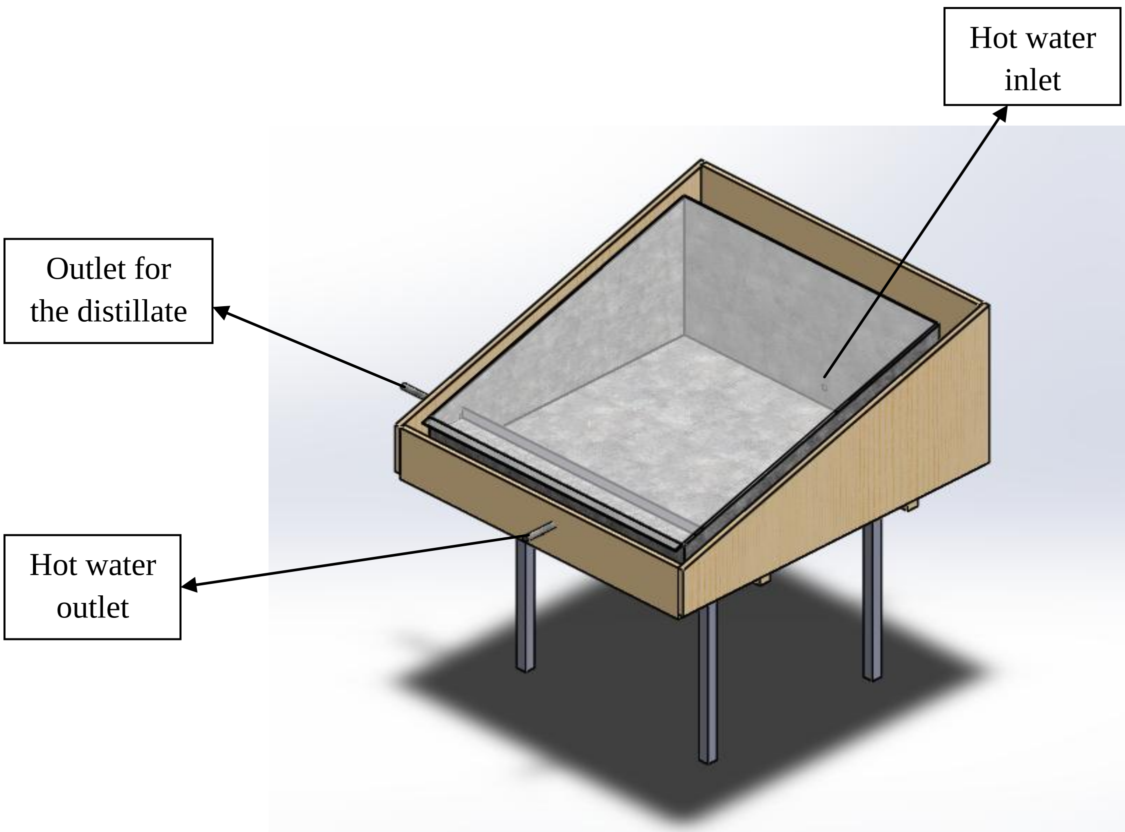


Figure 3. 1: Solidworks drawing of the geothermal still

The evaporation-condensation process is carried out using the heat (geothermal energy) from the hot water. Without using solar energy, the hot water is used as both water to be treated and an energy source that drives the geothermal still operation.

Table 3. 1: The major differences between solar still and geothermal still

Parameters	**Solar still**	**Geothermal still**
Source of energy	Solar	Geothermal
Operating time	Sunny daytime hours	24 hours
Basin water	Stationary	Constant flow of the hot spring water into the basin
Temperature of the basin water	Varies with the available solar radiation	Varies with the hot spring water temperature

3.2 Design selection for the geothermal still

On the literature review various solar still designs were discussed. Among the solar stills a design that fulfilled the following requirements was selected. The main criteria for the selection were:

- ✓ Easy to manufacture
- ✓ Material availability
- ✓ No external equipment attached

A solar still design made by Husham M. et al [19] was used as a reference design. In this research, three identical conventional single slope basin type solar stills have been designed and constructed from 1.4 mm thickness galvanized steel. The net basin horizontal effective area of each solar still was $1\ \text{m}^2$ $(1\ \text{m} \times 1\ \text{m})$. A 4 mm thickness glass cover was used for each solar still. The glass cover slope angle for all solar stills was set up at 32.5° with respect to the horizontal.

In order to keep the whole system of each solar still vapor tight, the glass cover was rubber lined and was rested on the basin structure and completely sealed by using superior silicon sealants. The inside of the three solar stills was painted black using black epoxy in order to increase the sun rays absorptions efficiency and also to eliminate any possible corrosion to the metal surfaces.

To prevent any heat loses, the bottom and sides of each solar still was insulated with a sheet of glass wool 50 mm thick. Each solar still construction was contained in a wooden frame of a trapezoidal shape.

A feed water tank was fixed at the same level as the three solar stills with a float to keep the saline water level inside the solar stills at constant value of 1 cm. An L shaped trough of 4 cm $\times$ 4 cm was made to collect the condensate water running down the inner surface of the inclined glass cover of each of the solar stills. The troughs were fixed at slight slope to ensure that the flow of condensate water is towards the outlet pipe.

A half inch diameter pipe and valve were fitted and connected to the lower end of each of the trough channels to control the collection of the condensate water. Flexible hoses leading to graduated flask were used to collect the distilled water of each solar still on hourly intervals.

All three stills had drainage pipes and valves fitted to the bottoms of the stills. Other sets of half inch pipes and valves were fixed at the lower end of the back of the still and were connected to the feed tank through the main pipe. A detailed cross sectional view of the solar still is shown in figure .

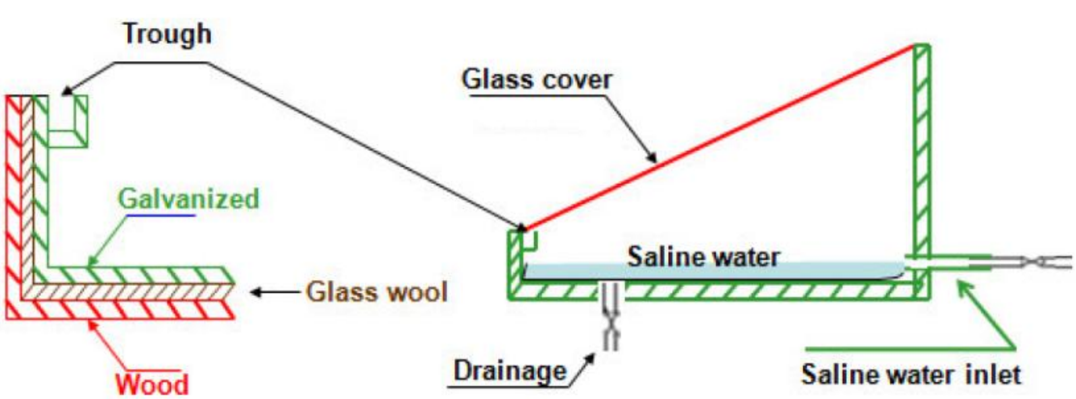


Figure 3. 2: Sectional view of the conventional solar still [19]

The first solar still was used as a reference still for comparison. The second solar still was used with uniformly spread and completely immersed wick material sheets in the saline water. The third solar still had a specially designed set up of steel mesh wires.

The mesh wires were made from twelve 5 mm diameter and 1 m long steel wires. A one square meter, 1.4 mm thickness galvanized steel plate and two 1 m long, 10 mm thickness and 50 mm high wooden boards were used to fix the wires in parallel rows horizontally across the solar still width. The wires were 60 mm apart and 50mm above the solar still basin. This design ensured that the wick materials sheets were partially immersed in the saline water. The schematic arrangement of the mesh wires is shown in figure .

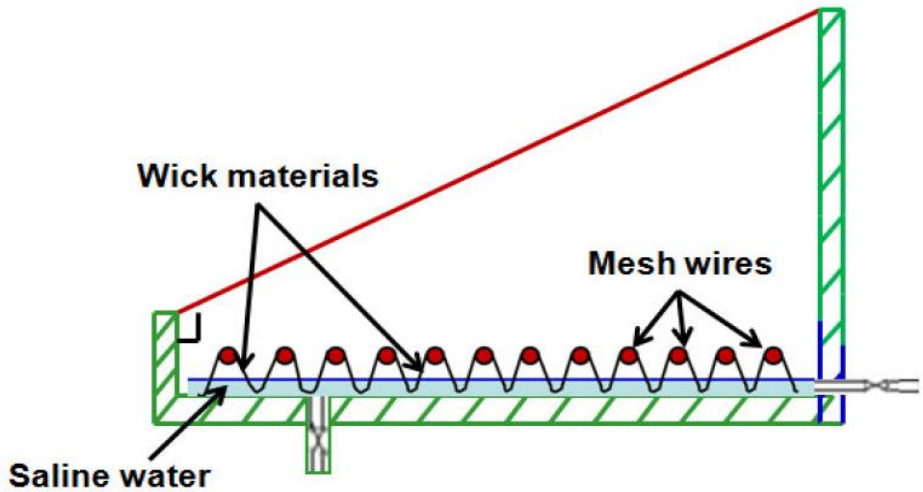


Figure 3. 3: Sectional view of the conventional solar still with mesh arrangements [19]

Five types of wick materials in the form of cloth sheets were used. They were light black cotton fabric, black sheer mesh fabric, black velvet fabric, light jute fabric and a 4 mm sponge sheet. The dimensions of the sheets used in the second solar still were one square meter, which was the same area of the solar still basin. The sheets in this situation were completely immersed in the saline water. In the third solar still that contain the mesh wires, the dimensions of the sheets used were 1 m $\times$ 1.25 m. The extra length of 0.25 m in sheet folding over the mesh wires. The wick material sheets in this situation were partially immersed in the saline water.

3.3 Experimental setup

3.3.1 Acrylic sheet cover

An acrylic sheet of 5mm thickness is used as a glass cover for the geothermal still. Acrylic is a transparent plastic material with outstanding strength, stiffness, and optical clarity. Acrylic sheets are thermoplastics, often purchased in sheets as a lightweight or shatter-resistant alternative to glass. Acrylic sheet can be used continuously in a temperature range of $77 - 88$ ℃.

The acrylic sheet slope angle for the geothermal still is set up at $20°$ with respect to the horizontal. In order to keep the geothermal still vapor tight, the acrylic sheet is rubber lined and is rested on the basin structure and completely sealed by using superior silicon sealant.

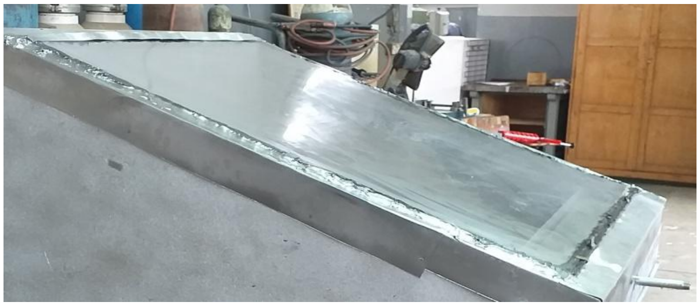


Figure 3. 4: Acrylic sheet cover

3.3.2 Galvanized steel frame

The geothermal still has been constructed using galvanized steel having a thickness of 1.4mm. The basin area of the geothermal still was $1000\text{mm} \times 1000\text{mm}$.

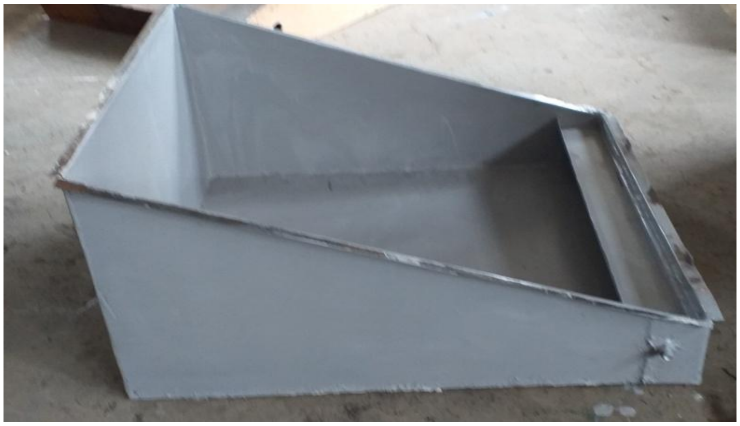


Figure 3. 5: Inner galvanized steel frame

3.3.3 Condensate channel

An L shaped condensate channel of $40\text{mm} \times 120\text{mm}$ is made to collect the distillate running down the inner surface of the inclined glass cover of the geothermal still. The channel is fixed at an angle of $45°$ from the horizontal to ensure that the flow of distillate is towards the outlet.

Figure 3. 6 : Condensate channel

3.3.4 The wooden frame

The geothermal still construction is contained in a wooden frame of a trapezoidal shape. The net horizontal effective area of the wooden frame is $1090\text{mm} \times 1200\text{mm}$.

Figure 3. 7: The outer wooden frame

3.3.5 Glass wool

To prevent any heat losses, the bottom and sides of the geothermal still was insulated with a sheet of glass wool having a thickness of 50mm. The glass wool is situated between the wooden frame and the galvanized steel frame.

Figure 3. 8: Glass wool insulation

3.3.6 Inlet and outlet pipes

The geothermal still has an outlet pipe at the front, an inlet pipe at the back and another outlet pipe on the right side through which the collected distillate on the condensate channel gets discharged. The diameter of each pipe is 20mm.

(a) Inlet pipe (b) Outlet pipe (c) Outlet pipe for the distillate

Figure 3. 9: Inlet and outlet pipes on the geothermal still

3.3.7 Geothermal still stand

A suitable frame was built on which the geothermal still was placed. The stand is made of 35mm × 35mm square steel hollow section (SHS). The stand has a height of 750mm. The area of the stand is 750mm × 680mm.

Figure 3. 10: Geothermal still stand

Figure 3. 11: The assembled geothermal still

3.4 Instrument used for data collection

Data logger is an electronic device which automatically monitors and records environmental parameters over time, allowing conditions to be measured, documented, analyzed and validated. Among those parameters the temperature is measured using thermocouples.

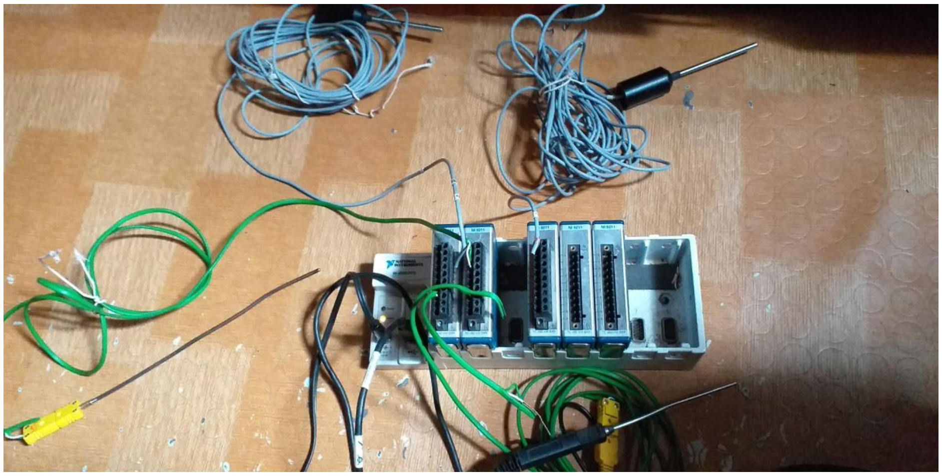


Figure 3. 12: Thermocouples of the data logger

The data logger contains sensors to receive the information and a computer chip to store the received information. National Instrument NI cDAQ-9172 type data logger was used for this experiment to measure the temperature. Then the information stored in the data logger is transferred to a computer for analysis. Lab view 2017 software is used to run the data logger.

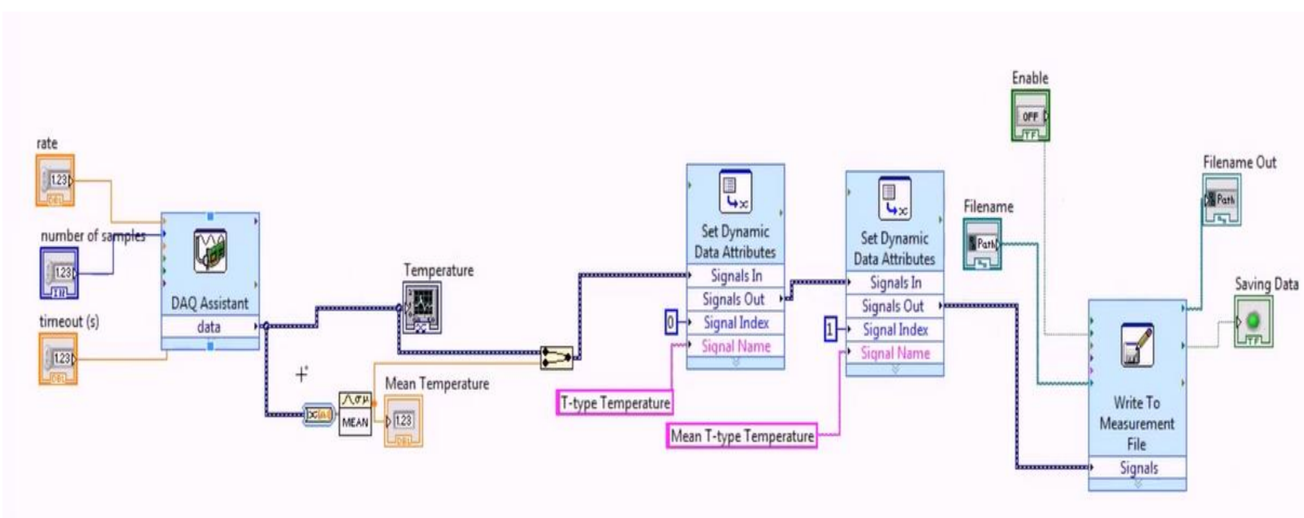


Figure 3. 13: The block diagram constructed to run the lab view software

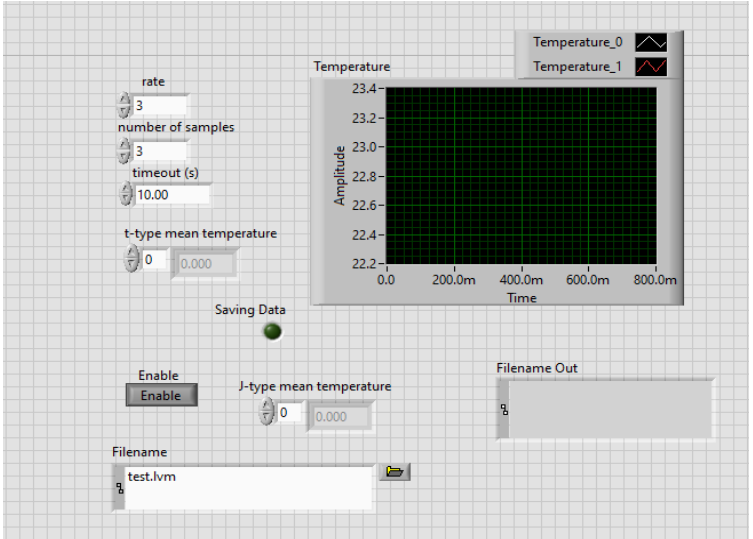


Figure 3. 14: Display for the temperature readings

3.5 Experimental procedure

1. The geothermal still was placed at the workshop located in the new filwoha hotel compound to carry out the experiment.

Figure 3. 15: The site of the experiment

2. The hot spring water entering the geothermal still through the inlet pipe was reduced from one of the distribution pipe lines running from the reservoir located at the source area of the hot spring water.

Figure 3. 16: The reservoir located at Finfine compound

The hot water coming from the reservoir through the distribution pipe line was reduced using a half inch pipe. Valves were connected to the reduced pipe in order to regulate the flow rate.

Figure 3. 17: The reduced hot water from the distribution pipe line

The time taken by the out flowing hot water to fill 1 L bottle was recorded using a stopwatch to measure the flow rate.

Figure 3. 18: The out flowing hot water from the geothermal still

Pipes having a horizontal length of 735 cm and a vertical length of 80 cm were installed connecting the reduced water source to the geothermal still inlet. A pipe having a length of 30 cm was connected at the side of the geothermal still for the distillate collection. At the front of the geothermal still an outlet pipe was installed.

Figure 3. 19: Pipe installation

3. The operating flow rate for the geothermal still was between $0.05 - 0.07$ L/sec. The experiment was performed at water depth of 2 cm. The water entering above this level flows out through the outlet pipe.
4. The evaporated and condensed water on the underside of the glass cover run into the condensate channel and then into an enclosed container.

Figure 3. 20: Distillate output

5. Using thermocouples of the data logger, the temperatures of the water vapor and the hot spring water on the basin were recorded.

Figure 3. 21: Thermocouples inserted through the glass cover

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Discussion on results

Experimental tests were performed in two rounds at Filwoha Spa Service Enterprise, Addis Ababa, Ethiopia. The first experiment was from February 11 to February 14/2022 and the second experiment was from June 15 to June 20/2022.

Temperature readings were recorded using thermocouples of the data logger. Temperature of the basin water and the water vapor were measured for every five minutes interval for an hour as presented on Appendix C**.**

4.1.1 Basin water temperature versus time

The averaged values of the recorded temperatures showed that the operating temperature range of the basin water was between 59 ℃ and 61 ℃.

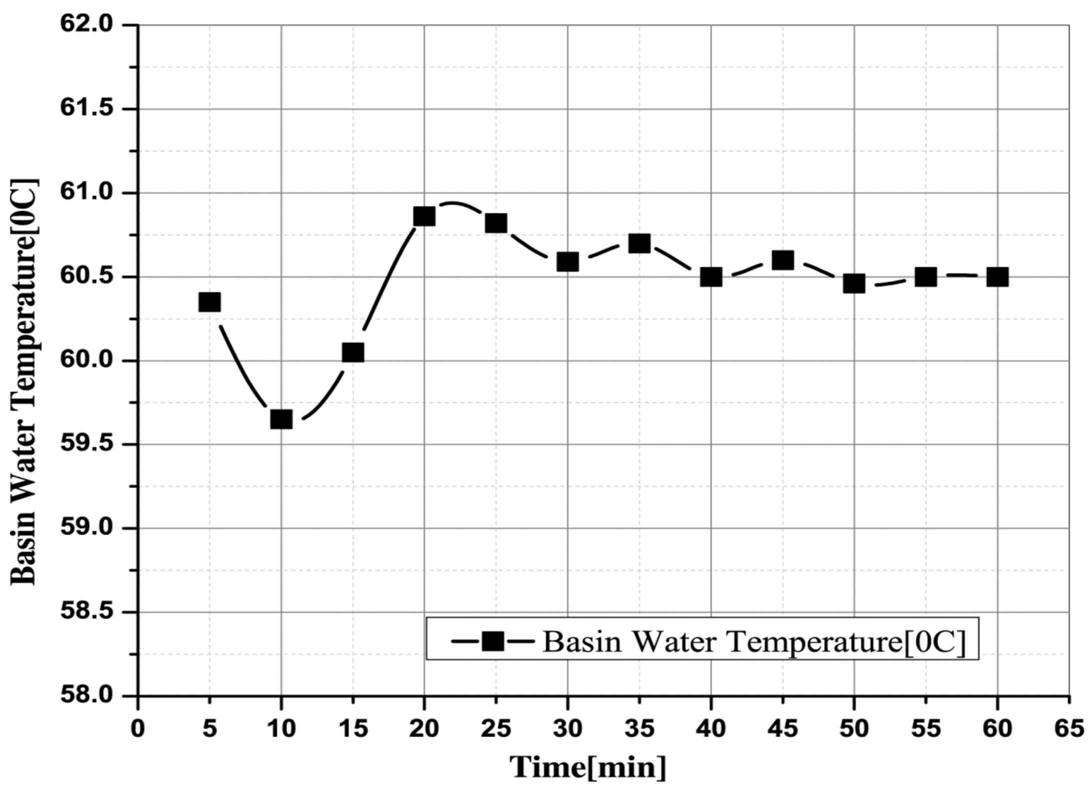


Figure 4. 1: Basin water temperature versus time

4.1.2 Water vapor temperature versus time

The averaged values of the recorded temperatures showed that the operating temperature range of the water vapor was between 50 ℃ and 51 ℃.

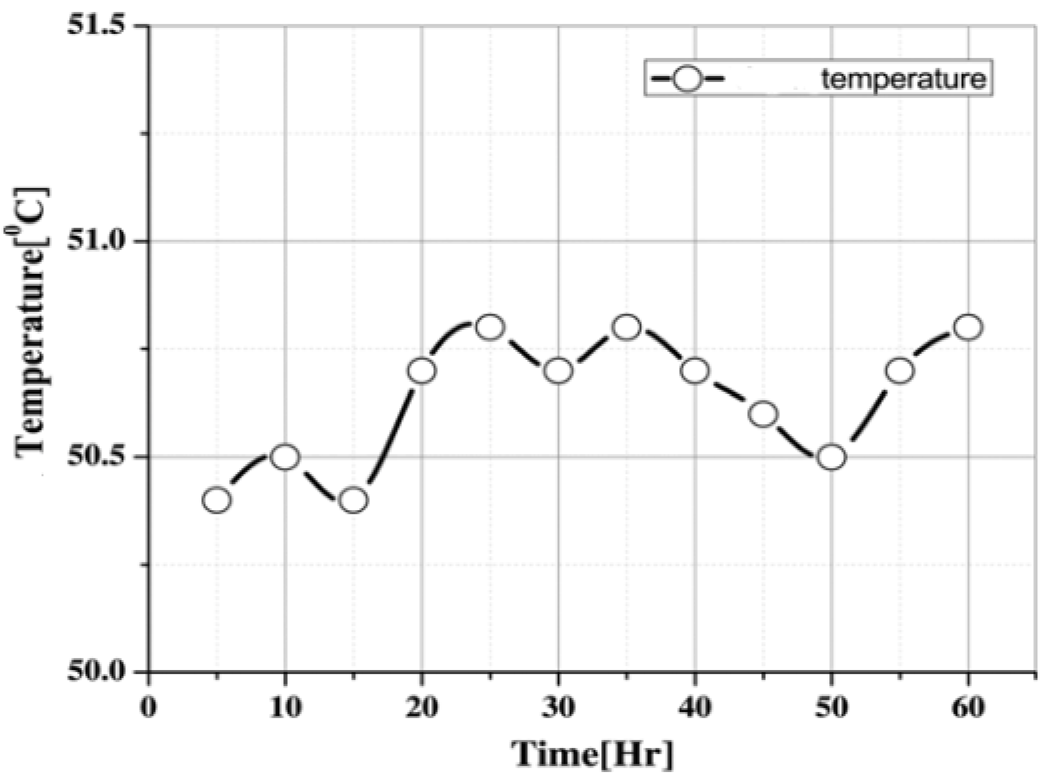


Figure 4. 2: Water vapor temperature versus time

4.1.3 Distillate output versus time

Within 3 hours the geothermal still produced 1 liter of distilled water. Based on this production rate it can be estimated that within 24 hours operating time 8 liters of distillate could be obtained.

Table 4. 1: Distillate output

Date	Time	Duration	Flow rate	Distillate production
16/06/2022	9:25 A.M – 12:25 P.M	3 hours	0.05 L/sec	1 L
17/06/2022	9:40 A.M – 12:40 P.M	3 hours	0.07 L/sec	1 L
18/06/2022	9:05 A.M – 12:05 P.M	3 hours	0.06 L/sec	1 L
20/06/2022	9:30 A.M – 6:40 P.M	3 hours	0.06 L/sec	1 L

On the selected solar still design it was stated that the first solar still (reference conventional bare still without wick materials) was found to produce an average value of 3.261 litter/day [19]. It has been found that the solar still with only wick materials and no special arrangement performed much better than the other two solar stills [19]. In both layout arrangements, it has been found that the light black cotton fabric was the most effective material and the sponge sheet was the less effective material in enhancing the still productivity [19].

Table 4. 2: Production rates of all tests in ml/day [19]

Wick materials	Cotton light black	Jute light	Black velvet	Black sheer mesh	Sponge sheet
Conventional solar still	3255	3260	3240	3280	3270
Solar still with wick materials	4455	4010	3890	3830	3645
Solar still with wick materials and mesh wire arrangements	4110	3810	3720	3690	3505

4.2 Water quality analysis

4.2.1 The collected water samples

A total of three samples were taken to the laboratory to be tested. The first two samples were taken to Addis Ababa Water and Sewerage Authority (AAWSA) and the third sample was tested by Ethiopian Conformity Assessment Enterprise (ECAE).

Table 4. 3 : The selected water samples

Water samples	Sample 1	Sample 2	Sample 3
Date of collection	11/02/2022	14/02/2022	16/06/2022
Water sample volume	1 L	1 L	1 L
Sample submitted	AAWSA	AAWSA	ECAE
Operating flow rate	0.07 L/sec	0.06 L/sec	0.05 L/sec

4.2.2 Laboratory test results for the collected water samples

The three samples are compared with the World Health Organization (WHO) standards for a drinking water on the table below. From the result it can be observed that the concentration of the total dissolved solid (TDS) and the fluoride was reduced to a considerable level.

Table 4. 4: Summary of the laboratory results from Addis Ababa Water and Sewerage Authority (AAWSA) for the three samples **[Appendix A and Appendix B]**

Parameters	Unit	Filwoha water	Sample 1	Sample 2	Sample 3	WHO
Turbidity	NTU	0.485	7.04	3.29	-	<5
Odor	Non obj.	Non obj.	Non obj.	Non obj.	-	Non obj.

Taste	Non obj.	Non obj.	Non obj.	Non obj.	-	Non obj.
PH	-	8.12	5.64	8.43	6.96	6.5-8
Total dissolved solid (TDS)	mg/l	1640	**208**	**84**	**71**	600
Ammonia as N	mg/l	0.15	2.4	1.8	-	1.5
Nitrite as N	mg/l	0.016	0.015	0.01	<0.05	1
Nitrate as N	mg/l	0.1	0.8	0.2	0.22	11
Fluoride as F	mg/l	23.5	**1.65**	**0.25**	**3.24**	1.5
Total iron as Fe	mg/l	0.1	0.86	0.35	-	0.3
Chloride as Cl	mg/l	3.3	5.5	2.05	1.01	250

The three samples are also compared with the standard requirements set by Ethiopian Conformity Assessment Enterprise for a drinking water on Table 4. 5.

Table 4. 5 : Summary of the laboratory results from Ethiopian Conformity Assessment Enterprise (ECAE) for the three samples **[Appendix A and Appendix B]**

Characteristics tested	**Unit**	**Filwoha water**	**Sample 1**	**Sample 2**	**Sample 3**	**Standard requirements**
Total hardness as $CaCO_3$	mg/l	224	179	195	12.21	400
Total alkalinity as $CaCO_3$	mg/l	2148	**306**	**728**	**44.78**	1100
PH value	-	8.12	5.64	8.43	6.96	6.5-8.5
Chloride as Cl	mg/l	3.3	5.5	2.05	1.01	250
Fluoride as F	mg/l	23.5	**1.65**	**0.25**	**3.24**	1.5
Nitrate as NO_3	mg/l	0.1	0.8	0.2	0.22	50
Nitrite as NO_2^-	mg/l	0.016	0.015	0.01	<0.05	0.1

From the above table, it can be seen that the concentration of the total alkalinity was reduced substantially. The laboratory results presented on Table 4. 4 and Table 4. 5 showed that the concentration of the total dissolved solid (TDS), the total alkalinity and the fluoride was reduced significantly. Among the three water samples taken, the second sample fulfilled the standard requirements set by Ethiopian Conformity Assessment Enterprise (ECAE) for a drinking water.

Table 4. 6: Test results of sample 2 versus the standard requirements set by Ethiopian Conformity Assessment Enterprise (ECAE)

Characteristics tested	**Unit**	**Sample 2**	**Standard requirements**
Total hardness as $CaCO_3$	mg/l	195	400
Total alkalinity as $CaCO_3$	mg/l	728	1100
PH value	-	8.43	6.5-8.5
Chloride as Cl	mg/l	2.05	250
Fluoride as F	mg/l	0.25	1.5
Nitrate as NO_3	mg/l	0.2	50
Nitrite as NO_2^-	mg/l	0.01	0.1

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Geothermal still is an apparatus that uses geothermal energy to separate fresh water from salts or other contaminants. The hot spring water entering the geothermal still through the inlet pipe was reduced from one of the distribution pipe lines running from the reservoir located at the source area having a water temperature range of 68 – 79 ℃. When a water depth of 2 cm is reached, the hot water leaves the basin through the outlet pipe located at the front of the geothermal still. The continues flow of the hot water across the geothermal still serves the purpose of maintaining the temperature of the water stored on the basin.

The operating flow rate for the geothermal still was between 0.05-0.07 L/sec. The averaged values of the recorded temperatures showed that the operating temperature range of the basin water was between 59 ℃ and 61 ℃ and that of the water vapor was between 50 ℃ and 51 ℃. The geothermal still has an estimated capacity of producing 8 L/m^2/day.

A total of three samples were taken to the laboratory to be tested. The first two samples were taken to Addis Ababa Water and Sewerage Authority (AAWSA) and the third sample was tested by Ethiopian Conformity Assessment Enterprise (ECAE).

From the results it can be concluded that after going through the purification process using the geothermal still, the parameters that were found in excess concentration in the hot spring water such as the total dissolved solid (TDS), the total alkalinity and the fluoride could be reduced to meet the standard requirements set by Addis Ababa Water and Sewerage Authority (AAWSA) and Ethiopian Conformity Assessment Enterprise (ECAE) for a drinking water.

5.2 Recommendation

To further increase the quantity of the distillate output the following points are recommended.

- ❖ The area of the geothermal still basin should be enlarged.
- ❖ The angle of the glass cover should be increased so that the water vapor condensed on the glass could reach the condensate channel.
- ❖ The water depth should be increased in order to increase the volume of hot spring water collected on the basin.
- ❖ The inlet and outlet pipes diameter should be enlarged to facilitate the flow of hot water across the geothermal still.

Future works;

- → Selection of the best size, shape and materials for the geothermal still fabrication.
- → The economic analysis of the overall system.

REFERENCE

1. Guidetoethiopia, Hot springs, https://guidetoethiopia.com/index.php/2016/05/27/hot- springs/

2. Market study communication , Filwoha spa service enterprise establishement and growth, 2013 E.C

3. Kalogirou, S., Solar energy engineering: processes and systems. 2009

4. Mahmoud S. El-Sebaey, A.E., Ahmed Hegazy and Tarek Ghonim Experimental Analysis and CFD Modeling for Conventional Basin-Type Solar Still. 2020

5. Bhupendra Gupta, R.S., Prem Shankar and Prashant Baredar, Performance enhancement of modified solar still using water sprinkler: An experimental approach 2016

6. Anshika Rani, R.K., S. Suresh and Anil Kumar, Experimental investigation on thermal behavior of hybrid single slope solar still

7. B.B. Sahoo and C.S., Performance enhancement of solar still by using reflectors-jute cloth-improved glass angle

8. G. S. Dhindsa, G.S.S. and Gurmail Singh, Augmentation of The Diurnal Productivity of Basin Type Single Slope Solar Still using Floating Wicks in The Basin

9. A. A. Ibrahim, M.D., G. Y. Pam and D. O. Obada, Design, construction and performance comparison of two solar stills having different absorber design

10. J. O. Ozuomba, A.E., C. U. Ozuomba and M. C. Udoye, Design and determination of the efficiency of a slanting-type solar water distillation kit

11. C. Tenthani, A.M. and C.Z.K., Improved Solar Still for Water Purification

12. J. D. Obayemi, F.O.A., S. T. Azeko, E. K. Arthur and D. Yiporo Design and Fabrication of a Single Slope Solar Still with Variable Collector Angle

13. S. Umar, U.K.M., A. Yakubu, M. Musa and S. B. Muhammad, Experimental Investigation and Performance Analysis of Single Slope Solar Still

14. Phillips O. Agboola and I.S.A.-M., Effect of cooling the glass cover of an inclined solar water distillation system under the climatic condition of Riyadh, Saudi Arabia

15. Bhupendra Gupta, A.K. and P.V.B., Experimental Investigation on Modified Solar Still Using Nanoparticles and Water Sprinkler Attachment

16. Abhay Agrawal, Assistant Professor, D.o.M.E., Rewa Engineering College, Rewa, MP, India and R.S. Rana Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal, MP, India, An experimental investigation of single sloped basin type spherical floating jute cloth absorbers solar still

17. Mulyanef, D., Kamaruzzaman Sopian, Kaidir, and Zulfika Rahman, Performance Experimental Study of Solar Still With Reflector To Produce Fresh Water and Salt

18. R. Dhivagar, M.M., Praveen Raj and Radha Krishna Gopidesi, Thermodynamic analysis of single slope solar still using graphite plates and block magnets at seasonal climatic conditions

19. Husham M. Ahmed, G.A.I., Performance Evaluation of a Conventional Solar Still with Different Types and layouts of Wick Materials

APPENDIX A: Physico-chemical water quality analysis report by Addis Ababa Water and Sewerage Authority

ADDIS ABABA WATER & SEWERAGE AUTHORITY
WATER QUALITY CONTROL SERVICE
P.O.BOX 1505, TEL.0116-621496/622919

PHYSICO-CHEMICAL WATER QUALITY ANALYSIS REPORT

Analysis requested by: **Addis Ababa Institute of Technology**
Source of sample: **Well**
Sampling site: **Filwuha, Addis Ababa**

Date of sampling: **11-14/02/2022**
Date of analysis: **17/02/2022**
Sampled by: **Kalkidan Minwuyelet**

S.No	Parameters	Unit	Filwuha Water	1^{st} day output	3^{rd} day output	WHO
1	Turbidity	NTU	0.485	**7.04**	3.29	<5
2	Odor	Non obj.	Non obj.	Non obj.	Non obj.	**Non obj.**
3	Taste	Non obj.	Non obj.	Non obj.	Non obj.	**Non obj.**
4	PH	-	8.12	5.64	8.43	**6.5 - 8**
5	Total Dissolved Solid(TDS)	mg/l	**1640**	208	84	**600**
6	Electrical conductivity(EC)	μS/cm	**3260**	436	175.3	-
7	Total Alkalinity as $CaCO_3$	mg/l	**2148**	306	728	-
8	Total Hardness as $CaCO_3$	mg/l	224	179	195	-
9	Calcium Hardness as $CaCO_3$	mg/l	37	103	97	-
10	Magnisium Hardness as $CaCO_3$	mg/l	187	76	98	-
11	Ammonia as N	mg/l	0.15	2.4	1.8	**1.5**
12	Nitrite as N	mg/l	0.016	0.015	0.01	**1**
13	Nitrate as N	mg/l	0.1	0.8	0.2	**11**
14	Sulfate as SO_4	mg/l	-	-	-	**250**
15	Phosphate as PO_4	mg/l	-	-	-	-
16	Fluoride as F	mg/l	**23.5**	1.65	0.25	**1.5**
17	Total iron as Fe	mg/l	0.1	0.86	0.35	**0.3**
18	Manganese as Mn	mg/l	-	-	-	**0.1**
19	Silica as SiO_2	mg/l	67	17	12	-
20	Chloride as Cl	mg/l	3.3	5.5	2.05	**250**
21	Bicarbonate alkalinity as HCO_3	mg/l	2148	306	728	-
22	Carbonate Alkalinity as $CaCO_3$	mg/l	Nil	Nil	Nil	-
23	Hydroxide Alkalinity as $CaCO_3$	mg/l	Nil	Nil	Nil	-

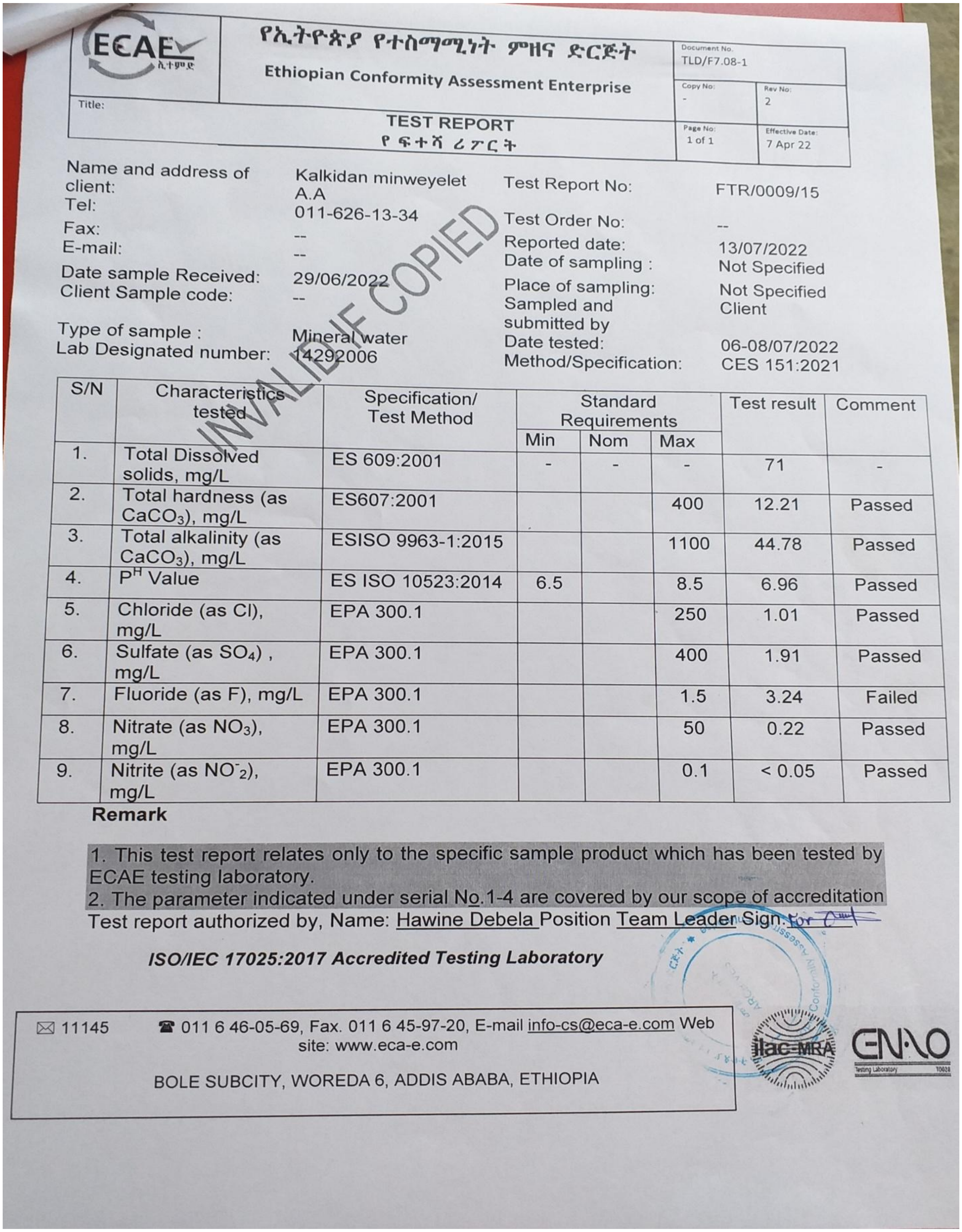
Analysed by: Biniyam Zetema
Chemist

Approved by:

City Goverment of Addis Ababa Water & Sewerage Authority

Solomon Tadesse
Catchment Management and Water Quality Control Case Manager

APPENDIX B: Ethiopian Conformity Assessment Enterprise test report



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Ethiopian Conformity Assessment Enterprise

Document No. TLD/F7.08-1

Copy No: -

Rev No: 2

Page No: 1 of 1

Effective Date: 7 Apr 22

Title:

TEST REPORT

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Name and address of client:	Kalkidan minweyelet A.A	Test Report No:	FTR/0009/15
Tel:	011-626-13-34	Test Order No:	--
Fax:	--	Reported date:	13/07/2022
E-mail:	--	Date of sampling :	Not Specified
Date sample Received:	29/06/2022	Place of sampling:	Not Specified
Client Sample code:	--	Sampled and submitted by	Client
Type of sample :	Mineral water	Date tested:	06-08/07/2022
Lab Designated number:	14292006	Method/Specification:	CES 151:2021

INVALID IF COPIED

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1.	Total Dissolved solids, mg/L	ES 609:2001	-	-	-	71	-
2.	Total hardness (as $CaCO_3$), mg/L	ES607:2001			400	12.21	Passed
3.	Total alkalinity (as $CaCO_3$), mg/L	ESISO 9963-1:2015			1100	44.78	Passed
4.	P^H Value	ES ISO 10523:2014	6.5		8.5	6.96	Passed
5.	Chloride (as Cl), mg/L	EPA 300.1			250	1.01	Passed
6.	Sulfate (as SO_4) , mg/L	EPA 300.1			400	1.91	Passed
7.	Fluoride (as F), mg/L	EPA 300.1			1.5	3.24	Failed
8.	Nitrate (as NO_3), mg/L	EPA 300.1			50	0.22	Passed
9.	Nitrite (as NO^-_2), mg/L	EPA 300.1			0.1	< 0.05	Passed

Remark

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.
2. The parameter indicated under serial No.1-4 are covered by our scope of accreditation

Test report authorized by, Name: Hawine Debela Position Team Leader Sign: for

ISO/IEC 17025:2017 Accredited Testing Laboratory

11145 ☎ 011 6 46-05-69, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com Web site: www.eca-e.com

BOLE SUBCITY, WOREDA 6, ADDIS ABABA, ETHIOPIA

ilac-MRA ENAO Testing Laboratory

APPENDIX C: Temperature readings from the experiment

Table C1: February 11/2022 temperature readings

Time (hr)	Basin water T° (℃)	Water vapor T° (℃)
2:37	61.59	55.97
2:42	61.35	56.05
2:47	61.44	55.78
2:52	61.09	55.67
2:57	60.82	55.65
3:02	60.95	55.29
3:07	60.74	55.73
3:12	60.48	57.49
3:17	60.37	58.7
3:22	60.38	58.74
3:27	59.05	58.2
3:32	59.86	57.94
3:37	59.84	57.46

Table C2: February 14/2022 temperature readings

Time (hr)	Basin water T° (℃)	Water vapor T° (℃)
10:57	64.55	59.93
11:02	64.46	60.32
11:07	64.39	60.41
11:12	64.4	60.73
11:17	64.47	61.11
11:22	64.94	61.09
11:27	64.94	61.51
11:32	64.82	62.93
11:37	64.87	63.76
11:42	64.29	63.93
11:47	64.1	63.4
11:52	64.35	63.95
11:57	64.71	64.59

Table C3: June 15/2022 temperature readings

Reading 1			Reading 2			Reading 3			Reading 4		
Time (hr)	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**
9:56	63.13	51.81	10:56	47.08	41.2	12:01	54.95	47.51	1:00	53.52	46.49
10:01	61.88	51.07	11:01	45.82	40.62	12:06	55.82	47.28	1:05	53.59	46.37
10:06	60.52	50.05	11:06	47.88	39.79	12:11	55.1	47.14	1:10	53.58	46.94
10:11	59.06	49.03	11:11	60.4	47.35	12:16	54.69	46.91	1:15	53.66	46.8
10:16	57.55	48.18	11:16	60.56	49.95	12:21	54.39	46.73	1:20	53.61	46.93
10:21	56.02	47.06	11:21	60.06	49.93	12:26	54.18	46.69	1:25	53.76	46.71
10:26	54.59	46.13	11:26	58.95	49.24	12:31	54.22	46.65	1:30	53.45	46.44
10:31	53.22	45.2	11:31	57.6	48.05	12:36	53.96	46.67	1:35	53.5	46.64
10:36	51.5	44.01	11:36	56.05	47.35	12:41	53.78	46.58	1:40	53.23	46.35
10:41	50.75	43.43	11:41	55.68	46.94	12:46	53.76	46.74	1:45	53.25	46.32
10:46	49.4	42.8	11:46	55.11	46.8	12:51	53.63	46.67	1:50	52.86	46.16
10:51	48.14	42	11:51	55	46.76	12:56	53.62	46.52	1:55	52.86	46.15

Table C4: June 16/2022 temperature readings

Reading 1			Reading 2		
Time (hr)	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**
9:35	57.49	47.91	11:28	61.05	50.86
9:40	55.39	49.09	11:33	61.39	51.19
9:45	57.93	49.34	11:38	61.19	51.09
9:50	59.73	49.65	11:43	61.53	51.26
9:55	59.77	49.52	11:48	61.51	51.24
10:00	60	49.56	11:53	61.32	51.28
10:05	60.65	49.86	11:58	61.48	51.39
10:10	60.41	50.19	12:03	61.44	51.08
10:15	60.81	50.32	12:08	61.49	51.33
10:20	60.96	50.55	12:13	-	-
10:25	61.17	50.72	12:18	-	-
10:30	61.16	50.85	12:23	-	-

Table C5: June 17/2022 temperature readings

Reading 1			Reading 2			Reading 3		
Time (hr)	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**
9:40	63.77	52.32	10:40	63.76	52.63	11:54	63.97	52.98
9:45	62.34	51.4	10.45	63.86	52.73	11:59	64.06	53.14
9:50	61.51	51.14	10:50	63.54	52.74	12:04	64.18	53.2
9:55	61.65	51.05	10:55	63.69	53.04	12:09	64.17	53.36
10:00	62.42	51.5	11:00	64.07	53.17	12:14	64.09	53.45
10:05	62.08	52.27	11:05	64.22	53.04	12:19	63.84	53.21
10:10	62.9	52.06	11:10	64.09	53.02	12:24	64.11	53.31
10:15	63.53	52.24	11:15	63.8	52.79	12:29	66.09	54.57
10:20	63.84	52.69	11:20	63.76	52.74	12:34	66.56	55.65
10:25	64.03	53.16	11:25	63.64	52.77	12:39	-	-
10:30	64.12	53.01	11:30	63.78	52.91	12:44	-	-
10:35	63.8	52.71	11:35	63.65	52.91	12:49	-	-

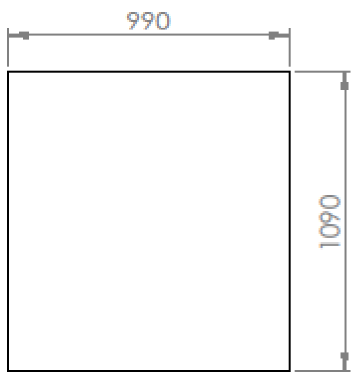
Table C6: June 18/2022 temperature readings

Reading 1			Reading 2			Reading 3		
Time (hr)	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**
9:06	65.87	54.59	10:06	64.18	53.68	11:06	63.25	54.54
9:11	66.17	55.09	10:11	63.97	53.27	11:11	63.26	54.92
9:16	66.64	55.46	10:16	63.67	53.03	11:16	63.08	54.77
9:21	65.86	55.04	10:21	63.4	53	11:21	63.16	54.91
9:26	64.96	54.41	10:26	63.65	53.25	11:26	63.34	54.84
9:31	65.79	54.52	10:31	63.69	53.19	11:31	63.28	53.95
9:36	65.5	54.65	10:36	63.74	53.16	11:36	63.01	54.23
9:41	65.11	54.32	10:41	63.63	53.16	11:41	62.75	52.36
9:46	64.43	53.82	10:46	63.72	53.16	11:46	62.9	52.88
9:51	63.51	53	10:51	63.58	53.37	11:51	62.84	52.95
9:56	63.36	53.2	10:56	63.72	55.11	11:56	63.2	53.06
10:01	63.45	53.77	11:01	63.42	54.63	12:01	63.63	53.36

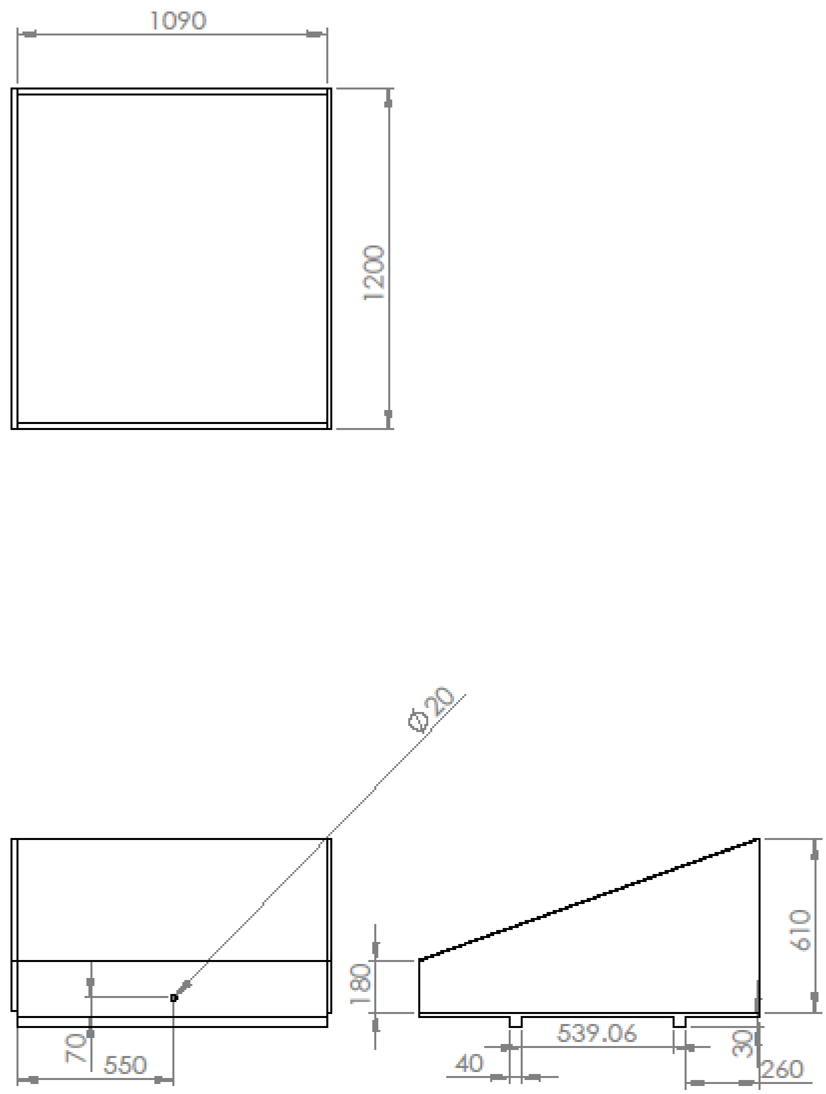
Table C7: June 20/2022 temperature readings

Reading 1			Reading 2			Reading 3		
Time (hr)	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**	**Time (hr)**	**Basin water T° (℃)**	**Water vapor T° (℃)**
9:57	59.85	49.19	11:11	62.36	51.69	12:31	62.98	52.26
4:02	59.58	49.29	11:16	62.45	51.44	12:36	62.55	51.97
4:07	59.46	49.25	11:21	62.57	51.36	12:41	62.71	51.83
4:12	58.96	48.62	11:26	62.57	51.44	12:46	62.68	51.84
4:17	58.5	48.73	11:31	62.56	51.56	12:51	62.72	51.95
4:22	56.3	48.38	11:36	62.89	51.58	12:56	62.8	51.94
4:27	57.04	49.18	11:41	63.1	51.71	1:01	62.97	52.24
4:32	57.24	49.51	11:46	63.14	51.7	1:06	63.09	52.3
4:37	59	49.08	11:51	-	-	1:11	63.29	52.4
4:42	58.48	48.41	11:56	-	-	1:16	63.32	52.52
4:47	59.05	48.45	12:01	-	-	1:21	63.67	52.55
4:52	60.94	49.84	12:06	-	-	1:26	63.49	52.66

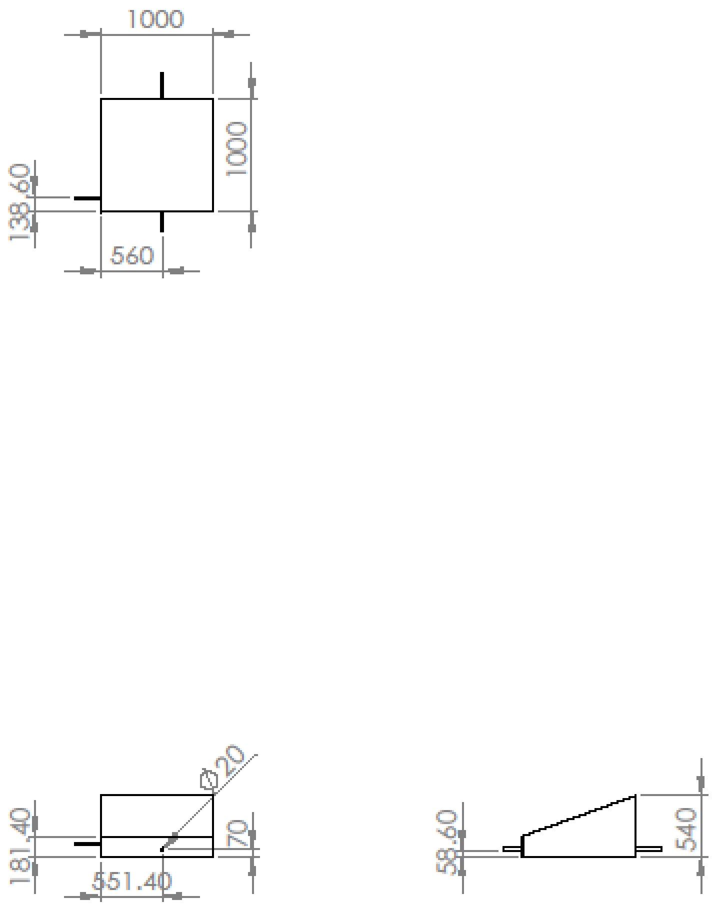
APPENDIX D: Parts and assembly drawings of the geothermal still



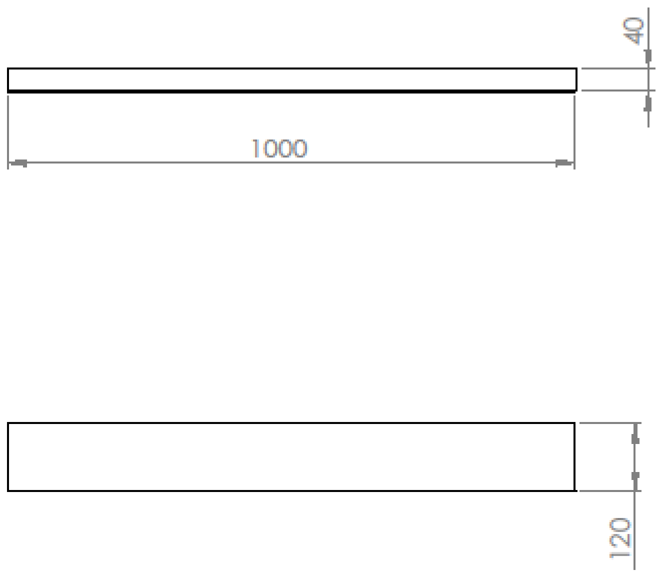
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	Addis Ababa University Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering	
DRAWN	Kalkidan Minwyelet		Dec.21/2021	TITLE: Acrylic sheet cover	
CHK'D					
APPV'D					
MFG					
Q.A	1		MATERIAL: Acrylic sheet	DWG NO. 1	A4
			WEIGHT:	SCALE:1:20	SHEET 1 OF 1



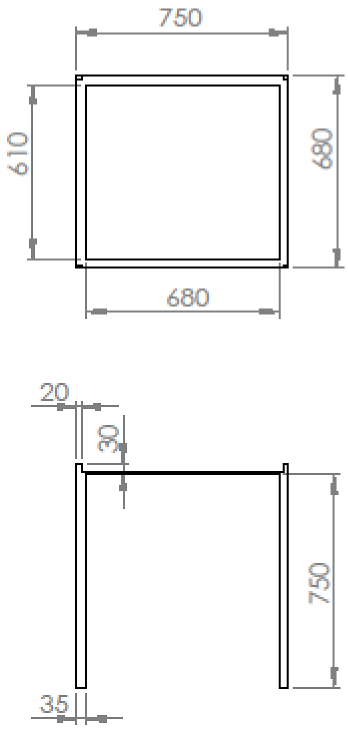
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION		
			Addis Ababa University **Addis Ababa Institute of Technology** **School of Mechanical and Industrial Engineering**			
	NAME	SIGNATURE	DATE			TITLE: **Wooden frame**
DRAWN	**Kalkdian Minvyelet**		**Dec.22/2021**			
CHK'D						
APPV'D						
MFG						
Q.A	**1**			MATERIAL: **Wood**		DWG NO. **2** / **A4**
				WEIGHT:		SCALE:1:1 / SHEET 1 OF 1



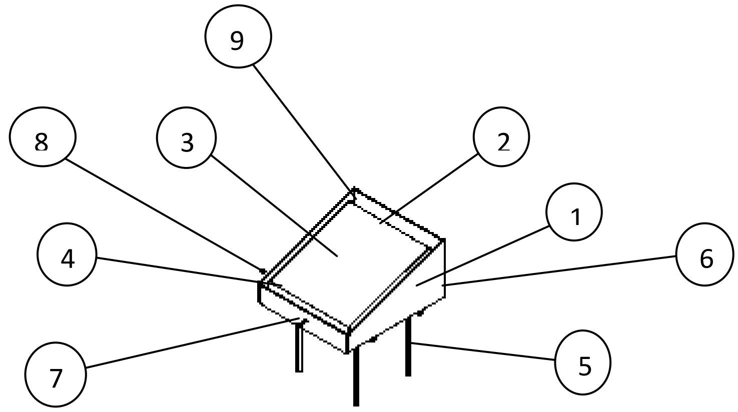
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
				Addis Ababa University Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering		
	NAME	SIGNATURE	DATE	TITLE: Galvanized steel frame		
DRAWN	Kalkidan Minwyelet		Dec.23/2021			
CHK'D						
APPV'D						
MFG						
Q.A	1		MATERIAL: Galvanized steel	DWG NO. 3		A4
			WEIGHT:	SCALE:1:1	SHEET 1 OF 1	



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION
					Addis Ababa University Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering	
	NAME	SIGNATURE	DATE		TITLE: Condensate channel	
DRAWN	Kalkidan Minwyelet		Dec.24,'2021			
CHK'D						
APPV'D						
MFG						
Q.A	1			MATERIAL: Galvanized steel	DWG NO. 4	A4
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
			Addis Ababa University **Addis Ababa Institute of Technology** **School of Mechanical and Industrial Engineering**		
	NAME	SIGNATURE	DATE	TITLE: **The stand**	
DRAWN	**Kalkidan Minwyelet**		**Dec.24/2021**		
CHK'D					
APPV'D					
MFG					
Q.A	**1**		MATERIAL: **Mild steel hollow square bar**	DWG NO. **5**	A4
			WEIGHT:	SCALE:1:1	SHEET 1 OF 1



ITEM NO.	PART NUMBER
1	Wooden frame
2	Galvanized steel frame
3	Acrylic sheet cover
4	Condensate channel
5	The stand
6	Inlet pipe
7	Outlet pipe 1
8	Outlet pipe 2
9	Glass wool

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering

	NAME	SIGNATURE	DATE
DRAWN	Kalkidan Minwyelet		Dec.26/2021
CHK'D			
APPV'D			
MFG			
Q.A	1		

TITLE:

MATERIAL:

DWG NO. 6

A4

WEIGHT:

SCALE:1:50

SHEET 1 OF 1