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FACTORS AFFECTING THE PERFORMANCE OF SOLAR STILL: A REVIEW

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ABSTRACT

Although many technologies exist for clean water production, the commodity is still scarce due to population explosion, contamination due to structural failure, frequent displacement of people in conflict areas, poor electricity supply, and high skill requirement in

INTRODUCTION

Although clean water is one of the biological needs of man, many people do not have access to it (Sharshir et al., 2016; Colaore, 2012). The world Health Organization (WHO), in Alkasim, Adamu and Ododo (2012), reports that provision of adequate supply of fresh water has become one of the most serious problems facing the world since the beginning of the 21st century. This is in spite of the fact that most of the earth is made up of water (Geography.about.com, 2014). The shortage of clean water supply has resulted in the spread of water borne diseases, threatening the existence and well being of man, especially in developing nations like Nigeria.

The shortage of clean water may be due to the fact that only one per cent of the earth's water is fresh. Contamination by underground rocks, dissolved gasses in the atmosphere and contact with industrial and household wastes are some of the causes of water pollution (Tiwari, 2013).

The increasing demand for clean water has resulted in efforts by individuals and organizations to produce clean water. Governments and business organizations have build water treatment plants, drilled bore holes, etc, which depend on electricity. The masses use techniques such as filtration, decanting, boiling, etc. These methods have however

the operation and maintenance of the systems. The solar still is a technology for clean water production that is cost effective, and does not require any skill for its operation and maintenance. It employs the principle of heat and mass transfer in the distillation of water through the use of solar radiation. It can be used in any place where there is sunshine. This paper reviews the various factors affecting the performance of the solar still as presented by researchers over the years. The aim is to provide information for researchers at a glance in order to help them in conducting more research to enhance the production of clean water by the solar still. This paper will help designers to consider all such factors that can make or mar their design of the still. Water depth, cover glass thickness, tilt angle, configuration, water salinity, absorber material, etc have been identified as factors which affect the water production capacity of the solar still.

Keywords: Solar still, clean water, Salinity, sustainability.

failed to meet the needs of the masses, due to inadequate access to electricity. More so, the water from treatment plants sometimes get contaminated before reaching the point of use due to pipe breakages. Bore holes also get contaminated by poorly disposed wastes which sip through.

One among the many cheap methods of producing clean water is the solar still. A solar still essentially consists of a mass of water in a container, which is covered by a transparent material (e.g. glass) and the interior surface of this enclosure is coated black to absorb solar radiation entering through the condensation of water vapour. The cover is sloped on one side to enable the condensate trickle into a channel. The whole enclosure (except the glass cover) is insulated to minimize heat loses from the sides and the bottom surface (Garg and Prakash, 1997). The technology employs the simple principles of heat and mass transfer in the distillation of water. This technique is attractive because of its simple technology, non-requirement of skilled labour for operation and maintenance, low energy consumption and its ability to be used anywhere provided there's sun shine (Tiwari, 2013). The advantage presented by the solar still gives some hope for increased availability of clean water, but its productivity is low, hence the need for its optimization. This optimization is not possible without the proper understanding of the various factors that affect its performance. This study therefore explored systematically the various factors affecting the performance of solar still with the aim of identifying those areas that will help in establishing key performance indicators for optimization. Many articles were consulted and only those that carried information on solar still performance were included in the study.

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The working principle of the solar still

The operation of the solar still is a combination of Heat and Mass Transfer, in which evaporation of water is caused by the rise in temperature as a result of heat energy transmitted to it through the glass cover and absorber. Heat and mass transfer occur due to the action of buoyancy resulting from density differences within the still, created by temperature difference between the water and glass. The buoyancy force causes convection currents to be set up, which carry water vapour from the water surface to the glass cover, where it is condensed and the resulting distillate is collected through an outlet pipe. Some equations which govern the operation of a conventional solar still are presented below.

The convective heat transfer coefficient of water surface to condensing glass cover is given by

$$q_{cw} = h_{cw}(T_w - T_g)\ldots\ldots\ldots\ldots (1)$$

Where h_{cw} is the convective heat transfer coefficient of the solar still.

The convective heat transfer coefficient is related to the dimensionless quantity, Nuseldt number, Nu.

$$N_u = \frac{h_{cw}}{\lambda} L_v = C(G_r \times P_r)^n \ldots\ldots (2)$$

Rearranging (2) yield

$$h_{cw} = \frac{\lambda}{L_v} C(G_r \times P_r)^n \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where $G_r = \frac{\beta\ g\ L_v^3\ \rho\ \Delta T}{\mu^2}$…………….. (4)

$P_r = \frac{\mu C_p}{\lambda}$……..……………..….. (5)

The C and n in (3) are constants which may be determined by regression analysis made from experimental data generated by Kumar and Tiwari. The Dunkle's relation (Dunkle, 1996) may also be used to determine h_{cw} , given by

$$h_{cw} = 0.884[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9 \times 10^3 - P_w)}]^{\frac{1}{3}}$$ ………….…………………………. (6)

The hourly yield of the still can be determined using the formula

$$m_{ew} = \frac{h_{ew}(T_w - T_g)}{L} \times 3600\ kg/m^2h\ldots..(7)$$

$$h_{ew} = 16.27 \times 10^{-3} \times h_{cw} \times \frac{(P_w - P_g)}{(T_w - T_g)}$$ (Cooper, 1973) ……………..…….(8)

The efficiency of the solar still may be obtained by using the formula

$\eta = \frac{h_{ew}(T - T_g)}{I(t)}$ (Tiwari, 2013)……..(9)

3.0 Factors affecting the performance of a solar still

The main objective of a solar still is to produce as much clean water within the shortest period of operation as possible. Every researcher therefore aims to improve the distillate output (Hitesh & Shah, 2011). In pursuance of this singular goal many researchers have made varied efforts to investigate the productivity of solar still (Selvaraj & Natarajan, 2018)

Configuration/Design

This refers to the various designs (shapes/configurations) that have been employed by various researchers in the course of their studies. The following results were obtained by various researchers. In a double slope-single basin solar still, the north cover was found to be cooler, and produced more water than the south cover due to the higher temperature difference between it and the water (Bilal, Mousa & Waleed, 2000). Goosen (2000) in Hitesh & Shah (2011), found through experimental analysis that the efficiency of a single basin solar still is lower than that of a multi-effect solar desalination system, which reuses the latent heat of condensation. Prem et al (2013) in his evaluation, found a micro –stepped solar still to produce an average daily distillate of 2380ml/day. In a thermal-economic analysis, Fath et al (2003) compared the performance of pyramid and single slope solar stills; the single slope performed better in terms of distillate output (30% in winter and 3% in summer) than the pyramid type. Arunkumar et al (2013) conducted a comparative study of various solar still designs (spherical, double basin, pyramid, hemispherical, concentrator-coupled single slope, tubular and tubular-pyramid) and found tubular-pyramid to be the best with a yield of 6928 ml/m^2/day, while spherical still was the poorest, with 2300 ml/m^2/day yield (see fig.1). The performance of the tubular-pyramid still was enhanced by the 'concentrator effect' obviously created by the presence of the pyramid.

Depth of Water in Basin

This refers to the level of water in the basin of the still. It indicates the volume of the water in the basin. The water production of a solar still has been found to vary linearly with the depth of water in the basin. It decreases with increasing depth. (Bilal, Mousa &Waleed, 2000). This was upheld by Muafag (2013) and Dwivedi (2013) when they found, with the aid of a double slope active solar still, that the output was maximum (4.82kg) for a water depth of 30mm, and least (4.36kg) for a water depth of 50mm. The relationship between water depth and productivity has been presented in fig. 3. The work of Tripathi and Tiwari (2004) and that of Malik, Kumar, and Sodha (1982) may be used to explain what happens when the water depth increases. The former found that the convective heat transfer coefficient decreased with increase in water depth, while the later found that increased water depth increased the heat capacity of the basin water during the day, resulting in lower performance in the daytime.

Cover Glass thickness and Tilt Angle

A study with a passive, single-slope, single basin solar still by Hitesh and Shah (2011) shows that lower glass cover thickness yields increased water temperature, evaporative heat transfer coefficient, as well as efficiency of solar still, hence increased distillate output. Out of the three thicknesses covered by the study (4mm, 8mm & 12mm), 4mm was adopted as the best for this work. The lower glass thickness permits faster penetration by sun rays, and faster cooling to enhance water- glass temperature difference, which is key to distillate formation.

The distillate output of a solar still has been found to vary with the cover tilt angle. In a study where cover tilt angles of 15^{o}, 25^{o}, 35^{o}, 45^{o}, and 55^{o} were used the distillate output initially kept increasing up to 35^{o}, and then declined beyond that up to 55^{o} (Bilal, Mousa &Waleed, 2000). Alkash et al (2000) confirmed this with an optimum tilt cover angle of 35^{o}.

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Climatic Condition

Cooper (1996), in Tiwari (2013) reports increased output for solar still of 11.5% for average wind velocities (0-2.15m/s), while an increase of only 1.5% for wind velocities of 2.15m/s-8.8m/s. "The wind blowing over the glass cover causes a fall in the temperature due to faster evaporation from it.

High yield of distillate has been reported with low relative humidity and high ambient temperature (Olaore, 2012 and Alkasim, Adam & Ododo, 2012). Tiwari (2013) however presents a contradictory argument concerning the effect of ambient temperature on still productivity. According to him, decreased ambient temperature results in an increase in the temperature difference the water in basin and glass cover, with a general fall in the overall temperature of the system, resulting in higher distillate yield.

The presence of deposits such as algae, mineral layers on the lining of the basin and water surface has been reported to negatively affect the yield of solar still (Cooper, 1972).

Absorber Material

In a study using Gravel and Black rubber lining as absorber materials, Nafey et al (2001) found that Black Rubber (10mm thick) improved solar still productivity by 20% at 60l/m^2 brine volume, 15^o glass cover angle, while Black Gravel (20mm-30mm size) improved productivity by 19% at conditions of 20l/m^2 brine volume, 15^o glass cover angle. Also in 2002, the same authors studied the effect of a floating, perforated aluminium plate on solar still productivity. It was found that the floating perforated aluminium plate increased solar still productivity by 15% (at brine depth of 3cm) and 40% (at brine depth of 6cm). The absorber materials enhance heat retention by the water, resulting in

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increased water temperature, hence increased evaporation due to a wider temperature difference between water and glass cover.

In an experiment with a double slop solar still, Hitesh (2011) found that a black dyed absorber performed better than violet and red dyed absorbers by 26% with red dye showing least performance. This shows that the black dye enhances the heat absorption capacity of the still. He also found that using a sprinkler to cool the glass cover resulted in higher distillate production, obviously due to increase in water-glass temperature difference.

Hitesh (2013) in an attempt to enhance still productivity through enhanced heat absorption, produced two double basin solar stills with one coupled with vacuum tube and the other coupled with a vacuum tube and black granite gravel. On comparison with the output of an ordinary double basin still, he found the daily output of the double basin solar still coupled with vacuum tube to be more by 56%, while that of the double basin still coupled with vacuum tube and black granite gravel increased by 65%. Economic analysis of the double basin still coupled with vacuum tube and black granite gravel showed a payback period of 165 days.

Salinity of Water

Salinity describes the concentration of salt in water. The level of salinity has been found to affect the performance of solar stills. Bilal, Mousa & Waleed (1999) and Alkash et al(2000) reported declining distillate production in a solar still with increasing salinity in a somewhat linear fashion. However at high concentrations, little variations were observed. An investigation on the influence of salinity on the heat capacity of water may be required to be able to explain this problem.

Increased salt concentration may result in increased corrosion damage to the components of the still (Tiwari, 2013), especially those with metallic basin.

Conclusion

Some factors affecting the performance of solar still have been reviewed. Information available shows that a lot of effort has been made in understanding the performance of solar still. Designers must therefore be careful to consider all the important factors to achieve a reliably productive system for the provision of clean water.

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