

Potentials of Solar Distillation Technologies for Provision of Portable Water for Makurdi Metropolis – A Review

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Abstract— For the past few years, solar distillation research has been going on in Department of Mechanical Engineering of University of Agriculture, Makurdi with the view of implementing it as an option/supplement for household drinking water production for several communities along both sides of the River Benue in Makurdi Metropolis. Purifying water by solar distillation though simple is effective as a means of providing drinking water in a reliable and cost-effective manner. These technologies effectively eliminate all water borne pathogens, salts, and heavy metals, and produce ultrapure water that is proven to be superior to most commercial bottled water sources. Makurdi is naturally well endowed with brackish water and abundant solar radiation required for solar distillation. The findings of research efforts so far have not been translated to the target end users to promote the use and development of solar distillation. Improvements and localization of these technologies will definitely enhance yield, uptake to the desired end users and reduce production costs. These improvements can hopefully be achieved through creation of a realistic synergy among stakeholders which are the researchers, end users, NGOs and the Benue State Government. Such collaboration has produced significant success in the US-Mexico Border region. This paper presents a review of efforts so far especially on water stills and multi-effect dehumidification systems in order to highlight the potentials they offer in provision of drinking water in a relatively cost effective way.

Keywords— Brackish water; multi-effect dehumidification; potable water; solar distillation; solar radiation; water stills.

1. INTRODUCTION

Makurdi Metropolis in Benue State of Nigeria faces serious water supply issues that are comparable to those found in many parts of the developing world. There are some parts of the town where pipe borne water is more of a myth than reality. Water vendors have become common place within the town thereby diverting human resource that could positively impact the economy in a more relevant manner by carrying out the duties of an ineffective/non-existent water supply system. Some of these vendors sell water directly obtained from the River Benue while the more reasonable or ‘hardworking’ ones push their carts for long distances in order to obtain pipe borne water. For those that have access to the pipe borne water, the quality does not meet the standards acceptable for drinking water. Many sachet water firms are springing up and though a package sells for ten naira (₦10.00) depending on the volume of business, time of the year, type of water or simply location, very few generally are of good quality although a very common name for them is *pure water* [1 – 3]. The state Government has continued to invest in a gigantic water works project for several years without achieving the desired success levels. Many children less than about ten years old and below do not have any appreciation of municipal water supply of any quality in Makurdi.

Solar distillation is one leading solar energy technology in particular that can positively impact drinking water quality throughout the less developed world with widespread adoption. It does not only purify water sources, but also effectively desalinates them [4, 5]. A solar still, for instance, operates by the basic principles of evaporation and condensation. The contaminated feed water goes into the still and the sun's rays penetrate a glass surface causing the water to heat up through the greenhouse effect and subsequently evaporate. When the water evaporates inside the 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. In this process the salts and microbes that were in the original feed water are left behind. Additional water fed into the still flushes out concentrated waste from the basin to avoid excessive salt build-up from the evaporated salts. Figure 1 shows the basic features of a single basin solar [6 – 9].

Solar still technologies bring immediate benefits to users by alleviating health problems associated with water-borne diseases. Solar stills have proven to be highly effective in cleaning up water supplies and in providing safe drinking water. A solar still effectively eliminates all waterborne pathogens, salts, and heavy metals. The effectiveness of distillation for producing safe drinking water is well established and long recognized. Distillation is the only stand-alone point-of-use (POU) technology with

National Sanitation Foundation (NSF) certification for arsenic removal, under Standard 62. Solar distillation removes all salts and heavy metals, as well as biological contaminants (e.g., *cryptosporidium*, *E. Coli*, etc.). For solar stills users, there is also a sense of satisfaction in having their own trusted and easy to use water treatment plant on-site [10 – 12]. Solar still production is a function of solar energy (insolation) and ambient temperature. Typical production efficiencies for single basin solar stills are up to 60% in the summer and 50% during the colder winter. Single basin stills generally produce about 0.8 litres per sun hour per square meter. They are also modular and can be linked easily together in series or parallel in order to magnify the yield of the system [6, 13].

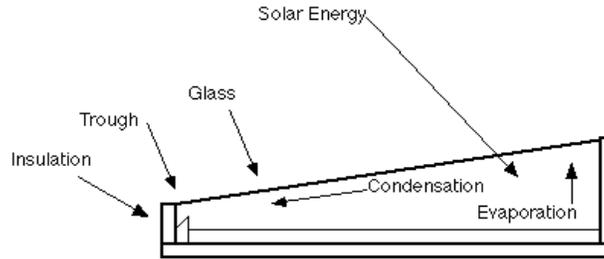


Fig. 1. Features of a Single Basin Solar Still [6]

General still operation is simple and requires facing the still towards solar noon, putting water in the still every few days to fill and flush the basin, and recovering distillate from the collection reservoir. Properly operating a still requires adding about three times as much make-up water as the distillate water produced each day. The excess water flushes the still basin through the overflow to prevent salt build-up. If this is done on a daily basis, the flushed water is of approximately the same quality as the original feedwater that was added to the still. The excess water is of suitable quality that it can be used to water landscaping, wash pots and pans, etc. No sediments or sludge will build up if the still is properly operated and flushed daily at about three times daily distillate production. The still can also easily be cleaned manually with the aid of vinegar to help remove deposited salts. There exists a misconception in some circles that drinking distilled water might be detrimental to one's health. The El Paso Solar Energy Association (EPSEA) met health conscious people who have only used distilled water for over 40 years in some cases and have enough information that distilled water is quite beneficial [6, 14 – 16].

Reference [17], a development charity, solar stills have also been used to produce pure water for lead acid batteries, laboratories, hospitals and in producing commercial products such as rose water. They also reported that despite a proliferation of more sophisticated designs, the single-basin still has the best track record in the field with hundreds of smaller stills are operating in Africa and India. The cost of pure water produced depends on the cost of making the still, cost of the land, the life of the still, operating costs, cost of the feed water, the discount rate adopted and the amount of water produced. An example of costs of a solar still in India was given as approximately \$38.3 per m². The average approximate cost obtained per m² in the Makurdi tests is quite lower than this. Reference [17] further reported that the single-basin still is the only design well proven in the field.

Another technology for smaller scale desalination systems is solar multi-effect humidification-dehumidification. This process uses solar energy to evaporate fresh water, which is condensed on a cool surface and collected. Solar desalination systems are simply and easy to operate and maintained. The main idea of the multi-effect humidification-dehumidification solar desalination system is based on the evaporation of water and the condensation of steam to and from humid air. The humid air circulation, driven by natural convection, between evaporator tower (humidifier) and condenser tower (dehumidifier). The evaporator and condenser are located in the same insulated box. The heated feed water from central receiver is distributed onto the evaporator tower through a vertically hanging sprayer and is slowly trickling downwards. The condenser unit is located opposite to the evaporator. Here the saturated air condenses on a single tube copper coil. Water at ambient temperature can be used as a coolant for the condenser. The distillate runs down to a collecting tank [18]. Reference [19] introduced two modifications on the desalination chamber to enhance the desalination system productivity. The first modification was using water jacket at one side of the dehumidifier tower to increase the condensation surface. The second modification was to use seven flat mirrors to concentrate solar radiation on one side of the humidifier tower (0.003 m ordinary window glass) to heat the humid air to increase the system productivity. They are also environmentally friendly because they do not require fossil fuels. In locations with abundant sunshine, such as Makurdi, capital of Benue State, Nigeria, solar desalination is a potentially viable option, especially for small-scale plants in remote locations [1, 20]. Multi-effect humidification-dehumidification solar system was suggested as an efficient method for the production of desalinated water, initially for small quantity in remote arid areas [19]. Practical Action however, reported that multi-effect stills have the potential to be more economic than single basin stills but still need to gain field experience first with a single-basin still.

On both sides of the River Benue, there are many unorganized communities that have limited infrastructural development including water supply. Several thousands of people live in *North Bank, Wurukum, Wadata* and along *Gboko* road for which safe drinking water can only be acquired by purchasing and probably hauling portable water from elsewhere. In these locations,

municipal water supplies do not meet drinking water standards if and when available. The unorganized nature or inexistence of water supply network and the quality of the so called 'treated' water leaves so much to be desired. Solar distillation could offer a real and effective solution for the inhabitants of these locations to clean their water supplies on-site.

Over the last few years, there have been efforts to develop simple solar distillation technologies that could be applied in these locations to meet drinking water needs. The Energy Systems Research Group of the Department of Mechanical Engineering at University of Agriculture, Makurdi has been working to further develop and localize the technology and demonstrate its practicality as an innovative, effective, simple, and decentralized on-site water treatment system that can provide safe water in a cost effective and reliable manner [20, 21]. These efforts which began in earnest several years ago are still on-going. This is because the abundant solar distillation feedstock (water) provided by the River Benue and the immense solar radiation that Makurdi is reputed for almost all year round can be harnessed to positively impact the availability of drinking water. Makurdi on latitude 7.7° N and longitude 8.73 °E receives an average insolation of 35430 kJ/m²/day from an average 6.13 hours of sunshine with the highest and lowest in August and December respectively [22, 23].

The arid U.S. - Mexico Border was an area that was faced with serious drinking water supply issues comparable to those found in Makurdi. The area is abundantly endowed with solar radiation; about 1300 W/m² at midday [24]. Many unorganized and incorporated communities, called *colonias* that have limited infrastructural development, water supply inclusive abound there. Over half a million people lived in these *colonias* which are tri-state and bi-national in nature. Safe drinking water was only acquired from elsewhere, and for many of these Border communities, municipal water supplies did not meet drinking water standards being laced with high arsenic, fluoride, etc. levels. Solar distillation hence, offered a real and effective solution for cleaning their water supplies at their own doorsteps [25].

Concerted efforts to develop solar distillation technology and apply it in the area to meet drinking water needs began from around 1994 to 1997 and tangible impacts in terms of its acceptance and use for drinking water provision were recorded over subsequent years. El Paso Solar Energy Association (EPSEA) worked with a commercial outfit called SolAqua, Sandia National Laboratories, and New Mexico State University (NMSU) to further develop the technology and demonstrate its practicality along the Border. Originally, sponsorship came from the Texas State Energy Conservation Office (SECO) [16]. EPSEA worked closely with NMSU during the initial pilot demonstration, where 40 pilot 3' x 8' solar stills were built and distributed to *colonia* families and health clinics in West Texas [26].

During 1998-99, NMSU worked with the U.S. Economic Development Administration to test solar still effectiveness at removing contaminants. EPSEA built 33 stills distributed to residences in southern New Mexico. The NMSU pilot study showed that solar stills effectively eliminate all salts, heavy metals, bacteria, and microbes from contaminated water sources. Testing even reported successful removal of some pesticides (due to UV rays, high temperatures, and atmospheric venting), although recommendations remain to use a carbon filter with stills for guaranteed removal of all volatile organic compounds [12]. NMSU also conducted a willingness-to-pay study along the Border to help determine a baseline for further technology commercialization.

The projects evolved till SolAqua, a solar still commercial enterprise, emerged to commercialize production. The company furthered the design and development of the technology with EPSEA, NMSU, and Sandia National Labs. It made vast improvements in manufacturability and materials, receiving its first solar still patent in the U.S. in 2004. EPSEA continued to implement solar stills in Texas, New Mexico, and Chihuahua. Two grants were awarded by the Border Partners in Action (BorderPACT) with the Consortium for North American Higher Education Collaboration to disseminate solar stills distributed to 27 Mexican families in Chihuahua [27]. EPSEA also won a community challenge grant from EPA to distribute stills to 80 families in Texas and New Mexico from 2000 - 2002. For these demonstration projects, families were asked to provide a cost share for solar stills. In addition, individual stills have been purchased directly from SolAqua by Borderland families and elsewhere on the internet. The company has now provided solar stills for a variety of water purification projects throughout the world [24].

This kind of partnership that greatly influenced the provision of portable drinking water in the US – Mexico Border is possibly the kind of effort that must be made in order to make this simple technology to impact on the Makurdi Metropolis drinking water situation. It has to be an effort with a focus to be able to achieve the desired results. This review is a clarion call to make use of what is available in order to achieve what is desired vis-a-vis the determination of the Benue State Government to provide portable water for the citizens. This indication is glaring with the commitment of several billions of Naira to the *Greater Makurdi Water Works* project which has been on-going for several years now. It may not be out of place to opine that a very small fraction of this investment of Government to the research efforts going on at the University will no doubt make a useful contribution in the way of increasing access to portable water by many citizens of the State.

2. SOME OF URESEARCH EFFORTS AT MAKURDI

The general thrust of the research efforts has been to improve on the yield of the stills without compromising the purity of the product, which is not only limited to Makurdi but a general one in the field of distillation/desalination [28 – 31]. Several

sophisticated systems are being developed in more developed areas but in order to ensure relevance, only the single slope basin solar still with some modifications and simple small scale multi-effect humidification systems have been considered and are still open for future development.

A comparative study of two solar stills with different lining configurations of aluminium. One had aluminium lining on both the base and sides while the other one had it only on the base. The first one had a better yield than the second one as well as a higher efficiency of collection. This supports the fact that the lining must be adequately conducting in order to facilitate heat transfer between the feed water and the radiation absorbing container. The highest average yield recorded for the period of this study was 0.124 litre/day. This translates to 19.7 litres/m²/day since the aperture area of the stills was 0.0063 m². The construction cost per still for this study was about eight thousand naira which currently translates to around twenty dollars. The minimum conductivity (salinity) of the product water obtained was within the acceptable range [32].

The effect of coupling a preheat tank and a plain mirror reflector on the performance of basin solar still was also tested. This test mainly aimed at optimizing the preheating of the feed water and concentrating the incident radiation with a reflector to enhance evaporation within the still and hence increase yield. Three stills, ordinary, coupled with a preheat tank and coupled with a mirror reflector, were tested under similar conditions. The efficiencies of the stills were not significantly different. The ordinary still produced the least quantity of distillate followed by the still coupled with preheat tank while the still coupled with mirror reflector produced. The low difference in cost of adding the mirror reflector justified its use. The quality of water produced also fell within the for drinking water acceptable range of the standards specified by WHO. The aperture cross-sectional for each of the stills was 0.55 m². The highest yield was about 1.86 kg/day which translates to about 3.38 kg/m²/day. Some of the tests carried out on the product included turbidity, total suspended solids (TSS) and color, conductivity, total dissolved solids and salinity, and dissolved oxygen. The total cost was in the region of twenty thousand naira [3].

The effect of coupling a rock bed thermal storage to a simple basin solar still was also investigated. The idea was to take advantage of stored heat energy during the day time to facilitate the yield of the still during the night. In the evening, the water in the still is drained out and water from the storage medium released into it, part of which is evaporated in the night and the balance used as the feed water for the next day. The aperture cross-sectional area was 0.25 m² while the average yield for daytime operation was 67 cm³ and that for night operation was 75 cm³. These translate to 268 cm³/m² and 300 cm³/m² of still aperture respectively. The yield for the night operation was obviously higher than that in the day time which indicated that the overall yield of the simple still could be enhanced by including the night time operation when solar radiation is absent [33].

The effects of the angle of inclination and thickness of the still glazing on the yield were also studied. Since solar energy is location – sensitive, it is usually very useful to determine certain parameters to use within a given location instead of mere generalization. The determination of an optimal angle of inclination as well as thickness of the glazing for Makurdi location were the aims of these studies. In the first instance, five single basin solar stills with varying angles of inclination of the covers but having the same aperture area of 0.24 m² were designed and constructed. Angles of inclination of 4°, 7°, 10°, 13° and 15° were used. Measurements of temperature, solar radiation and volume of water produced were carried out and the data was used to compute the efficiencies of the stills. The still with an angle of inclination 15° had the highest efficiency of 0.585 and also produced the highest mean volume of water produced of 62.9 cm³. The results indicate that the optimum angle of inclination for simple basin solar stills for Makurdi location is greater than 15°. This is a useful observation and will erase the usual tendencies of utilizing low angles as efforts to optimize still productivity in Makurdi continue [34]. Figure 2 shows the set up used for the tests.



Fig. 2. Set up for the tests on glazing angle of inclination [34]

For the glazing thickness test, five solar stills of the same size and configuration but with different glass cover thicknesses were designed, constructed and their performances evaluated. Still 1 had a glazing of a sheet of ordinary window glass, still 2 had two sheets of glass lying on each other, still 3 had two sheets of glass with airspace between them, still 4 had three glass sheets without airspace between, and still 5 had three glass sheets with an air space between each. A storage medium was designed and constructed

to boost the night yield of the stills. The daily insolation, ambient, cover and water temperatures and the output for the five stills were measured. The efficiencies for the daytime operation were computed. The output volumes and efficiencies of the stills were compared. Still 1 had the highest mean water output volume of about 306 cm^3 and an efficiency of 24 % indicating that for better daytime yield, a window glass solar still glazing in Makurdi location should have a thickness in the region of 4 mm. Still 3 had the better night time yield which implies that the glazing configuration could be exploited to boost overall still output [35]. Figure 3 shows the set up for the study.

The daytime and night yields of a simple solar still have also been studied. In this work, 2 solar stills of aperture 0.003 m^2 inclined at 10° were designed and constructed along with a rock bed thermal storage unit. One, still 1, was linked to the storage unit. Hourly ambient and still water temperatures, incident insolation and volumes of water distilled were measured daily in May 2011. The water in still 1 was drained daily at 16:00 hour and water from the storage unit introduced into it. The temperatures of the water in the storage unit were measured at 10:00 and 16:00 hours daily. The volumes of the water distilled during the night by the stills were measured daily in the morning. The efficiencies of the stills were computed. Stills 1 and 2 distilled maximum daily daytime mean volumes of 78.2 and 57.3 cm^3 respectively on the 6th day. The respective corresponding night time yields were 181 and 242 cm^3 . The maximum mean daily distillation efficiencies were respectively 31.1 and 25.1%. The total night time yield was about 43% of the total. The cost of distilled water was computed to be about N52.50/litre/ m^2 . The study affirmed that solar distillation remains a viable option for provision of potable in Makurdi metropolis and its environs [21]. Figure 4 shows the set up for the work.



Fig. 3. Set up for the study of the effect of glazing thickness [35]

Reference [36] studied the effect of the utilization of a parabolic reflector as well as bee wax as a phase change material to improve the yield of a single slope solar still. The findings were quite encouraging apart from the fact that it was more expensive than the plain basin solar still to construct. However, further work is being contemplated in order to strike a better balance between improved yield and cost.



Fig. 4. Set up for the study of daytime and night yield [21]

In order to investigate the contribution of a multi-effect humidification system, a flat plate collector was first evaluated for its suitability. 17.7° was used as the angle of tilt for the collector. A blackened storage tank was provided to supply slightly pre-heated water to the collector. 10 mm diameter copper pipes were formed into loops to serve as the water passages. A flow rate of 0.0034 kg/s was used for the passive system while 0.0039 kg/s was used for the active one. The hourly ambient temperature, initial and

final water temperatures, the outer surface cover temperature of the collector and the incident radiation were measured daily from 08.00 to 17.00 hours. The efficiencies of the collector were computed from the measured data. The experimental results showed that the mean temperature of the water from the collector was 48.44 °C for the passive option and 45.54 °C for the active one on hourly basis. These values are lower than the minimum required for the operation of a MEH system and informed further work targeted focus on increasing the resident time of the water within the collector. The respective efficiencies on daily basis were 0.71 and 0.60 [1].

Reference [20] designed and evaluated a multi-effect humidification (MEH) solar desalination system utilizing a solar collector. A blackened aluminium storage tank was used for the feed water and was positioned so that water enters the collector by gravity for the passive test and through the pump for the active case with slight preheating. The heated water exits the collector into the desalination chamber made up of a humidifier and a dehumidifier. The ambient, collector inlet and outlet water, evaporator and condenser temperatures were measured hourly as well as the volume of water produced 10.00 to 16.00 hours. The collector was able to achieve a mean elevation above the inlet condition of about 20.8 °C and 29 °C respectively for the active and passive cases. The mean collector, water production and the overall efficiencies were computed as 0.51, 0.50 and 0.256 respectively for the active case while the corresponding values for the passive case were 0.69, 0.55 and 0.37. The respective mean daily yields of the active and passive options were 0.298 cm³ and 2.39 cm³ per unit volume of evaporator, 0.098 cm³ and 0.785 cm³ per unit volume of condenser or 0.0035 cm³ and 0.028 cm³ per cm² of collector aperture. A good potential for the system to contribute significantly to the production of safe drinking water in relatively larger quantities especially with the passive option exists. Figure 5 shows one the active system used for the study.



Fig. 5. The Active Multi-Effect Humidification system evaluated [20]

It can be safely deduced from the foregoing that there is growing interest and experience in this area in Makurdi. Currently, exergy analysis studies on some configurations of solar stills are being undertaken by these researchers. The time to take the initiative of reaching out to mobilize the populace and other stakeholders concerning the potentials that this simple contraption can bring into the water supply mix seems to have come. There is so much work to be done however, in the area of awareness for the end users and sponsors. A majority of the people living in the areas of Makurdi Metropolis earlier highlighted are hardly literate so that convincing them that a solar still could be part of the solution to their drinking water problems is a rather daunting task. This is more so because they can become responsible for the quality of the water they consume since it will be an on-site issue requiring little or no skills but some measure of carefulness. An aspect of awareness that may be necessary is the setting up of pilot solar stills in these locations. This can be achieved by situating future solar still research works in these locations. This will require funding and Government backing in case legal issues arise

The Energy Commission of Nigeria, NGOs affiliated with portable water delivery and Government agencies saddled with rural development can become involved through organized seminars and/or by submitting proposals of solar still projects to them. Also, the Energy Research Group intends to deliberately solicit for funding impacting the provision of clean and affordable drinking water. Carving a niche for solar distillation research in the University Strategic plan is another focus. The neighboring Communities could be positively impacted as far as drinking water is concerned. Sachet water entrepreneurs can embrace the use of solar distillation which will eventually return a good measure of profit though the specific payback period is still a subject for further study. They can start with solar stills being complementary to their current equipment. Apart from making money out the abundant resources of feedwater and sunlight, they will be making a difference in terms of selling high quality drinking water. The

Government of Benue state could play a very strategic role by producing funds that could enhance improvements of the solar distillation technologies investigated before now and to facilitate the access to this simple but unique technology for the purpose of ensuring access to portable water for the people in these locations.

The experience along the U.S.-Mexico Border is one classical example of utilizing what you have to get what you need especially when established systems fail due to several factors prominent of which is a lack of political will with its attendant consequences. While work on projects such like the *Greater Makurdi Water Works* drags on, pilot solar still projects can be constructed and distributed to households in the identified locations. Their performance can then be evaluated over a period of time. It took almost a decade to obtain the kind of success recorded along the U.S.-Mexico Border. That kind of commitment, consistency and teaming up over a period of time between the Academia, the private sector and the Government is required to be able achieve any tangible result.

3. CONCLUSION

Clean drinking water remains one of the most challenging international health issues of today. As municipal water supplies grow increasingly scarce and more difficult to purify (for whatever reasons), solar distillation offers a practical, effective, and relatively inexpensive means for residents to purify their drinking water. It can be practically applied on a decentralized and immediate basis by any end-user around the globe. Solar stills offer a realistic and cost-effective means to provide safe drinking for many Makurdi Metropolis residents who have few other realistic and affordable options available.

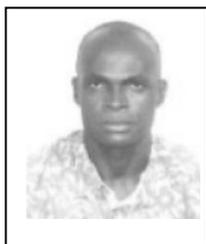
The U.S.-Mexico Border region solar distillation water purification projects have been an overall success. A similar pragmatic approach can be adopted by stakeholders in Makurdi and its environs. The Energy Research Group at University of Agriculture Makurdi is paying greater attention to solar distillation research. This area of research can be drafted into the University Strategic Plan. Better documentation and dissemination of same is the next step in order to get the end-user, NGOs and the State Government to become more aware and committed to realizing the immense potentials that this option provides.

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