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Removal of hardness from well water using a solar still

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Provision of potable water with the aid of a solar still is a promising technology in remote areas of developing countries. This study investigated the treatment of hard well water by using a single-slope solar still. The water sample was obtained from a solar-powered borehole in a students' hall of residence in Obafemi Awolowo University, Ile-Ife. The solar still was constructed with a 2 mm thick galvanized iron sheet with basin area of 800 mm x 600 mm and covered with transparent plain glass sheet of thickness 4 mm. Laboratory tests were carried out before and after treatment to determine the degree of removal of hardness. The still removed, on the average, 92% of the hardness of the well water.

Introduction

Water is a basic necessity of life. The provision of potable water has been one of the major challenges facing mankind today; this challenge is particularly critical in developing countries. The lack of potable water relates to the enormous capital investment and operating expenses that must be incurred to be able to provide reliable and safe water; such fund is out of reach of most developing countries (Ray and Jain, 2011).

The main goal of drinking water treatment is to provide potable and aesthetically pleasing water. Conventional treatment plants are often the choice in developing countries. Such plants have centralized treatment units while the water produced is transported over long distances to major towns in the region. This arrangement clearly leaves out the inhabitants of many small rural communities without potable water. A good option for the unserved population is a decentralized low-energy technology such as a solar still (Avvannavar et al., 2008).

According to Dev and Tiwari (2011), a solar still is a device in which saline or polluted water is fed to obtain distilled water through the process of solar distillation. On the basis of various modifications and mode of operations introduced in conventional solar stills, Tiwari et al. (2003) classified solar distillation systems as passive and active solar stills. In a passive solar still, the solar radiation is received directly by the basin water providing the source of energy needed for driving the evaporation process. In the case of active solar stills, an extra-thermal energy by external mode is fed into the basin of passive solar still for faster evaporation. Fig. 1 shows the schematic diagram of the conventional single-slope passive solar still. Dev and Tiwari (2011) and Granadason et al. (2012) have described the basic principle of the solar still. A shallow airtight basin lined with a black, impervious material, contains saline or polluted water; the enclosure is formed by a sloping transparent cover at the top. The basin is made of materials such as wood, galvanized iron sheet, fibre reinforced plastic, or concrete while the cover is often made of glass, plastic or plexiglass. Solar radiation received at the surface is absorbed effectively by the black surface and heat is transferred to the water in the basin. Temperature of the water increases thereby increasing the rate of evaporation. Water vapour produced by evaporation rises upward and condenses on the inner surface of the glass cover which is relatively cold. Condensed water vapour trickles down into the trough and from there it is collected in the storage container as the distillate.

The advantages and disadvantages of the solar still have been enumerated in literature. According to Dev and Tiwari (2011), there are various advantages of solar stills over other desalination technologies such as: (a) an easy, small-scale, and cost effective technique for providing safe water in homes or in small communities; (b) producing distilled water, (c) simplicity in design; (d) no moving parts (pumps, motors, etc.) are required to run the unit in passive mode of operation; (e) no conventional sources of energy are required which helps in reducing the environmental pollution as it requires only solar energy (low grade energy), which is renewable and non-polluting; (f) no skilled operator is required for operation and maintenance; (g) local manufacturing/repairing is possible; (h) purifying highly saline water (even seawater); (i) a sense of satisfaction in having their own trusted and easy to use water treatment plant on-site at home, for solar still users; and (j) effective removal of pathogens and chemicals reduces risk of health problems associated with water borne diseases, etc. Some of the drawbacks of the solar still, which sometimes limit its use for large-scale production, include (a) large solar radiation collection area requirements, (b) vulnerability to weather-related damage, (c) low yield, (d) low efficiency, (e) less market demand of technology, and (f) low interest of the manufacturers.

Water hardness is due mainly to the presence of dissolved calcium and magnesium in combination with bicarbonate, sulphate and/or chloride. Hard water causes two major problems for the domestic consumer: (a) hard scale formation in the hot and cold water systems, this reduces efficiency of boilers and appliances which heat water, and causes unsightly deposits on taps and sanitary ware, and (b) scum formation and increased use of soap, along with a difficulty in producing an acceptable lather with soaps and detergents (British Water, 2004). Hardness is classified as carbonate (or temporary) and noncarbonate (or permanent). Expressed in mg/l as $CaCO_3$, water having hardness level below 15 is generally accepted as very soft; 15-60, soft; 61-120, medium hard; 121-180, hard; and more than 180, very hard. Natural surface waters are usually soft while groundwaters often have high hardness levels. Though the World Health Organisation (WHO) standard fixes a limit of 500 mg/l as $CaCO_3$, acceptability levels vary according to a consumer's acclimation to hardness (Peavy et al., 1985; Linsley et al., 1992).

Ogedengbe et al. (1984) have reported that people complained that water procured from certain wells is 'not palatable' and they preferred to travel long distances to fetch 'good-tasting' water. This feeling still subsists as observed in a recent study to characterise the water quality of selected wells in Ife North Local Government Area, Osun State, Nigeria. The people use the water from the wells in their compounds for cleaning and cooking while they travel on motor bikes to procure water for drinking. Therefore, the objectives of this study are to sample randomly selected wells in areas in the vicinity of the Obafemi Awolowo University (OAU), Ile-Ife campus; determine the level of hardness in the samples; and evaluate the performance of a solar still in the treatment of the raw water to produce drinking water.

Materials and methods

As a preliminary experiment, samples of water were collected from randomly selected wells and boreholes in Ile-Ife and its environs and the hardness were determined using standard methods. One of the sources with considerable hardness was selected as the raw water for the study.

The solar still used for the study is shown in Photograph 1, the dimensions are given in Table 1. The base of the still was painted with coal tar while the glass was fixed in position using sealants so as to ensure water tightness. The distillate collecting trough was made from polyvinyl chloride pipe and fixed at the top edge of the south wall at the base of the glass cover; the trough slants to one end into a collection port where a hose was fixed to collect the distillate and empty it into a container. There is another hose fixed to the raw water inlet port at the centre of the north wall. The basin serves as the container for the raw water. The still was placed on a stand in the Solar Laboratory[1] and oriented facing south as recommended by Garg and Mann (1976) and Duffie and Beckman (1991). During the study, five litres of water was fed into the still basin at 9.00 a.m. in the morning; the total volume of distillate was collected at 9.00 a.m. on the following day. The hardness of the collected distillate was determined using standard methods.

The raw water was also treated by using ion-exchange cartridges procured from a retailer. The flow rate through the system was maintained at 20 l/h. The residual hardness of the treated water was monitored in order to determine when the resin was exhausted.

Results and discussion

The hardness levels of water samples from the preliminary experiments are presented in Table 2. Because of ease of accessibility, the solar-powered borehole at Fajuyi Hall was chosen as the source of raw water for the study. The initial hardness of the raw water was 274.74 mg/l. Table 3 shows the residual hardness for the

[1] Located in the Civil Engineering Building, Obafemi Awolowo University, Ile-Ife.

ion-exchange system while Table 4 shows the results from the daily distillates from the solar still. The ion-exchange resin was exhausted after treating 300 litres of water and it removed all the hardness in the raw water. On the other hand, the results indicate that the distillates from the solar still have residual hardness ranging from 18 to 27 mg/l with an average removal of 92%. The daily yield of the solar still ranged between 1.6 and 3.1 l/m^2, this is in agreement with values obtained from literature.

On the cost of treatment, the ion-exchange cartridge which produced 300 l of water cost N3750.00 (about US$24). The cartridge would be discarded once it gets exhausted. The production cost of the solar still was N10,000.00 (about US$63). However, after the initial cost of the solar still, no further cost would be required to produce potable water.

Key lessons

The context of this study has been to obtain drinking water from a hard well water in a rural setting by employing a solar still. In such a circumstance, the ion-exchange cartridge could not be a sustainable alternative. The sloar still used in this study produced drinking water of acceptable quality from the raw well water. The average daily yield was 2.4 l/m^2/d. The solar still would be an effective means of producing ‘good-tasting’ water from the well water considered ‘not pallatable’ by the rural community.

Conclusion

Hard water has been treated by using a solar still, the hardness was reduced, on the average, by 92%. The raw water was also treated using an ion-exchange system which removed the entire hardness in the raw water. However, the solar still was found to be cost-effective in the production of water of acceptable quality.

Table 1. Dimensions of the solar still

Description of item	Value
Area of basin (m^2)	0.48
Height of south wall (m)	0.1
Height of north wall (m)	0.318
Angle of inclination of glass cover (^{o})	20
Thickness of glass cover (mm)	4
Size of glass (m^2)	0.511
Thickness of the galvanized iron sheet (mm)	2

Table 2. Level of hardness in selected wells

Source of water	Hardness (mg/l as $CaCO_3$)	
	Carbonate hardness	Noncarbonate hardness
Borehole at General Hospital, Ipetumodu	353.00	229.70
Shallow well at Ode-Omu	144.12	45.04
Solar-powered borehole at Yakooyo	346.81	225.20
Shallow well at Ede Road, Ile-Ife	175.66	72.06
Solar-powered borehole at Fajuyi Hall, OAU,Ile-Ife	274.74	261.19
Well at Ibadan Road, Ile-Ife	171.15	63.06
Tap water at Moremi Estate, Ile-Ife	117.10	54.05

Table 3. Residual hardness in deionised water

Volume of water passed through the cartridge (l)	Residual hardness (mg/l)	% Removal
1-300	0.00	100.0
300-305	4.50	98.3
306-310	18.00	93.3
311-315	45.00	83.3
316-320	108.00	60.0
321-325	270.24	1.7

Table 4. Residual hardness in the distillate from solar still

Day	Volume of distillate (l)	Residual hardness (mg/l as $CaCO_3$)	% Removal
1	1.2	18.00	93.3
2	1.0	27.00	90.0
3	1.0	18.00	93.3
4	1.3	18.00	93.3
5	1.2	22.52	91.7
6	1.1	27.00	90.0
7	1.5	18.00	93.3
8	0.9	22.52	91.7
9	0.8	22.52	91.7
10	1.4	18.00	93.3

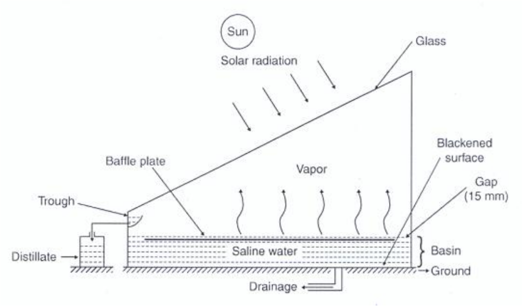

Figure 1. Schematic diagram of a conventional single slope passive solar still

Source: Dev and Tiwari (2011)

Photograph 1. Constructed solar still

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