Department of Mechanical Engineering

Improving the Performance of Solar Stills using Sun Tracking

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Signed: Taiwo, M. Olalekan   Date: September 2, 2010

Abstract

Worldwide, some 1.1 billion people lack access to safe water and another 2.6 billion people lack access to sanitation. For the UN to achieve its Millennium Development Goals of reducing by half the population without access to water and sanitation by 2015 there is need for concerted efforts in funding research to stern the tide of global water shortage.

The challenge of providing potable water is quite prevalent in the developing and poorest countries of the world, especially in the tropics and arid regions. While it would be quite difficult or challenging to invest in huge/gigantic desalination plants, they are well endowed with the required energy to drive solar desalination.

Conventional means of providing potable water, especially from fossil fuel, is becoming increasingly expensive and might be unaffordable by the poorest countries of the world where water and sanitation is a major challenge. There is a need to find viable alternative sources of energy.

Various renewable energy sources were explored and the solar energy is adjudged the best option. With abundance of solar energy in many of the poorest parts of the world where access to potable water is a challenge; it is reasoned that this is the best and most viable option.

With solar energy as the source to power our plant; the solar still is the simplest desalination technology consisting of a shallow basin with a transparent cover and it is considered because of its cost, simplicity of design, operation and maintenance. It is equally very compatible for use in the world's poorest countries and adaptable, for it does not require complex technical know-how to operate and maintain.

The efficiency of solar energy deployment and performance of a basin-type still is considered. The effect of sun tracking on the design and operating factors such as the ambient temperature, basin temperature, brine temperature, cover temperature, and solar radiation (irradiance/intensity) and how they influence productivity were

examined and analysed. Basin and brine temperatures have positive effects on the productivity, but the effect of glass cover temperature was not so obvious. It was evident from the results that the solar intensity impacted on the productivity directly and positively. A sun tracking mechanism was explored to determine how this affects the performance of the still.

The still with the tracking mechanism was found to show some significant improvement by increasing the distillate yield by 19.6% with an additional 3.8% increase in overall still efficiency. With the use of a tracking mechanism, the space required to provide a daily consumption of 2-3 litres of water per person is expected to be about $1.4m^2$. This is a significant improvement over the traditional fixed still.

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Nomenclature & Abbreviations

A_e	Area of evaporation (m^2)
A_c	Area of condensation (m^2)
E	Water evaporation (and condensation) rate (kg/m^2h)
ED	ElectroDialysis
$h_{c,I}$	Convective heat transfer coefficient from salt water surface to cover of still (W/m^2K)
$h_{c,o}$	Convective heat transfer coefficient from cover to atmosphere (W/m^2K)
$h_{r,I}$	Radiation heat transfer coefficient from salt water surface to cover of still (W/m^2K)
$h_{r,o}$	Radiation heat transfer coefficient from cover to atmosphere (W/m^2K)
L	Net miscellaneous heat loss rate (W/m^2K)
MEB	Multi-Effect Boiling
MED	Multi-Effect Distillation
MSF	Multi-Stage Flash
P	Daily production of still (kg/m^2 day)
Q_{sh}	Net solar energy absorption rate on basin bottom (W/m^2 day)
R	Amount of incident radiation (W/m^2 day)

RO Reverse Osmosis

t_a, T_a Ambient temperature, ^{0}C, K respectively

t_b, T_b Basin temperature, ^{0}C, K respectively

t_g, T_g Cover temperature, ^{0}C, K respectively

VC Vapour Compression

W_{da} Mass of dry air circulating per unit time (kg/h)

W_{H20} Mass of water distilled per unit time (kg/h)

1 Introduction

Water is essential to life. Next to oxygen, fresh water is the most important substance for sustaining human life. Access to water is considered to be a basic human right. However, the increased use and misuse of this resource by the growing population and increasing industrial activities may lead to a situation whereby countries need to reconsider their options with respect to the management of its water resources. About 1.2 billion people in the world lack access to potable water, over 2.6 billion without access to adequate sanitation, and 1.8 million children killed each year by preventable water-borne diseases [1]; many of these people live within the poorest countries of the world.

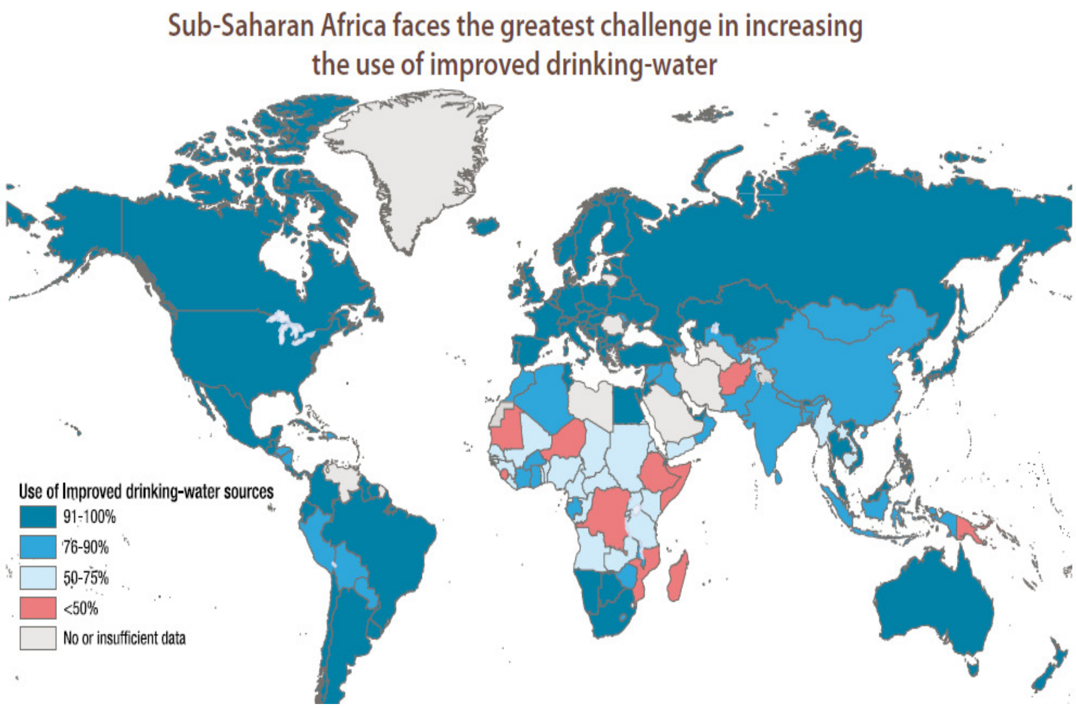


Figure 1: Global distribution of drinking water availability [2]

Water is life, and the threat of unsustainable means of potable water supplies has led to the reviews of various renewable energy sources to create a cleaner and more efficient solution for potable water supply. Various modular technologies existed, in which potable water can be produced, but these have proved to be quite expensive as large and very complex designs are involved. Because this problem is prevalent in the world's poorest countries, there is need for the technology to be simple in design, affordable and sustainable.

Conventional solar stills are one method of supplying potable water through using a renewable and free energy source. The solar still is point-of-use technologies that have been proven to remove pathogens, heavy metals and reduce salinity. Despite the fact that this technology can provide a cheap source of potable water they have the disadvantage that they are on average only 30% efficient and require $2m^2$ to provide for one person's daily needs [3]. The solar stills have often been used in the tropics where there is abundant supply of solar energy.

In this thesis, a basin-type solar still was designed to investigate the effect of sun tracking in the performance of conventional solar still using actual environmental conditions.

Basically, the still consists of a black-lined shallow basin of saline water enclosed by a transparent cover with sloping sides. Solar radiation passing through the transparent cover is absorbed by the brine and the black basin liner. This radiation is changed to heat by absorption, which serves to warm the brine. The warm brine partly evaporates and humidifies the air above the surface, thereby reducing the density of the air and causing it to circulate upward.

The moving air comes in contact with inner surface of the relatively cool transparent cover, and part of the humidity condenses thereon. The liquid condensate forms a film and flows to the base of the cover, from where it drips into the condensate trough and is conducted to the outside of the enclosure. The cooled air returns to the surface of the warm water to repeat the process of humidification. The circulation of air is thus due entirely to free convection.

Many adaptations have been made to the solar still design to improve the efficiency, however not so much attention has been paid to sun tracking. This study will investigate the use of sun tracking to improve the potable water yield from a conventional solar still.

The next four sections of this thesis will cover the literature review of solar desalination systems and more importantly the various renewable systems available and some research on sun tracking; this will be followed by the method, which is the storyline of the experiment conducted on the roof top of the James Weir building, University of Strathclyde, Glasgow involving the design, build and test phases of the different variables of the still; followed by results and discussion of the data acquired as well as the analysis of this data; Finally, conclusions will be made and recommendations regarding future improvements will be proposed.

The purpose of this research was to investigate the effect of sun tracking in the conventional solar still design. The results were correlated and analysed for subsequent trends. It was hoped that the sun tracking would improve the overall potable water yield of the solar still.

2 Literature Review

The inadequate supply of potable water to meet household needs and the inability to provide proper sanitation facilities in the world's poorest countries has become a major global crisis. This is evident as reported in the United Nation's Human Development Report [1], which cites figures of over 1 billion people without access to clean water, over 2.6 billion without access to adequate sanitation, and 1.8 million children killed each year by preventable water-borne diseases as a result of lack of safe water and proper sanitation facilities.

Due to its prime importance, especially from a socio-economic perspective, the looming water crisis as emphasised in this report reflected on the growing international recognition of the importance of this crisis. This is important because forecasts of future water accessibility, demand and availability have already indicated that greater pressures are likely to be placed on potable water supplies as all regions of the world continue to develop, especially with the rural-urban drift and urban sprawls.

Figure 2: In search of water in an arid region [2]

Due to the pressures placed on water, it can longer be seen as an infinitely renewable resource that was once thought it was. As a matter of fact, the shortage of water threatens to make water an endangered natural resource. As it stands, it is potentially a more critical and vital resource than energy. A water crisis, in contrast to an energy crisis, is life threatening and if not quickly and properly handled could bring about grave consequences. Water has no viable substitute, and its depletion both in quantity and quality has even very great socio-economic implications. Moreover, there are available means of providing potable water technically and economically.

Water desalination is usually the last resort to overcome the issue of water shortages, which in the case of seawater is principally an unlimited source. Producing potable water from seawater through desalination may be quite expensive, but as it is continually being deployed at different places and the result of thorough studies of available options with adaptations and improvement both in addressing demand management and existing resource technology the cost is more likely to come down and be more readily affordable for all. This global water crisis can be resolved by using non-conventional approaches and resources, that is, by using treated wastewater and distillation.

Water Desalination through Distillation

There are different methods and approaches to desalination depending on application, use and resource. For very huge industrial desalination technologies using either phase change or semi-permeable membranes to separate impurities; desalination methods can be categorised into phase change (or thermal process) and membrane (or single phase process) [4].

The aforementioned processes require some form of chemical pre-treatment of undiluted seawater in order to avoid corrosion, foaming, scaling, growth of algae, fungi and fouling. It equally requires some form of post chemical treatment. However, it is more convenient and useful to classify these desalination processes by separating them into the change of phase and the separation type without change of phase, the membrane type.

A brief mention should be made of the phase change processes. They are: Multi-Stage Flash (MSF) (a distillation process); Multi-Effect Boiling (MEB) or Multi-Effect Distillation (MED) (distillation processes); Vapour Compression (VC); Thermal and Mechanical (a distillation process); Solar Distillation (a distillation process); Freezing. While the Reverse Osmosis (RO) (a membrane process) and the Electrodialysis (ED) (a membrane process) [4] are in a single phase category, the membrane process.

2.1 Energy Sources

Different desalination processes require energy in different forms, notably electro-mechanical or thermal. The effectiveness and viability of a desalination process is largely due to the quality and availability of energy. It is also dependent on energy costs.

This account for the high cost of water for water derived from huge desalination plants running solely on fossil fuel. It makes water from such plants to be unaffordable, especially for people from small rural communities. Due to the aforementioned reason, desalination processes are often compared on their energy consumption and source. As clearly stated above, the quality of the energy is very important.

High grade energy, such as electricity is seen to be much more valuable than the same quantity of energy in the form of low grade thermal energy. When selecting a desalination process, a lot of factors are usually considered. The budget for the process, options for water purification, sources of energy available and of course, to whom the project is for (end-users) and at what cost. Obviously for small rural communities, it would be foolhardy to recommend a huge desalination plant.

Therefore, it is important to note that mere comparison of technologies or schemes based on their energy consumption alone is not the absolute criteria for selecting a desalination process [5]. Energy for the desalination system can come from a variety of sources. The conventional sources of energy are: Diesel generators, Grid

Electricity, and Waste Heat. The renewable energy sources are: Biomass, Geothermal, Hydro, Solar, Wave and Wind.

Diesel Generators

Diesel generators usually can provide a continuous and uninterrupted supply of electricity provided it is being fuelled and maintained as at when due. It is therefore true that, a desalination plant coupled to a diesel generator is as good as being coupled to a grid supply because of its firm and continuous power. Generators are usually considered as a 'perfect' source of energy for the desalination plant because of its consistency and predictability. Since electricity is the usual and major output, desalination plants using electricity are appropriate and they are the ED, RO or VC.

Diesel generators normally run with an efficiency of about 35%. The remaining energy is dissipated in the exhaust and in jacket cooling water [6]. For large generator, the waste heat might be used to run thermal processes such as, MSF and MEB.

It is also possible to use diesel generators for hybrid systems, where the diesel generators are used in combination with other renewable energy powered systems; such that, the period of fluctuation of renewable energy supplies can be augmented by the generator supplies.

The hybrid system is designed in such way that the generator can cut in and out in order to match demand and supply. In a rural setting, diesel generator is not likely to be an option as the cost of transporting fuel would be so high to afford and the technical know-how for the hybrid system, thereby compromising its use.

Grid Electricity

Grid electricity is regarded as a high grade fuel in terms of quality and consistency of supply. It is generated by burning hydrocarbons and depending on the raw material used the conversion efficiency is usually about 35%. For certain reasons, it is cheaper than electricity derived from renewable energy sources even though there might be times when this does not apply.

Grid electricity is widely used in huge desalination plants based on electro-mechanical energy requirements of the following plants; ED, RO and VC. This is due to the fact that, it is relatively cheap and readily available.

Waste Heat

Waste heat is usually referred to as low grade heat due to its conversion rate and ability. Waste heat is usually in form of a ‘useful waste’ from a power plant. This is the rejected heat from a steam turbine. While the thermal plant provides power to the community, the rejected heat in the form of low pressure steam extracted from the turbine supplies heat to the desalination system usually large desalination units such as, the MSF or MED. This could also be harnessed and used to heat a simple solar still.

Renewable Energy Sources

It is needful that the use of renewable energy be encouraged for desalination systems. Although renewable energy is not a firm source of power due to variations in supply and energy is expensive to store in large quantities, there is still a need for it to be encouraged. It should be encouraged because it is a clean source of energy, environmental friendly nature and of course, it is naturally occurring. Water is naturally occurring as well - hence there is compatibility between renewable energy and desalination.

The major challenge in the deployment of the renewable energy source to desalination systems is the fluctuation and intermittency of the supply of power and the availability in terms of time and quantity. This challenge is applicable to wind, solar and wave energy, but not to geothermal and biomass which can be said to be readily available and predictable [7].

Since water can be stored relatively easily, the inconsistency in production of water is not a challenge from a water supply point of view. If desalination systems can be run satisfactorily (technically and economically) with regular periods of shut down without resulting into downtimes, then renewable energy resources can play a major role in supplying energy to desalination plants.

Wind is a renewable energy source; wind energy is very widespread, with mean wind speeds in excess of 5 m/s being quite common. It is not in general a predictable or dependable energy source, although there are exceptions: thermally-driven winds around the edges of desert regions will exhibit a daily cycle. Southern California, which has been densely populated with wind turbines, is a prime example.

It is possible to use the wind energy to supply either electricity or mechanical power. Though good wind energy is often available on an intermittent basis in arid areas, particularly islands the affordability of this means poses a challenge for the dwellers in these areas.

Geothermal energy is another source that can be used as a power input for water desalination, but this is not suitable for this project.

Biomass is another source of renewable energy. This is not likely to be a popular option as the availability of biomass suggests that there is adequate water in supply to grow it (biomass) which then implies that a desalination system is not necessary. Although there are times and circumstance that could inform the availability of biomass and yet there is inadequate water supply. In that circumstance, biomass energy based system could be used. This however, would only produce electrical power to power huge desalination plants. There is also another issue of supply of the biomass as this is seasonal.

It is not likely that the biomass would be appropriate in the desert and some arid locations due to the fact that these areas are not likely to support the growth of biomass and the cost of getting same would be prohibitively high.

Battery systems are not a source of renewable energy, but a means of storing energy. Battery systems are a very expensive means of storing energy as they have limited storage capacity. Batteries practically are not a good energy source for desalination. Although it is possible to use them for some hybrid systems, using them alongside some renewable sources possibly.

In some instances, they can be used as a backup for some specific periods when there is short supply from the renewable source. They can be used as a stop gap for systems instrumentation in order to reduce downtime. More often than not, they are used in small system as a buffer system when the renewable energy plant is down.

The demand for water is increasingly becoming a global challenge. In many parts of the world local demand is outstripping conventional resources. More economical use of water, reducing distribution losses and increased use of recycled water can help alleviate this problem but if there is still a shortfall then desalination of seawater or brackish water may be an option [4]. From all available energy sources, solar energy is the one that correlates best with the demand for water, because it is obviously the main cause of water scarcity.

Solar

Energy from the sun is said to be the solar energy. This is the earth's primary energy flow and equally too, the most abundant on the earth crust. There are two major ways in which the solar energy can be used or harnessed. It can be used either as a thermal energy by heating a fluid or by converting it into electricity using photovoltaic arrays (PV). The former would be looked in detail in the design of the solar still. Solar energy is a relatively diffuse source of energy. It is also available almost everywhere, unlike geothermal, wave, wind or even conventional fuels.

Depending on the energy demand of the application, it may require large areas. Yet, most solar energy conversion systems are modular and can be installed almost everywhere which relieves the space availability problem [4].

The solar energy can be deployed and use for simple desalination systems especially, the solar still for production of potable water in the tropics and arid regions of the world where there is abundance of this natural resource. These regions are well endowed with this resource and it should be fully exploited.

Solar Thermal

Solar thermal energy is one of the most promising applications of renewable energy to seawater desalination. A solar distillation system may consist of two separated devices, the solar collector and the conventional solar still. Indirect solar desalination systems usually consist of a commercial desalination plant that is connected to commercial or special solar thermal collectors.

The possibility of capturing energy with the distillation process using a simple solar still is not only possible, but achievable. However, the still is simple and relatively cheap, but it is not particularly efficient. That is why over the years, different types of designs (for example; the baffle type, the wick type, the single slope type, the double slope type) have been developed to improve on the performance of the still and to increase its efficiency. Moreso, production of higher grade energy in the form of hot fluids which can be used to drive more thermally efficient desalination processes such as MSF and MEB have also been deployed.

The deep solar ponds and concentrating parabolic collectors are also good examples of adaptations and modifications to the simple still [26]. In all of these, the energy collected is proportional to the area of the collectors and the efficiency of the device.

Solar ponds are by their design and nature quite static, but the energy storage is cheap. This energy can be connected to a desalination system to generate potable water. Most of the other collectors can be made to track the sun which in turn improves their efficiency but might also have some cost implications. The thermal energy storage is relatively cheap. This is stored in the form of a hot fluid in insulated tanks or in the case of solar ponds - within the solar pond.

There are two main methods for the deployment of solar energy in seawater desalination. The first method uses the ‘greenhouse’ effect to evaporate clean water from salty water in an enclosed simple solar still. Figure 3 shows a typical basin type solar still containing the sea water covered with a transparent air tight top. The second technique which applies the use of solar energy for desalination is somewhat complicated and often involves more than one subsystem: one for energy collection, another for energy storage, and a third subsystem for energy usage in the desalination process. The desalination process may be distillation, electro-dialysis, or reverse osmosis [8]. The last two are particularly attractive for the desalination of brackish or low salinity water.

The distillation process is the most developed thus far for seawater.

Figure 3: A typical basin-type solar still [9]

2.2 Solar Distillation

Solar distillation has been used for many years, usually for comparatively small plant outputs. Over the years, substantial research has been carried out to find out ways into improving the efficiency of the process. Research work has been carried out in many parts of the world.

Solar distillation uses, in common with all distillation processes, the evaporation and condensation modes, but unlike other processes energy consumption is not a recurrent cost but is incorporated in the capital cost of the solar collector. The solar still therefore, is of a simple design, construction and maintenance with ease of operation. It is best suitable for regions of the world with high solar intensities.

The mechanism of operation is based on the transmitting, absorption and reflective properties of glass and other transparent materials. The glass has the property of transmitting incident short-wave solar radiation which passes through the glass, the glass being a medium of transfer of heat, into the still to heat the brine.

However, the re-radiated wavelengths from the heated water surface are infra-red and very little of it is transmitted back through the glass as it is shown in Figure 4.

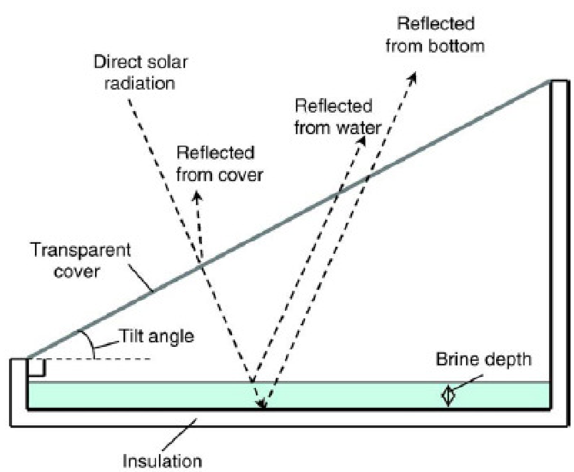


Figure 4: Schematic diagram of a basin-type solar still [34]

Today, producing volumes of pure potable water is not only technically feasible but equally economically viable using the desalination of seawater. The challenge though has been to produce potable water for rural communities for drinking and sanitation to help meet the Millennium Development Goal without compromising standards.

In meeting the challenges of the provision of potable water for drinking and sanitation, huge desalination plants have been built. The introduction of dual-power plants were also deployed to reduce the cost of electricity and water which could impact negatively on the populace. Exhaust heat from power plants were also deployed as an alternative for running desalination systems. These are large desalination systems though. However, not all water demands are coupled with the need for additional electric power.

Solar energy may be deployed to produce fresh water from the sea. This may be accomplished in a large system or in a simple basin-type solar desalination unit.

On a practical basis, certain things ought to be taken into consideration while designing and operating a solar still. For instance, shallow basins require large expanse of land. This land has to be cleared and levelled in readiness for the installation of the still; obviously this attracts some additional cost. Oftentimes and because the water to be treated is salt water, salt crystals build up on the dry part of the basins. This can reduce the overall absorption area of the basin, thereby impacting negatively on the effective basin area. Leakage can cause distillate to leak back into the basin or even leak out of the basin [10]. It is equally necessary to flush the still basin on a regular basis so as to remove accumulated salts and microbes that might have grown in the brines. The use of algaecides might also be encouraged to control the growth of algae.

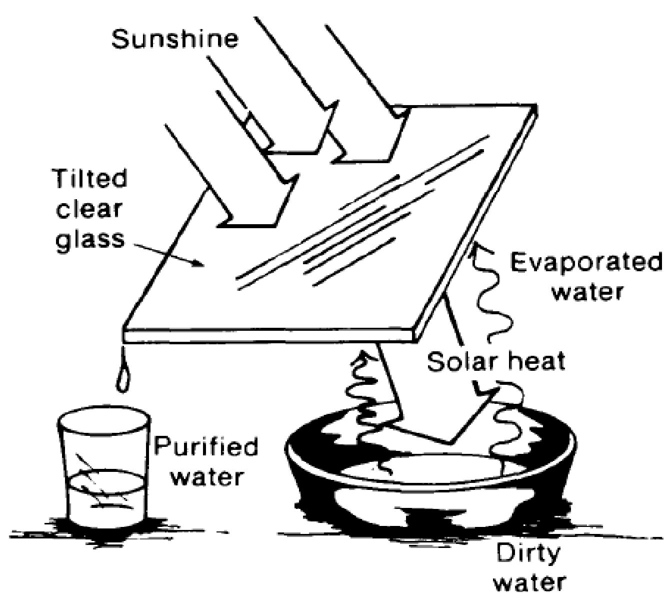


Figure 5: Basis concept of solar distillation [35]

2.3 Basin-Type Solar Still Design

Certain factors influence the choice or selection of different Renewable Energy Sources for any given desalination technology. Since the primary focus is the world's poorest countries believed to be in the tropics, the most viable renewable source would be the solar energy. However, the most important considerations should be the simplicity of the design, its affordability, sustainability, and maintainability and operational ability.

The basin-type solar still is an artificial way of replicating the hydrological cycle. The stills apply the principles of evaporation and condensation that is seen within the precipitation cycle. Stills can however, be classified into two main categories; active and passive. Active stills often employ mechanical methods to replenish the water supply; these stills require more maintenance, skilled labour and an energy input. For these reasons the active basin solar stills are not regarded as an economical option for providing potable water, especially in developing countries.

There are a few concepts that are generally applied to the conventional still design. The glass must be at a minimum of 10^0 to the horizontal to allow the condensate to flow effectively into the collecting tube; yet still allow as much solar energy to reach the water as possible. The angle of the glass should be increased for different latitudes to obtain the optimum angle. It is also important to note that the positioning of the solar still in terms of North and South will change with the hemisphere. The basin is often painted black to absorb a greater amount of radiant heat; the most suitable application would be a coat of matt black paint to ensure that very little is reflected.

Despite the fact that solar stills are easily constructed and employ principles that have been known for centuries there are major inefficiencies within the system. The conventional still suffers from: low water yield due to the combination of condensation and evaporation in one chamber; microbial contamination when subjected to long periods of low temperatures; shallow basin stills store small amounts of sensible heat and it relies on human factors to maintain optimum performance. The success of the still relies on the replenishment of water; and maintenance routines such as the flushing of the basin to remove microbial build-up and clearing dust particles and dirt from the glass surface. These factors all contribute to the average efficiency of the still.

There has been extensive research on the adaptations that can be made to the conventional still design to improve the performance of the system. These investigations have included structural changes such as baffle plates, reflective back plates, wick methods; physical methods such as evacuation; use of coupling of a flat-plate; storage methods by use of dye or sensible heat storage; the performance of a single slope basin still with some computational model; development of active passive still with separate condenser; and the use of phase change materials (PCM) [11-16]. These methods are all an attempt to improve the water yield over the 24 hour period; however the more adaptations that are made the more expensive the still becomes. A simple, cheap but effective solution must be found.

The biggest contributing factor to the effectiveness of the conventional still is the temperature difference between the basin and the glass – the larger the temperature difference the greater the condensation rate. Shallow basin stills are more productive than deep basin stills overall, however during the night the water cools rapidly as little sensible heat is stored within the water.

Adaptations such as incorporating a sun tracking system which can be used with single-axis solar concentrating systems as an enhancer have been attempted to improve the performance of the still [17]. The key objective of this project therefore, is to improve the performance of a traditional single slope solar still through the combined functioning of the solar still with a sun tracking mechanism to increase the solar still capability to capture more solar radiations which in turn would increase distillate yield.

Figure 6: Basin-type Solar Stills having varying Angles of Inclination [18]

2.4 Heat Transfer Mechanisms in a Solar Still

The mechanisms of heat transfer within a solar still are basically dependent on the climatic effects and the amount of solar radiation that enters the basin. More importantly and frankly too, the performance of the still depends on how much of the solar irradiance that reaches the water in the basin of the solar still.

When the sun's radiation reaches the Earth it is both scattered and absorbed by the atmosphere. The radiation that then travels through the Earth's atmosphere is known as "sky" radiation, this is the radiation incident on the Earth's surface after the initial waves from the sun have been absorbed and scattered by the atmosphere [19]. The "sky" radiation that travels to the Earth's surface can then be used as a valuable energy source for desalination.

The direct and diffuse radiation enters the still through the glass cover after partially being reflected and absorbed by the glass itself. Once in the evaporating chamber the radiation is further transmitted, reflected and absorbed by the water until it reaches the blackened basin where most of it is fully absorbed. The basin then begins to heat up and in turn through convective processes heats the water causing it to evaporate.

Due to the fact that the glass cover remains at a temperature lower than the dew point temperature (the temperature at which water saturates) the vapour begins to condense on the inside of the glass surface through the mechanism of drop-wise condensation. This is where the vapour condenses in discrete droplets and grows by means of some form of accumulation until it becomes large enough to move under gravity down the glass and can be collected in a pipe at the lower end of the still. This method of condensation has a heat transfer rate of 10 times that of film condensation which allows the heat to be dissipated at a faster rate [20]. This allows the excess heat absorbed by the glass to be dissipated and is lost to the atmosphere.

A simple representation of the heat transfer mechanisms within a still can be seen in Figure 7. Often the formation of drop-wise condensation can reduce the amount of radiation entering the still, and can contribute to a reduction in distillate production in the latter part of the day.

The heat received by the film of condensed water, by radiation from the brine surface, by convection from air-vapour, and by conduction of vapour is conducted through the water film and glass to the external surface of the cover. The small amount of solar energy absorbed in the cover is also conducted outward. The heat which the cover (glass) has received is then transferred from the outer surface to the atmosphere by convection and radiation.

The heat transfer processes in the solar still are all dependent on the difference in temperature between the brine surface and the glass. The higher the difference, the greater is the energy transfer rate by each mechanism. Furthermore, the higher the brine temperature, the greater the proportion of energy usefully transferred by evaporation.

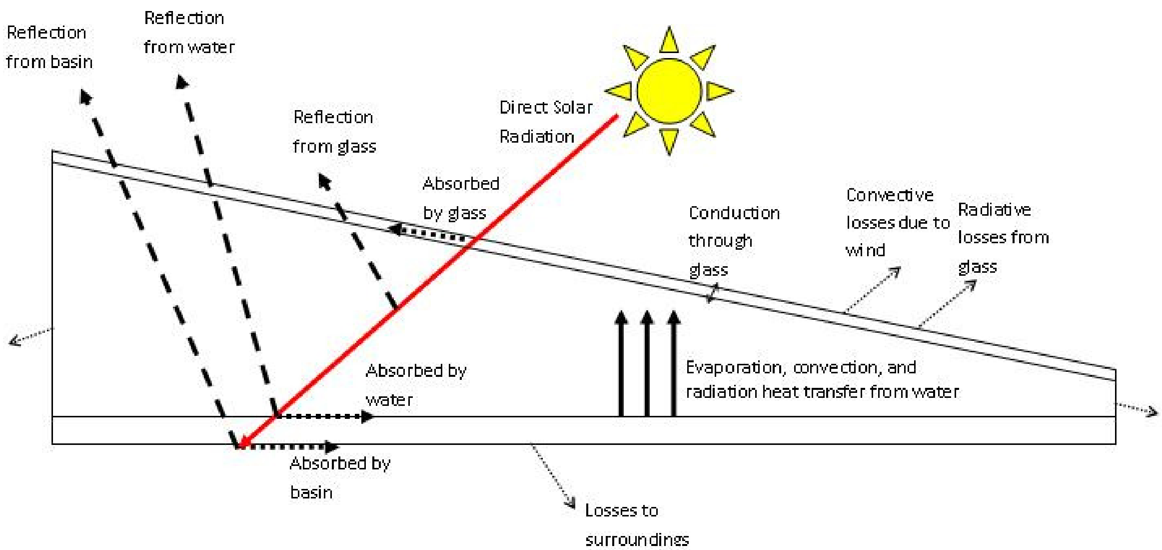


Figure 7: Heat transfer in a Basin-type Solar Still [21]

The solar energy transmitted by the glass is partly absorbed in the brine, with the majority of it being absorbed on the basin base. Heat is conducted from the basin base surface into the brine, thereby increasing its temperature and vapour pressure; partial vaporisation then occurs. The warm vapour saturated air is carried by the convection currents to the transparent glass cover, which is generally cooler than the brine. Moisture condenses on the underneath of the glass, the heat of condensation being conducted through the glass cover to the surrounding atmosphere; the partly dehumidified air drifts back to the surface of the brine for further moisture addition. A thin film of condensate flows down the transparent glass cover to the collecting trough, from which it passes to storage.

The incoming solar radiation, usually composed of direct radiation from the sun and diffuse radiation from the clouds and sky, is partly reflected by the outer and inner cover surfaces, very slightly absorbed in the cover, slightly reflected by the brine and the base of the basin; the balance is absorbed by the brine and the bottom of the basin. Another small portion of energy is lost by conduction through the bottom into the ground or through insulation under the base from the energy absorbed by the basin bottom.

The brine is warmed by the convection currents in the shallow basin to the air-water interface, where transfer of mass and energy takes place. Since the vapour pressure of the surface water is greater than the partial pressure in the air space, evaporation into the overlying air film occurs [22]. This transfer of water is accompanied by sensible-heat transfer from the warm brine into the air-vapour mixture in contact with it. Both processes produced a temperature rise and density decreased in the air-vapour mixture, causing it to rise toward the transparent glass cover.

Supplementary to the convective heat transfer from brine surface, is a transfer of heat to the cover by radiation. The glass cover is cooler than the brine partly due to the breeze from the outerside and partly due to the condensate on the inner underside, so the radiant transfer process is essentially between two water surfaces, net radiation being from the brine in the direction of the glass cover. Since the glass cover is cooler than the air-vapour mixture coming in contact with it, the difference in vapour pressure causes diffusion of water vapour through the air film to the water layer on the underside of the cover. Condensation occurs due to the latent heat being released from the water film.

2.5 Sun Tracking Mechanisms

Sun tracking, simply put, is the process whereby the solar radiation of the sun is sensed and being followed from sunrise to sunset. This can be achieved in two ways; manually and by means of an automated device.

The reason for sun tracking is not far-fetched. Since the basin-type solar still requires much of the solar irradiance to be transmitted into the still basin to heat the brine for evaporation and condensation to take place. It is therefore, evident that the more solar intensity, the faster the evaporation and the higher the condensate which would eventually give rise to a higher distillate yield.

The Sun moves relative to the Earth's surface at the rate of 15° per hour east to west and by approximately 46° per annum north to south. This means that fixed solar stills will hardly ever by perfectly aligned with the Sun [23]. At latitude 55° north, a south-facing solar still angled at 10° will only be perfectly aligned at midday on mid-summers day. Solar stills having tracking systems will be perfectly aligned with the sun all the time it is shining. The fixed solar still system will only be aligned to the sun at about midday and only a fraction of the glass cover is being presented for the rest of the day.

A Sun Tracking mechanism is a device incorporated into a solar still which follows the movement of the sun across the sky with the aim of ensuring that maximum solar irradiance is transmitted through the glass cover of the still into the basin and is absorbed by the brine from sunrise to sunset, throughout the day.

The sun tracking mechanism is grouped into two types, the single axis and the double axis models. The single axis is usually on a horizontal axle or vertical axle depending on the region of use and application. The horizontal is used in the tropics where the sun is very high at midday, but with shorter days while the vertical is used in high latitudes where the sun is slightly high, but with very long summer days. The double axis sun tracking mechanism has both a horizontal and vertical axle so, can be deployed anywhere in the world [24].

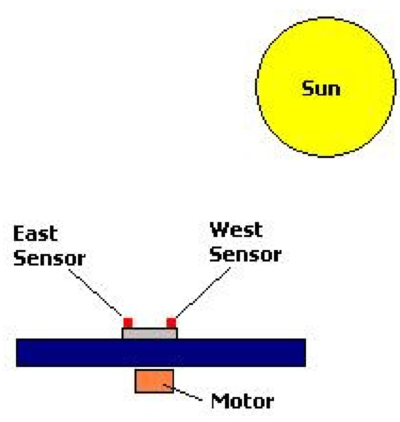


Figure 8: A schematic diagram of a simple sun tracking mechanism [24]

In the last century, Pasteur used a concentrator to focus sun rays onto a copper boiler containing water. The steam thus generated from the boiler was then connected to a conventional water-cooled condenser where the distillate was collected [4].

Before now, some researchers have used sun tracking systems to investigate performance enhancement for distillate yield in the solar still or for power production in photovoltaics arrays (PV) [25]. The experimental investigation of a collector with six parabolic troughs using sun tracking systems [26] was also considered.

The primary aim of using sun tracking system was to investigate how it improves the performance, either in the solar still or in any other systems for which it was deployed. The purpose of this research is to investigate the effect of sun tracking in the conventional solar still design.

3 Method

3.1 Theoretical Analysis

Supplying the heat for evaporating the condensate and removing heat from the condensate are basic requirements for energy transfer in a solar still [27]. These two heat rates are quite importantly equal at about 577.8 kJ/kg of distilled water. The efficiency of energy usage in the solar still would depend on the percentage of total incident solar radiation available for the distillation process.

The assumptions stated in the equations below have been carefully studied and properly analysed. They have been found to be consistent and have a direct bearing on this project.

Suppose the absorption of solar intensity by the glass and temperature drop through the glass is negligible, the heat balance on the glass per unit area is:

$$(h_{c,o} + h_{r,o})(t_g - t_a) = (h_{c,i} + h_{r,i})(t_b - t_g) + E\lambda \quad (1)$$

Suppose also, the glass area is equal to the basin area, the overall energy balance of the still can be represented as follows:

$$Q_{sh}/24 = (h_{c,o} + h_{r,o})(t_g - t_a) + E(t_b - t_g) + L \quad (2)$$

According to Löf [28], the individual terms in equations (1) and (2) can be represented as follows:

Convective heat transfer (glass to air) = $1.514(t_g - t_a)$ (3)

Thermal radiation (glass to air) = $0.461 \times 10^{-8}(T^4{}_g - T^4{}_a)$ (4)

Convective heat transfer (basin to glass) = $0.145(t_b - t_g)^{1.25}$ (5)

Thermal radiation (basin to glass) = $0.444 \times 10^{-8}(T^4{}_b - T^4{}_g)$ (6)

Heat of condensation (basin to glass) = $0336(t_b-t_g)^{0.25}(W_{H2O}/W_{da})\lambda$ (7)

Substituting the above into equations (1) and (2), then the heat balance on the glass per unit area is:

$$1.514(t_g-t_a) + 0.461 \times 10^{-8}(T^4{}_g-T^4{}_a) = 0.145(t_b-t_g)^{1.25} + 0.444 \times 10^{-8}(T^4{}_b-T^4{}_g) + 0336(t_b-t_g)^{0.25}(W_{H2O}/W_{da})\lambda \quad (8)$$

Suppose there is a heat of conduction losses of about 13.56 W/m^2 [27], the relationship for the overall energy balance on the still per unit area is:

$$Q_{sh}/24 = 1.514(t_g-t_a) + 0.461 \times 10^{-8}(T^4{}_g-T^4{}_a) + 0.605(t_b-t_g)^{1.25}(W_{H2O}/W_{da}) + 13.56/24 \quad (9)$$

In terms of daily performance, the overall efficiency of the solar still can be expressed as:

$$\text{Still Efficiency (\%)} = (57.78 \times 10^6 P)/R$$

3.2 Design

This project took into cognisance the fact that the structure to be used should possess a number of features intended to guarantee an efficient and effective evaluation of the results.

The design is a basin-type solar still (horizontal water-filled basin), covered by a sloping surface transparent to solar radiation, on which water is condensed and collected. Salt water was supplied to the basin with a depth of 110mm. The bottom of the still has a black surface to absorb solar energy. A transparent glass cover is placed on top of the basin such that its surface slopes down into a small trough at its lower edge. The trough is connected to a flexible hose for collection of the distillate.

The still was designed with an optimum basin aspect ratio of 2 [29], where the length is twice the width, to ensure that the maximum amount of solar radiation reflected by the walls was absorbed by the water. The basin was constructed with stainless steel (2mm thickness) and painted black to absorb the radiant heat. It was then secured inside an insulated casing of expanded polystyrene (50mm thickness) and plywood (3.6mm thickness). A semi-circular PVC pipe was attached at the lower end of the box to collect the distillate and directed it out to be collected. A glass panel (4mm thickness) was then placed on top of the still at an angle of 10^0 to the horizontal to ensure that the minimum amount of condensate dripped back into the basin [30].

The still was then constructed in the workshop. After construction the basin edges were sealed with waterproof sealant and the basin liner was painted black. The basin of the solar still is made water-tight to avoid water leakage and the inside surface is blackened to absorb maximum solar radiation.

The bottom and sides of the basin are insulated to reduce the heat losses to the surrounding. There were also some minor modifications made to the outlet pipe to ensure that there was no seepage and to decrease humidity. Once all of the modifications were made the solar still was set-up on the roof top of the James Weir building for testing.

There are many adaptations and variations that could be made to this design; however the main focus was to investigate whether sun tracking would increase the efficiency of the desalination process. As a result the other modifications were not considered in great detail.

Table 1: Technical specifications of the solar still

Width	0.45m
Length	0.90m
Glass area	0.478m^2
Base area	0.405m^2
Glass thickness	4mm
Glass slope	10^0

3.3 Practical Experiment

The experimental work was carried out on the roof top of the James Weir building, using actual environmental conditions. The experiment was carried out at the peak of summer between July and August, 2010. Due to the intermittency in weather variations; measurements, testing and readings were taken every 15 minutes to ensure accuracy.

The temperature fluctuation of the brine and the glass was monitored using a number of temperature sensors, type-K thermocouples. The type-K thermocouples were used for accuracy and because of its resilience in water. Each of the type-K thermocouples (with a range of 0-100^{0}C) was first tested to ensure that the voltage output increased with increasing temperature. The thermocouples were stripped, welded, and tested for adequate voltage variations on temperature changes and then secured in the basin.

Once working the thermocouples were soldered, covered with heat shrink wire and protected with a waterproof sealant. Six of the temperature sensors were placed on the glass and six in the brine. Two were placed in between the basin and the insulation; another five were placed on the basin. The sensors were then connected to a digital microprocessor (The accuracy of this device is in the range of $\pm 0.1^0C$ for the temperature measurements between 0 and 100^0C) and then calibrated to read the temperature measurements to allow the temperatures to be recorded every 15 minutes throughout testing. To ensure that the temperature of the glass was measured correctly and not affected by the ambient environment insulating and aluminium tape were applied to cover the sensor.

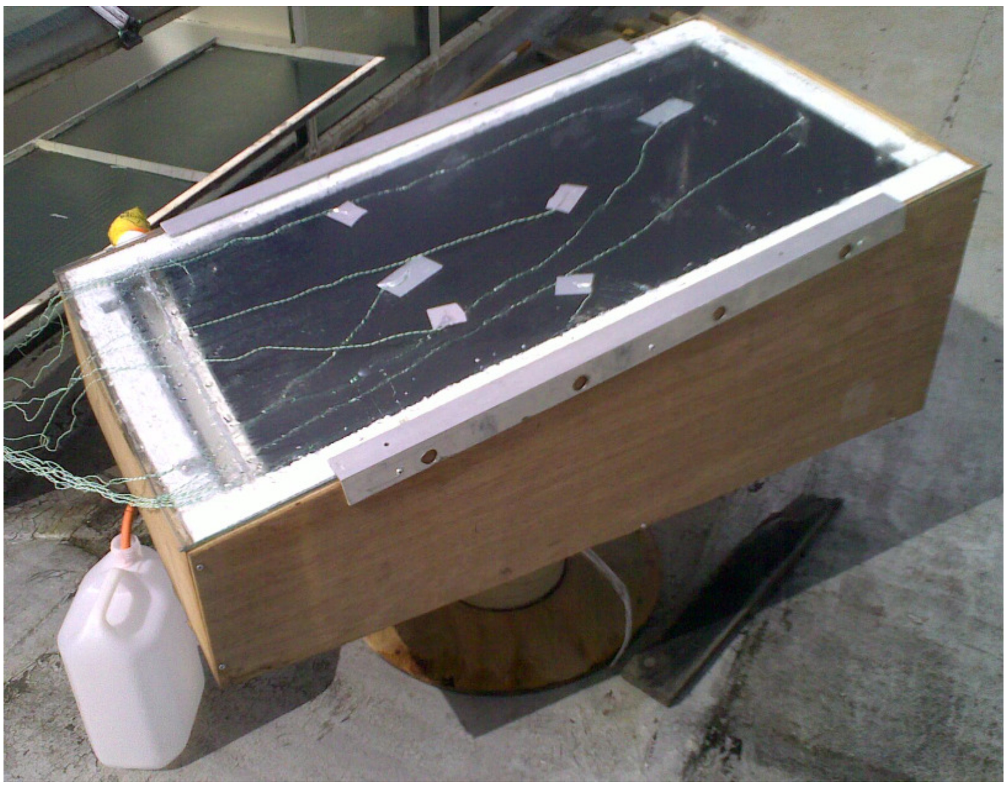


Figure 9: Showing the still and the attached type-K thermocouples

The solar intensity was measured using a pyranometer, which measures the instantaneous intensity of the radiation in (W/m^2); having a range from 0 to 1500 W/m^2. The twenty type-K thermocouples were coupled to a digital microprocessor (thermometer with a range of 0 to 100^0C with $\pm 0.1^0C$ accuracy) and were used to measure the temperatures of the various compartments of the still system.

Figure 10: Showing tracking in progress

The testing was carried out over a continuous period to simulate the performance of the still over a prolonged time. It was decided to conduct the experiment in this way because it is known that the performance of the still decreases over time due to the increased temperature of the glass. The condensate was measured at sunset. The still was then left to collect its night-time distillate and the new level of water was weighed each morning at sunrise before the experiment was repeated. The full experimental set-up can be seen in Figure 9. The still was positioned facing south to allow for direct solar radiation and allowed the conditions to simulate the most direct period of sunlight hours (sunrise to sunset) in the day. A number of assumptions were made to allow the models to be compared and conclusions to be drawn. It was assumed that: no condensate or evaporate escaped from the still; the still was completely airtight; there was no obstruction caused by the temperature sensor wiring in the practical experimentation; and there were no losses of the condensate to the atmosphere or retention in the collection pipe.

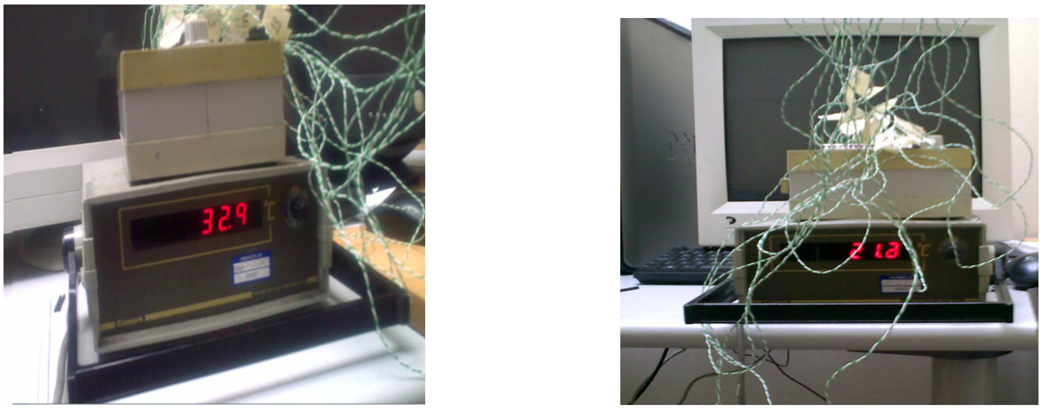


Figure 11: Digital microprocessors showing thermocouple readings

3.4 Sun Tracking

To capture the maximum solar intensity for irradiance during the day by the solar still, there is a need for the solar radiation, direct and diffuse to be tracked for optimum performance. The essence of sun tracking is to ensure that the effective solar irradiance is achieved from sunrise to sunset. This can be carried out in two ways, either by incorporating an automated tracking device/system in the still or it could be done manually.

The latter was preferred as this design is meant to be as simple and as easy to operate as possible without any such encumbrances associated with huge/gigantic solar desalination plants.

This is the method deployed in this project. The solar still was tracked from sunrise to sunset in order to follow the movement of the sun so as to track as much solar radiation as possible from the sun.

For the purpose of this project, the sun tracking is done in a 2-dimensional direction. The beauty of the design however, is that the still is perpendicular to the solar radiation when tracked especially during the mid-afternoon when the intensity is supposedly high. So, the solar irradiance is appreciably high.

4 Results and Discussions

Results of the experiments are presented in the form of graphs and tables, to show the effect of using sun tracking on different solar still systems (a fixed still and a tracked still) on the still output, and to highlight the effect of using tracking mechanism on the received solar intensity, basin, brine temperatures, glass temperature, and the distillate yield with respect to time, h.

Table 2: Design features of the Solar Still

Cover material	Shape cover	Area of (A_e) evaporation (m^2)	Area of (A_c) condensation (m^2)	A_c/A_e
Glass	Flatly inclined	0.405	0.478	1.18

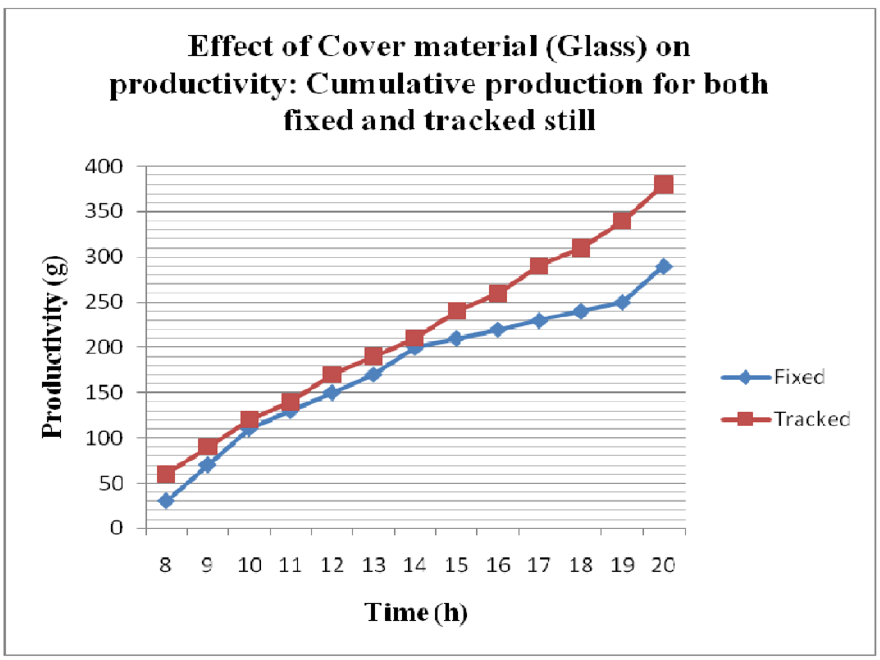


Figure 12: Effect of Cover (Glass) material on Productivity

It can be seen from Figure 12 that the tracking system has increased the glass cover temperature due to the increase of the temperature of the vapour inside the still, and this is due to the high concentration of solar irradiance that passed through the transparent cover to the black evaporating basin.

Table 3: Brine Temperature for both Fixed Still and Tracked Still

Local time	Brine Temperature (^{0}C)	
	Fixed Still	Tracked Still
8	-	25
9	23	28
10	32	39
11	37	44
12	54	63
13	59	65
14	62	64
15	60	62
16	55	59
17	51	60
18	48	53
19	38	48
20	29	41

Table 4: Basin Temperature for both Fixed Still and Still with Tracking

Local time	Basin Temperature (^0C)	
	Fixed Still	Tracked Still
8	25	28
9	29	32
10	35	41
11	44	47
12	51	56
13	48	64
14	45	55
15	38	52
16	35	47
17	35	44
18	30	41
19	29	36
20	26	31

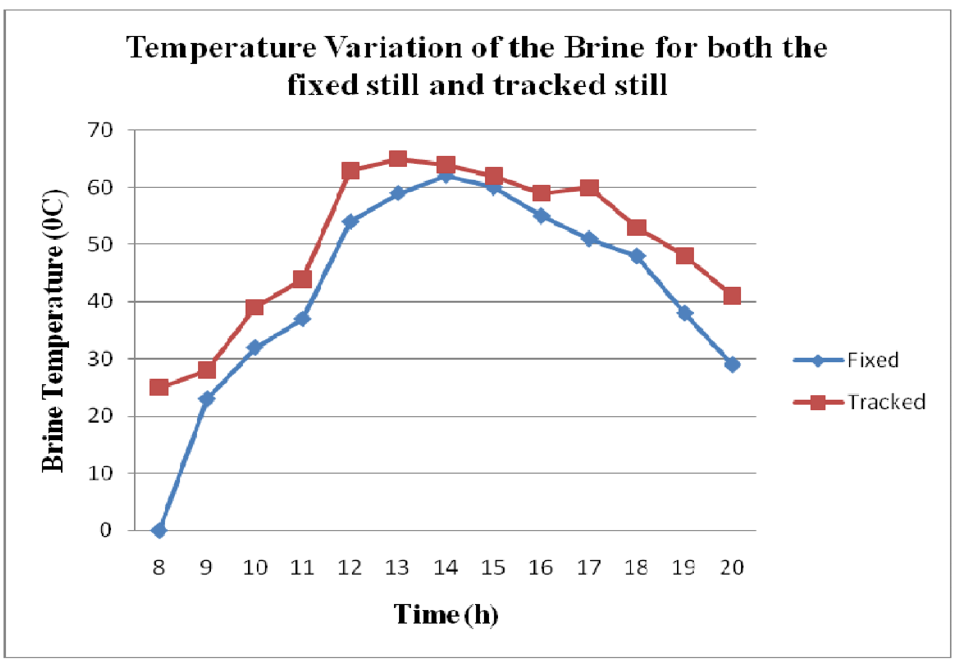


Figure 13: Temperature Variation of the Brine for both the fixed still and the tracked still

The Figure 13 shows the effects of solar intensity on brine temperature for the two different systems, the fixed still and the tracked still. It can be seen that the brine temperature increases for both systems as the solar intensity increases till noon, then decreases as the solar intensity decreases. It was discovered that the brine temperature for the tracked still is higher than the fixed still due to the increase of the radiation concentrations on the absorption capacity of the basin, especially in the morning hours, which invariably decreases the heat capacity.

Table 5: Cover (Glass) Temperature for both Fixed Still and Tracked Still

Local time	Cover Temperature (^0C)	
	Fixed Still	Tracked Still
8	23	27
9	25	35
10	30	39
11	33	41
12	34	40
13	36	40
14	35	39
15	33	36
16	31	32
17	29	30
18	27	30
19	24	28
20	23	26

Table 6: Ambient Temperature for both Fixed Still and Tracked Still

Local time	Ambient Temperature (^{0}C)	
	Fixed Still	Tracked Still
8	25	28
9	31	36
10	34	37
11	30	33
12	36	39
13	38	44
14	41	42
15	39	40
16	38	39
17	36	38
18	31	34
19	28	30
20	27	29

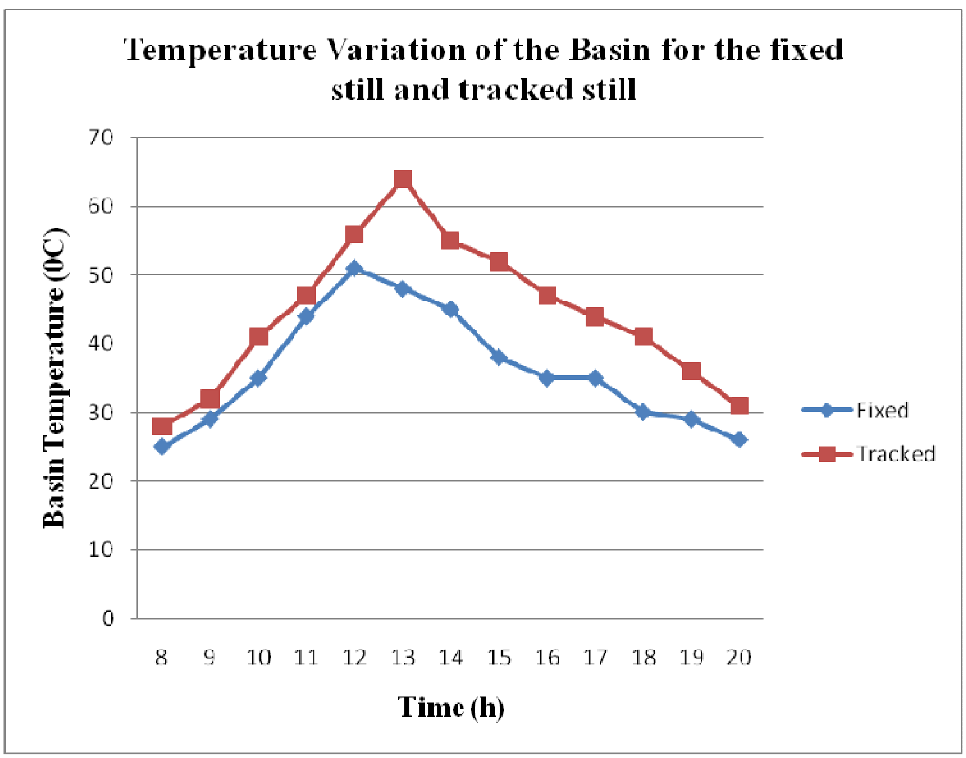


Figure 14: Temperature Variation of the Basin for both the fixed still and the tracked still

Table 8: Experimental Results and Percentage increase in Total Production

Parameters	Fixed Still	Tracked Still
Daily Production (g)	290	380
Total Production (g)	370	460
Estimated efficiency (%)*	16.2	20.1
Percentage increase in Total Production	19.6	

* Based on an average solar intensity of 550W/m^2 day and an average evaporation area of 0.405m^2

Figure 15 shows the increases in the temperature of the cover (glass) as the solar radiation incident on glass increases. But the temperatures are lower than the brine temperature as shown in Figure 13, due to the effect of air cooling on glass. There is basically energy transfer from the brine to the glass cover by the water vapour evaporating from the brine surface and then loosing its heat of vaporisation to the glass cover, which in turn cools off.

Table 9: Solar Intensities (W/m^2) for both Fixed Still and Tracked Still

Local time	Solar Intensities (W/m^2)	
	Fixed Still	Tracked Still
8	160	360
9	400	540
10	700	780
11	620	830
12	830	920
13	910	960
14	780	840
15	640	760
16	410	580
17	250	350
18	160	190
19	50	80
20	0	0

4.1 Effects of Sun Tracking on the Still

4.1.1 Effect on Construction Material

Due to the material of the construction of the condensation surface, which was glass, productivity was high from sunrise to sunset (as shown in Figure 12). However, in Figure 20, this soon disappeared after sunset, as productivity began to decline due to decrease in solar intensity. The basin also impacted positively on the productivity as its black colour was able to absorb, emit and transmit much heat into the brine, which in turn was able to release much condensate to the glass underside.

4.1.2 Effect on Basin and Cover (Glass) Temperature

Tables 4 and 5 give the results of basin and cover temperatures and its plot is given in Figures 14 and 15. Figure 14 gives the hourly values for the basin temperatures for the fixed and the tracked stills. That for the tracked still was higher than that of the fixed still. This is due to the fact that the tracked still is always following the sun radiation and is often perpendicular to it, while the fixed still is stationary. The results in these tables and the subsequent figures indicated that a higher basin temperature is associated with a high productivity.

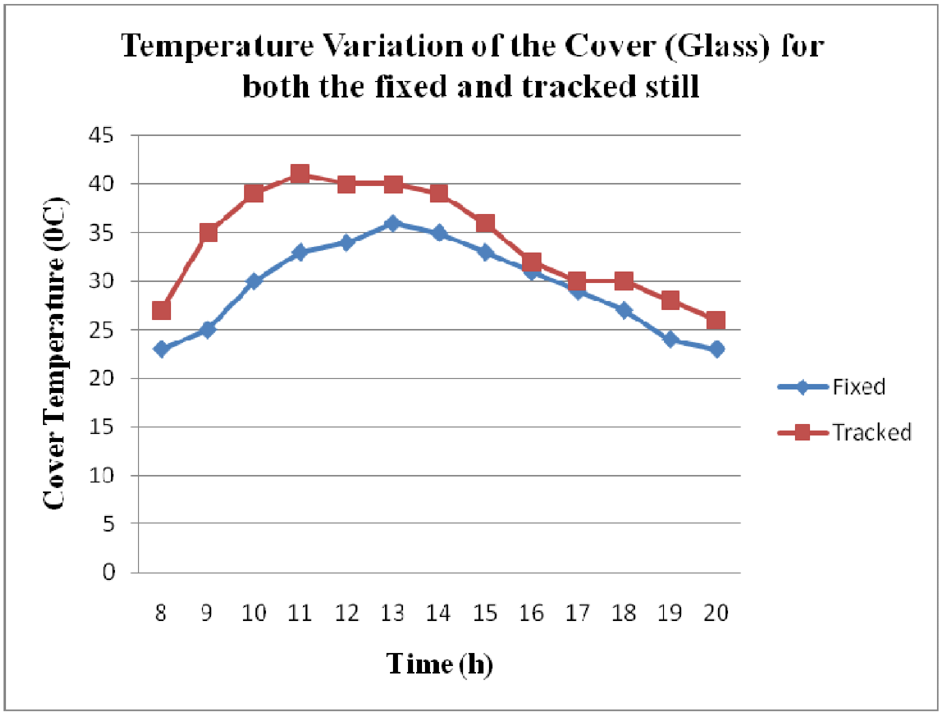


Figure 15: Temperature Variation of the Cover (Glass) for both the fixed still and the tracked still

The experimental results together with the ambient temperature are plotted in Figures 15 and 16. In Figure 20, the hourly values of the productivity are plotted against local time and in Figure 19; the solar intensity is plotted against time. Figure 20 shows that the productivity increases until it reaches the maximum in the afternoon then decreases in the late afternoon. The decrease is due to a corresponding decrease in solar intensity in the late afternoon (about the same period). This impacted both on temperatures and distillate production.

4.2 Effect of Solar Intensity

Figure 16 gives the ambient temperature and Figure 19 gives the corresponding solar intensity. It is clear from these figures that a higher solar intensity corresponds firstly to a high still productivity and secondly to a high ambient temperature. Thus, the intensity of solar radiation has the prime importance on the still productivity. Figure 15 clarifies that at sunset, the productivity of the still decreases suddenly and during the period of diffuse radiation, a very low productivity is attained and little or no productivity at all when the solar intensity reaches zero.

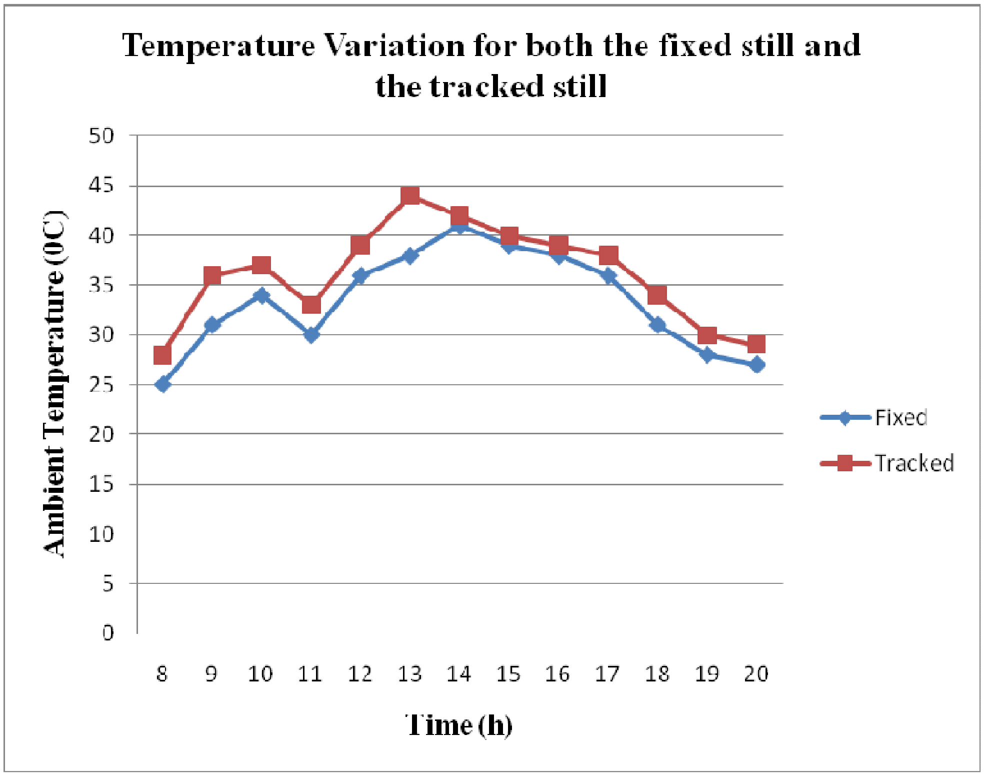


Figure 16: Temperature Variation for both the fixed still and the tracked still

From Figures 13, 14, 15 and 16, it can be seem that an increase in the brine temperature occurs until it reaches the maximum in the afternoon because the absorbed solar radiation exceeded the losses to the ambient. From about 14 h, water temperature decreases due to the losses from the solar still which becomes larger than the absorbed solar radiation. It can be noted that the basin temperature got closer to the brine temperature because of the continuous contact between them which lead to equilibrium in heat dissipated.

Also, Figure 16 shows that vapour temperature is the largest temperature in the solar still because at this temperature the particles have enough energy to evaporate. As the glass temperature is much smaller than the vapour temperature, it causes condensation of vapour on the glass. In the early hours of the morning (8–9 h), the glass temperature is higher than the brine and vapour temperatures causing small productivity due to the small energy absorbed by the brine at these times.

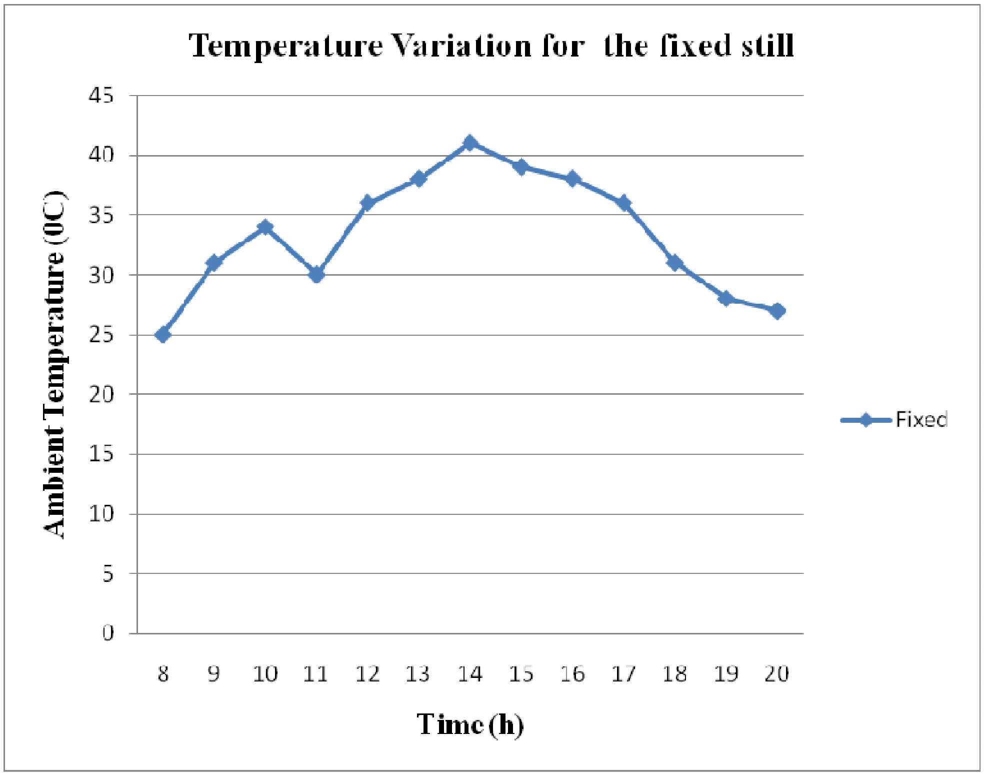


Figure 17: Temperature Variation for the fixed still

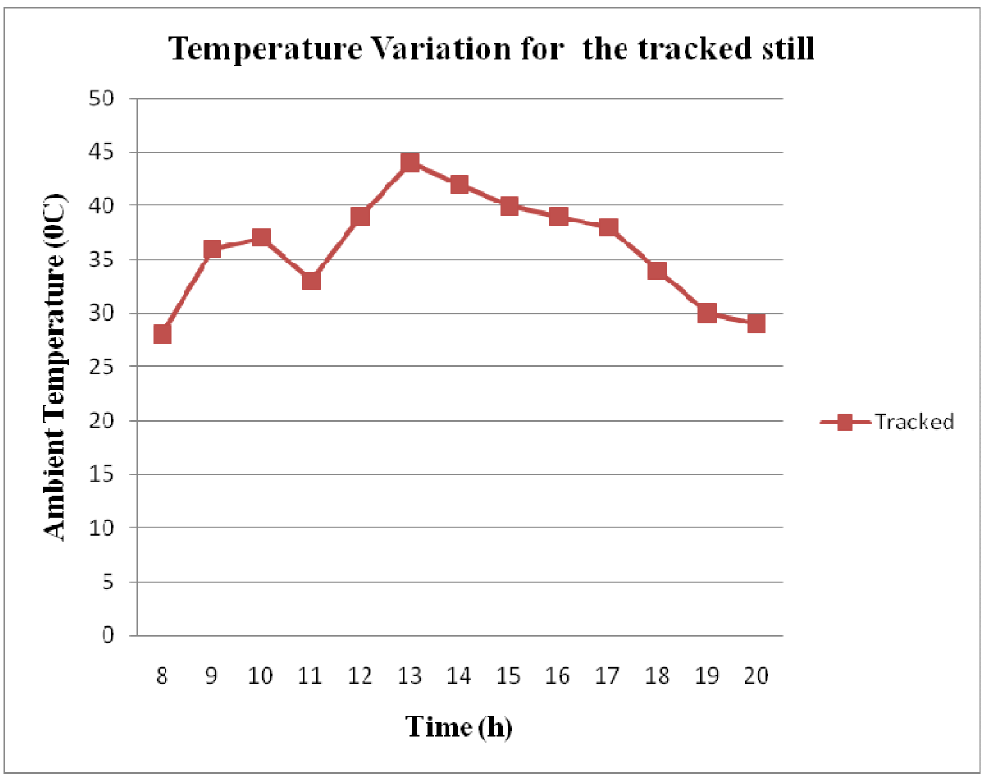


Figure 18: Temperature Variation for the tracked still

A careful analysis of these results showed that both the fixed and tracked stills have very good hourly productivity for most of the sunshine hours. The period from solar noon to 15 h is excluded from this rule. This is because; the period corresponds to the highest cover (glass) temperature, thus a lower condensation effect.

The solar distillation process fluctuates with the solar energy intensity as its production varies from zero for most of the night to a maximum in the early afternoon of a sunny day. The hourly production of distillate also varies as seen in Figure 20.

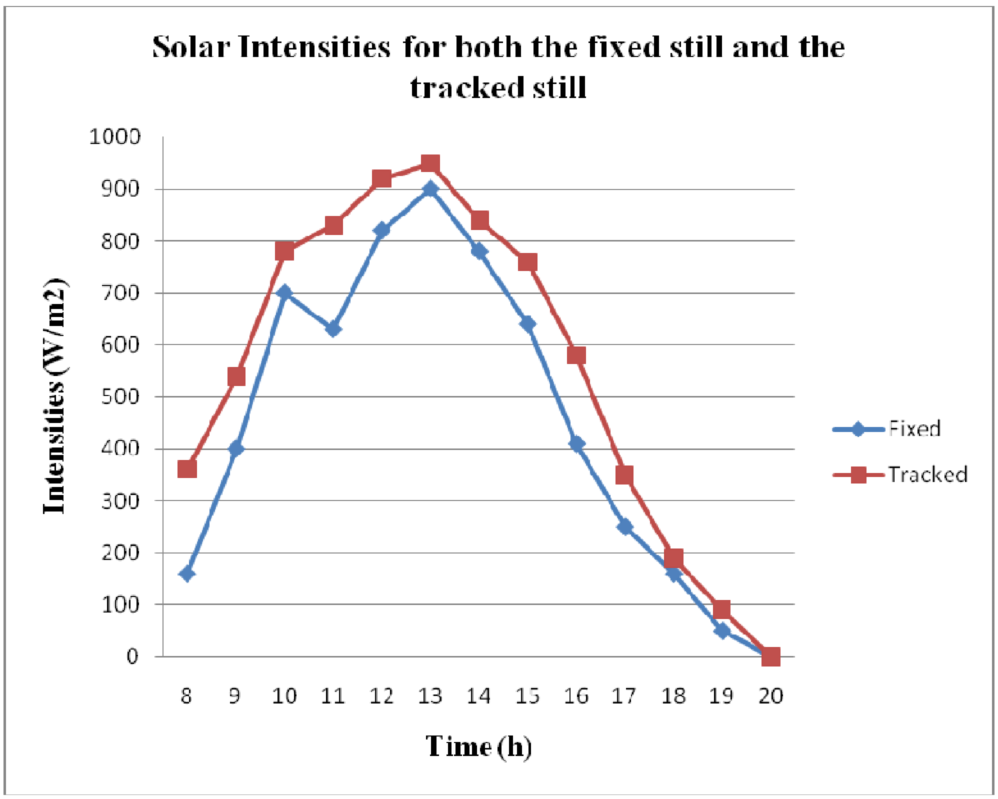


Figure 19: Solar Intensities for both the fixed still and the tracked still

Figure 19 shows the solar intensity and variation with the time of the day. This represents the increase in the solar intensity in the early morning until it reaches the maximum at around 12 and 13 h, then decreases in the late afternoon. The solar intensity has an important effect and a positive consequence on the solar still (distillate) productivity. As the solar intensity increases, the productivity increases due to the increase in heat gain for water vaporisation inside the still. The productivity rate varies with time as time passes from early morning until late afternoon.

The intensity of solar radiation reaching the earth surface varies from zero during the night to about 830 W/m^2 and 920 W/m^2, on a bright afternoon, for both the fixed and the tracked stills respectively. It is imperative to note that, the climatic condition and the hour of the day affects the radiation intensity. It can be seen in Figure 19 that the solar intensity for the tracked still was higher than that of the fixed still for most of the time. There were conspicuous differences in solar intensities for both the fixed and tracked still in the early morning till mid afternoon, while in the late afternoon until the evening the trend subsisted with a nominal difference from the mid afternoon intensities of the day. The highest differences were in the morning till mid day with an average increase of about 38%, while in the evening the average increase is about 17%. This is due to the sun tracking mechanism which makes the solar intensity striking a horizontal surface greater on the tracked still than on the fixed still because it is being followed all through. Hence, the sun's rays were vertical on the surface most of the time during the day.

4.3 Still Efficiency

Table 8 gives a summary for the experimental test and the percentage increase in total productivity of both the fixed and tracked stills under consideration. The distillate collected from the still from sunset to the next day morning was added to the daily production and the resulting total production was used for the calculation of the increase in total productivity.

It was observed that the still with the tracking mechanism gave an increase in total distillate yield of 19.6% and an additional increase in overall estimated efficiency of 3.8%

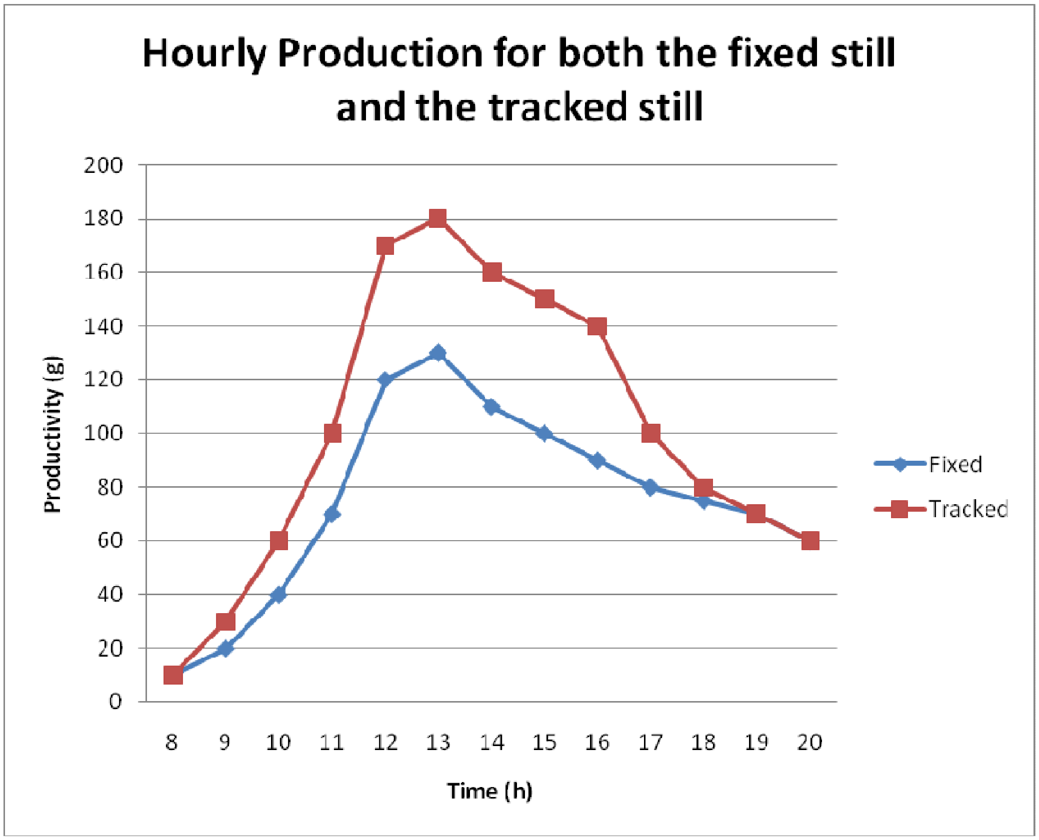


Figure 20: Hourly Production for both the fixed still and tracked still

Figure 20 shows that the productivity increases until it reaches the maximum in the afternoon then decreases in the late afternoon unto the evening. The brine temperature can be taken as one of the parameters that have a direct effect on the productivity after the solar intensity.

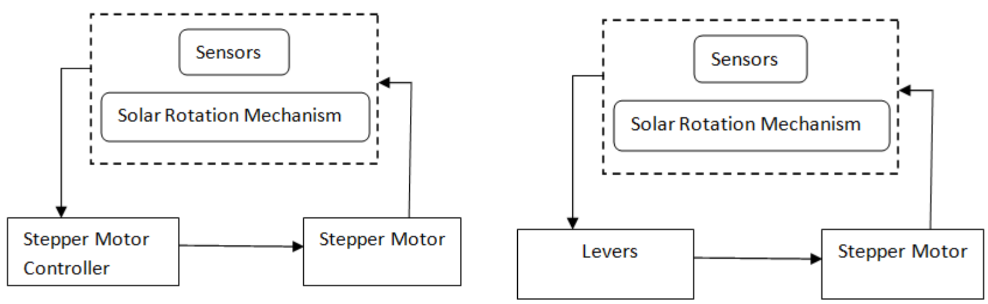
4.4 Realisation of the Tracking System

Solar radiation capturing is dependent on the angle of incidence of the sun to the solar still's surface, and the closely perpendicular it is, the more the irradiance. If the solar still is mounted on a bench, it is more likely that from sunrise to sunset the sunlight will have an angle of incidence close to 90°in the morning and the evening; thereby, the radiation gathering ability of the glass cover is practically zero [31]. As the day advances to midday, the angle of incidence approaches 0°, resulting in an increase in solar intensity until when the incident radiation on the solar still is completely perpendicular, and maximum solar intensity is achieved.

With the foregoing, there is then a need to keep the angle of incidence as close to 0^0 as possible in order to achieve higher solar intensity. This can be done by using the sun tracking system by rotating the solar still to continuously follow the sun as effectively as possible.

The tracking system can either be automated or manually operated. The automated, as seamless as its operation might be, has an additional cost attached to it. It might also be too sophisticated for the rural communities for which this system is designed. So the viable option for this system is the manually operated tracking system. This has a simple design, relatively cheaper, affordable and easy to operate.

The automated sun tracker consists of a stepper motor with gear trains, a stepper controller and some sensors. The sensors sense the solar radiation and send signals to the controller while the motor rotates the still in order to follow the solar radiation from sunrise to sunset as shown in the schematic diagram below.



A: An Automated Tracking System B: A Manual Tracking System

Figure 21: Schematic diagram of Automated and Manual Tracking Systems

The automated tracking system uses some form of smart controllers, stepper motor (inside the motors are some gears, some have got brakes) for the rotation of the still. Stepper motor are robust drives which carry out step by step movement and are controlled by a positioning controller, such as a programmable controller as shown in Figure 21. Some have rotation monitoring and holding brakes with planetary gears extended applications. They require stepper motor controllers with microcomputer-controlled applications used with discrete power device in a step motor. The programmable controller can control three independent axes of motion with flexible setup for storing locations, recalling locations and other functions as required. This is an ideal controller for microscope, x-y, or x-y-z stage applications.

A: Stepper Motor B: Stepper Motor Controller C: Programmable Motor Controller
Figure 22: Various components of an Automated Sun Tracking System [32]

In the automated tracker, the solar still is connected to a computer controlled mounting system so as to ensure that the solar still is always gaining the maximum amount of irradiance. It calculates the angle required by the motor and adjusts the motor's current angle. It moves the solar still to achieve optimal solar irradiance.

There are usually two sensors being used in the automated tracking system, the balance and tracking sensors. While the balance sensor sets the system to a zero point, the tracking sensor determines the orientation of the solar radiation. The signals fed back by the sensor form the basis of the controller input.

The manual tracker has got some simple set of gears and levers as seen in Figure 21. In place of a smart controller is an operator. The operator is given some basic training and a chart stating the solar azimuth and the altitude for each given period of the year. Table 10 shows the sun or moon rise/set for Lagos, Nigeria from June to December, 2010. The operator relies on the charts or tables such as this to rotate the solar still with the aid of attached levers, according to the available data on the charts or tables, at different intervals from sunrise to sunset. This was the approached used in this project.

The principle is basically the same, but while the automated sun tracker is sophisticated with an inherent additional cost, the manual tracker boasts of a simple design at a very reduced and reasonable cost and of course pocket-friendly for the remote communities for which it is deployed; and the end-users would be more than willing to rotate the still in order to track the solar radiation using the levers. After all, this is better than travelling some kilometers in search of water. The manual tracker requires little or no maintenance at all. However the operator is to clean it regularly so that dirt and other foreign bodies do not hinder its operation.

Table 10: The Rise and Set for the Sun for June-Dec., 2010 [33]
Location: E003 20, N06 35; LAGOS-NIGERIA

Universal Time

Day	June Rise Set h m h m	July Rise Set h m h m	Aug Rise Set h m h m	Sept. Rise Set h m h m	Oct. Rise Set h m h m	Nov. Rise Set h m h m	Dec. Rise Set h m h m
01	0530 1759	0536 1805	0541 1805	0540 1754	0535 1738	0534 1727	0543 1729
02	0530 1759	0536 1806	0541 1805	0539 1753	0534 1738	0534 1727	0543 1729
03	0530 1759	0536 1806	0541 1805	0539 1753	0534 1737	0534 1727	0543 1729
04	0530 1800	0536 1806	0541 1804	0539 1752	0534 1737	0534 1726	0544 1730
05	0531 1800	0536 1806	0541 1804	0539 1752	0534 1736	0534 1726	0544 1730
06	0531 1800	0537 1806	0541 1804	0539 1751	0534 1736	0534 1726	0545 1730
07	0531 1800	0537 1806	0541 1804	0539 1751	0534 1735	0535 1726	0545 1731
08	0531 1801	0537 1806	0541 1803	0538 1750	0534 1735	0535 1726	0546 1731
09	0531 1801	0537 1806	0541 1803	0538 1750	0534 1734	0535 1726	0546 1732
10	0531 1801	0538 1806	0541 1803	0538 1749	0533 1734	0535 1726	0547 1732
11	0531 1801	0538 1807	0541 1802	0538 1749	0533 1733	0535 1726	0547 1732
12	0532 1802	0538 1807	0541 1802	0538 1748	0533 1733	0536 1726	0548 1733
13	0532 1802	0538 1807	0541 1802	0538 1748	0533 1733	0536 1726	0548 1733
14	0532 1802	0538 1807	0541 1801	0537 1747	0533 1732	0536 1726	0549 1734
15	0532 1802	0539 1807	0541 1801	0537 1747	0533 1732	0537 1726	0549 1734
16	0532 1802	0539 1807	0541 1801	0537 1746	0533 1731	0537 1726	0550 1735
17	0532 1803	0539 1807	0541 1800	0537 1745	0533 1731	0537 1726	0550 1735
18	0533 1803	0539 1807	0541 1800	0537 1745	0533 1731	0537 1726	0551 1736
19	0533 1803	0539 1807	0541 1800	0537 1744	0533 1730	0538 1726	0551 1736
20	0533 1803	0540 1807	0541 1759	0536 1744	0533 1730	0538 1726	0552 1737
21	0533 1804	0540 1807	0541 1759	0536 1743	0533 1730	0538 1727	0552 1737
22	0534 1804	0540 1806	0541 1758	0536 1743	0533 1729	0539 1727	0553 1738
23	0534 1804	0540 1806	0541 1758	0536 1742	0533 1729	0539 1727	0553 1738
24	0534 1804	0540 1806	0541 1758	0536 1742	0533 1729	0540 1727	0554 1739
25	0534 1804	0540 1806	0540 1757	0536 1741	0533 1728	0540 1727	0554 1739
26	0534 1805	0540 1806	0540 1757	0535 1741	0533 1728	0540 1727	0555 1740
27	0535 1805	0540 1806	0540 1756	0535 1740	0533 1728	0541 1728	0555 1740
28	0535 1805	0541 1806	0540 1756	0535 1740	0533 1728	0541 1728	0556 1741
29	0535 1805	0541 1806	0540 1755	0535 1739	0533 1727	0542 1728	0556 1741
30	0535 1805	0541 1805	0540 1755	0535 1739	0533 1727	0542 1728	0557 1742
31		0541 1805	0540 1754		0533 1727		0557 1742

5 Conclusion and Recommendations

I hesitate to draw sweeping conclusions from the results presented in this thesis. Experience has shown that the correct conclusions are not always immediately clear even though the results might seem to suggest the contrary. Some care and considerable thought need to be devoted to the interpretations of the findings.

The experimental results on the solar stills performance and the consequences of the design parameters have been presented and discussed. It has been concluded that: A high basin/brine temperature is often associated with high productivity, and the reverse is true for cover (glass) temperature. A high solar intensity corresponds to a higher productivity.

The main drive for this study is to evaluate the effect of sun tracking in the improvement of solar still performance, usability and maintenance in order to help alleviate world water poverty.

To further help improve the productivity of the still, the following should be considered: Insulation under the bottom of a shallow basin still reduces the effect of heat capacity and allows the still to benefit from higher average operating temperatures. Higher temperatures result in a greater fraction of the absorbed solar energy being usefully employed in evaporation of water, with lower fractions being wasted by sensible heat transfer and radiation.

The solar still is a relatively inexpensive, low-technology system, especially useful in the rural and remote communities of the developing countries where the need for small plants is promising. There is equally need for innovation and room for improvement both technically and economically. If properly harnessed, the solar still provides a considerable economic advantage over other sea water desalination systems.

The design and operation of a basin-type solar still has been examined experimentally. The output between fixed still and tracked still were investigated and compared. It was found that the productivity of the sun-tracked still is found to be 19.6% higher than the fixed still. It can be concluded that, the present still design leads to higher distilled water output due to higher brine temperature.

Introducing the sun tracking mechanism to a fixed solar still has improved the performance (this is relative to the distillate yield) of the conventional fixed single slope solar still by 19.6% with an additional increase in overall estimated efficiency of 3.8%. This means that there is a possibility to improve the performance of this conventional solar still system using sun tracking.

By using the sun tracking mechanism the water temperature increased, and the thermal capacity of the water decreased causing the evaporation rate to increase, hence the production increased. The conventional single basin-type solar still is the simplest and most practical design for an installation and less complexity than the other types.

Solar distillation may be considered as one of the alternatives for fresh water production in developing countries where potable water is scarce in both quantity and quality needed for drinking, sanitation and other purposes. The tracking of solar still will be able to follow the sun during the day, as this method will increase the concentration of solar radiation; reduce the thermal capacity of the water in the basin, and increase the productivity.

From the results obtained, it is inferred that the use of a tracking mechanism makes a solar still to be predictable and it equally increases its efficiency in terms of distillate yield and overall performance. Tracking system was also found be of immense assistance and value, having been used in the past to increase the power output of PV systems.

For rural and isolated communities without technical facilities, the solar still with its simplicity is the best means of supplying potable water. Since a solar still with a tracking mechanism can be predicted, the area of production for a daily consumption of about 2-3 litres per person can be known. From the results obtained, the area required would be about 1.4m^2.

As a result of the suitability of solar stills for comparatively small output in sunny climate, the regions of greatest potential application and utilisation appears to be outside the UK. In many remote communities and arid regions where only brackish or water is available, solar stills are viable options. The simplicity of the system, the absence of skilled-labour requirements for construction and operation, and the matching of high stills capacity with periods of high water demand and natural fresh water scarcity make this process particularly suitable for use in the developing countries.

Despite the fact that the model may work and adaptations can be made to allow the still to be far more productive, considerations of the recipient community must be taken into account. In many cases development projects fail because they do not consider the culture and understanding of the community itself. There is the need to enlighten and sensitise the end-users so as to appreciate the benefits of the technology and why they should adapt the current best practices.

The users must also be educated on the maintenance of the solar still, the operation of the tracking system and the storage methods that must be implemented to ensure that the water remains safe to drink. A major barrier to the technology would be common perception; in some communities it is believed that all of the nutrients will be removed if it has been distilled. However, this can be overcome by some form of enlightenment and getting community leaders involved.

As this is expected to be used in a remote community, this could serve as a means of employment as operators would be employed and trained on the operation and maintenance of the tracking system. Despite the barriers of integrating new technology into a community, it has been proven that point-of-use technologies hold huge advantages over point-of-source treatment.

Future Work

Time and circumstance did not allow for full practical experimentation. To fully analyse the full potential and improve the productivity of a solar still, a number of other contributing factors must be considered:

- Method of deploying the principles of a low cost, low-emissivity glass coating for increasing night-time temperatures;

- The design and use of other materials of construction and analyses for material of best fit in terms of cost and performance;

- The economic viability of inclusion of an automated sun tracking device for proper monitoring;

- An in-depth analysis into the most appropriate type of tracking device/system for this application;

- Critical analysis of condensation area and associated shading is worth exploring.

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Appendix

Table 7: Effect of Cover material on Productivity

Local time	Productivity (g)	
	Fixed Still	Tracked Still
8	30	60
9	70	90
10	110	120
11	130	140
12	150	170
13	170	190
14	200	210
15	210	240
16	220	260
17	230	290
18	240	310
19	250	340
20	290	380

Table 11: The Rise and Set for the Sun for Jan.-Sept., 2010 [33]
Location: E003 20, N06 35; LAGOS-NIGERIA

Universal Time

	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.	
Day	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
01	0558	1743	0605	1756	0559	1759	0545	1756	0533	1754	0530	1759	0536	1805	0541	1805	0540	1754
02	0558	1743	0605	1756	0559	1759	0545	1756	0533	1754	0530	1759	0536	1806	0541	1805	0539	1753
03	0559	1744	0605	1756	0558	1759	0544	1756	0533	1754	0530	1759	0536	1806	0541	1805	0539	1753
04	0559	1744	0605	1756	0558	1759	0544	1756	0532	1755	0530	1800	0536	1806	0541	1804	0539	1752
05	0559	1745	0605	1757	0558	1759	0543	1756	0532	1755	0531	1800	0536	1806	0541	1804	0539	1752
06	0600	1745	0605	1757	0557	1759	0543	1755	0532	1755	0531	1800	0537	1806	0541	1804	0539	1751
07	0600	1746	0605	1757	0557	1759	0542	1755	0532	1755	0531	1800	0537	1806	0541	1804	0539	1751
08	0600	1746	0604	1757	0556	1759	0542	1755	0532	1755	0531	1801	0537	1806	0541	1803	0538	1750
09	0601	1747	0604	1757	0556	1759	0541	1755	0531	1755	0531	1801	0537	1806	0541	1803	0538	1750
10	0601	1747	0604	1758	0556	1758	0541	1755	0531	1755	0531	1801	0538	1806	0541	1803	0538	1749
11	0601	1748	0604	1758	0555	1758	0541	1755	0531	1755	0531	1801	0538	1807	0541	1802	0538	1749
12	0602	1748	0604	1758	0555	1758	0540	1755	0531	1755	0532	1802	0538	1807	0541	1802	0538	1748
13	0602	1749	0604	1758	0554	1758	0540	1755	0531	1755	0532	1802	0538	1807	0541	1802	0538	1748
14	0602	1749	0604	1758	0554	1758	0539	1755	0531	1756	0532	1802	0538	1807	0541	1801	0537	1747
15	0603	1750	0603	1758	0553	1758	0539	1755	0530	1756	0532	1802	0539	1807	0541	1801	0537	1747
16	0603	1750	0603	1758	0553	1758	0538	1755	0530	1756	0532	1802	0539	1807	0541	1801	0537	1746
17	0603	1750	0603	1759	0552	1758	0538	1755	0530	1756	0532	1803	0539	1807	0541	1800	0537	1745
18	0603	1751	0603	1759	0552	1758	0538	1755	0530	1756	0533	1803	0539	1807	0541	1800	0537	1745
19	0604	1751	0602	1759	0551	1758	0537	1754	0530	1756	0533	1803	0539	1807	0541	1800	0537	1744
20	0604	1752	0602	1759	0551	1757	0537	1754	0530	1756	0533	1803	0540	1807	0541	1759	0536	1744
21	0604	1752	0602	1759	0551	1757	0537	1754	0530	1757	0533	1804	0540	1807	0541	1759	0536	1743
22	0604	1752	0602	1759	0550	1757	0536	1754	0530	1757	0534	1804	0540	1806	0541	1758	0536	1743
23	0604	1753	0601	1759	0550	1757	0536	1754	0530	1757	0534	1804	0540	1806	0541	1758	0536	1742
24	0604	1753	0601	1759	0549	1757	0535	1754	0530	1757	0534	1804	0540	1806	0541	1758	0536	1742
25	0604	1754	0601	1759	0549	1757	0535	1754	0530	1757	0534	1804	0540	1806	0540	1757	0536	1741
26	0605	1754	0600	1759	0548	1757	0535	1754	0530	1758	0534	1805	0540	1806	0540	1757	0535	1741
27	0605	1754	0600	1759	0548	1757	0534	1754	0530	1758	0535	1805	0540	1806	0540	1756	0535	1740
28	0605	1755	0600	1759	0547	1757	0534	1754	0530	1758	0535	1805	0541	1806	0540	1756	0535	1740
29	0605	1755			0547	1756	0534	1754	0530	1758	0535	1805	0541	1806	0540	1755	0535	1739
30	0605	1755			0546	1756	0534	1754	0530	1758	0535	1805	0541	1805	0540	1755	0535	1739
31	0605	1755			0546	1756			0530	1759			0541	1805	0540	1754		