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Design and Construction of a Simple Portable Water Treatment Plant For Use in Rural Areas

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ABSTRACT
In the rural areas, accessibility to a constant supply of pipe-borne water is difficult for some of the population, especially those living in rural areas. The research paper is the design and fabrication of a simple portable water treatment plant. . There are three layers of horizontal frames: top, middle and bottom layers. The three layers are each 1.52m square. The top layer which carries a capacity of 450 liters (L) and the diameter water inlet tank is 0.8 metre (m). . The device was designed using a gravitational flow treatment process with no need for a conventional power source. The untreated water is placed into the inlet tank. The water then flows through the system by means of gravity passing through a simple locally made filter of sand, clay and gravel. After filtration, the effluent was then passed through a chlorination chamber and then through a carbon filter into the storage tank located at the base of the system. The device was tested using three types of untreated water: rain water, pond water and river water. The treated water in all three cases was chemically tested to determine the quality and the effectiveness of the device.

The results were compared favorably with the World Health Organization Standards for drinking water. This portable device would ensure that potable water is both economical and easily available to the rural and other regions worldwide.

Keywords: Water, treated, rain, drinking, potable, rural areas

I. INTRODUCTION

Drinking water comes from several sources among which are surface water (lakes, rivers and reservoirs). Ground water (wells boreholes) and rain. Treatment of water depends on the source surface water is exposed to environmental elements like wildlife dropping, urban and agricultural run-off, and trash. Groundwater has historically been assumed safe without treatment seeps through. Groundwater is stored in underground reservoir known as aquifers and is more protected from environmental elements, than surface water. As it is freed from air pollution (Adejuyigbe 2000) arid regions.

The major problems confronting most Nigerian local communities Today is the Non-availability portable water for domestic use. Portable water is that which is suitable for drinking and this is a commodity which is very scare to come by in so many communities from cities to villages. A large percentage of communities are blessed with abundant surface and underground waters; but various government and individuals find it difficult to turn the available raw water to suitable ones for the public, because of many factors ranging from economic, technical and management in adequacies.

The water available for use in the public today are those procured by the people themselves, through the various unhygienic, which do not satisfy basic requirements of portability. Freedom from pathogenic organism; physical and chemicals qualities and aesthetic qualities. Common diseases which can be contacted from drinking bad water include dysentery, gastro entities, typhoid fever and cholera. Other viral diseases include infectious hepatitis, polingetities etc. the best approach to alleviating the highlighted problems is through a system of water treatment which includes, sedimentation, flocculation of impurities, clarification filtration, and disinfection. The major water treatment methods include using coarse filters, coagulation, flocculation, sedimentation or clarification, filtration and chlorination. These conventional methods of treatments are available, for a huge population in rural areas in developing countries. However, they could be inappropriate or too costly to implement (Vigneswaran and Sundaravadivel, 2008). Rural communities therefore adopt simple and rudimentary water treatment techniques that can serve communities of individual households. These treatments mainly aim at removing visible impurities like leaves, twigs or large particles from water and mainly involve simple filtration using a sieve or cloth or other local materials like stones and plant materials (Vigneswaran and Sundaravadivel, 2008). The most common material that is used for water filtration is natural sand (Peavy et al., 1985) since it makes for a very efficient strainer for small colloids. Fair and Geyer (1961) developed an accurate theory for predicting a head loss across a bed of clean sand. Although this method of filtration is successful, it is very costly for implementation at a rural setting. Ekwue and Ramdeen (2004) investigated the use of a sand and clay filter and found that the measured properties of the effluents from wastewater were reduced to levels that were safe for discharge into the environment. They did not test the effect of this filter on rainwater or other sources of freshwater neither did they investigate whether this filter could produce potable water safe enough for drinking by the human population. It is therefore not clear whether it could be used for this purpose in a local setting.

This paper involves the design, construction and testing of a portable water treatment plant that could be used to produce potable water for drinking for a household in a local setting.

II. LITERATURE REVIEW

Many water treatment plants use a combination of coagulation, sedimentation, filtration and disinfection to provide clean, safe drinking water to the public. Worldwide, a combination of coagulation, sedimentation and filtration is the most widely applied water treatment technology, and has been used since the early 20th century (Peterson, 2001).

As of 2006, water borne diseases are estimated to have caused 1.8 million deaths each year. These deaths are attributable to inadequate public sanitation systems and in these cases, proper sewerage (or other options such as small scale wastewater treatment) which need to be installed (UCDCP, 2006).

Appropriate technology options in water treatment include both community scale and household scale point of use (POU) designs (Center for affordable water and sanitation technology, 2008).

New military style reverse osmosis water purification units (ROWPU) are portable, self-contained water treatment plants are becoming more available for public use (Lindsten, 1984).
Conventional treatment includes the following: pre-sedimentation or screening, chemical coagulation and flocculation, final setting or clarification, filtration and disinfection. Not all process are required in every case, hence actual process selection depends upon careful review of overall raw water quality and characteristics (AWWA, 2005).

III. METERIALS AND METHODOLOGY

3.1 METERIAS

The materials are listed in the table 1 below.

TABLE 1

I	37.8mm x 37.8 x 6.3mm angle iron
11	6,3mm thick metal sheet
III	6.3 mm thick stainless sheet
IV	Sand ad clay filter made from 300mm diameter pvc pipe
V	127mm caster wheel
VI	40 liters water tank
VII	1.0 HP electrical water pump

3.2 DESIGN AND CONSTRUCTION

Figure 1 shows the clear picture of a simple portable water treatment plant. There are three layers of horizontal frames: top, middle and bottom layers. The three layers are each 1.52m square. The top layer (as shown in Figure 1) which carries a 450 litre (L) capacities and 0.8 metre (m) diameter water inlet tank is made from a 50.8 mm x 50.8 mm x 6.3mm angle iron rod and has three supporting bars. These bars included one 50.8 mm x 50.8 mm and 6.3 mm angle iron rod with length, 1.52 m at the centre of the square and two 37.8 mm x 37.8 mm x 6.3mm angle iron rods, 0.25 m on each side (see Figure 2). The total weight of the

450 L tank and the three supporting bars is 4,846 N, making the load on each supporting bar to be 1,615.3 N. The maximum bending stresses on the 50.8 mm and the 37.8 mm bars due to loading were calculated as 82 mega Pascal (MPa) and 86 MPa, respectively, which are much less than the design stress of 125 MPa for mild steel, using a factor of safety of 2. A winch assembly consisting of the winch, the frame attachment and the pulleys was positioned so that it would be in line with the 50.8 mm size middle support bar and carry a sand and clay filter (see Figure 3). Two U-brackets were attached to the same supporting bar. The brackets were positioned with one on the end of the bar on the left and other 0.36 m on the left of the centre of the bar when viewed from the front of the system. The total weight of the sand and clay filter assembly is 1024 N. The diameter of the winch cable and chain is 9.5 mm with a cross-sectional area of 0.00748 m2. With the tension in each of the two cables used to hold the sand clay filter being 512 N, the average normal stress on each cable was calculated as 0.00684 MPa. This is safe since it is much less than the design stress of mild steel. The average stresses on the small and large U-brackets were also calculated as 0.00342 MPa and 0.00202 MPa respectively

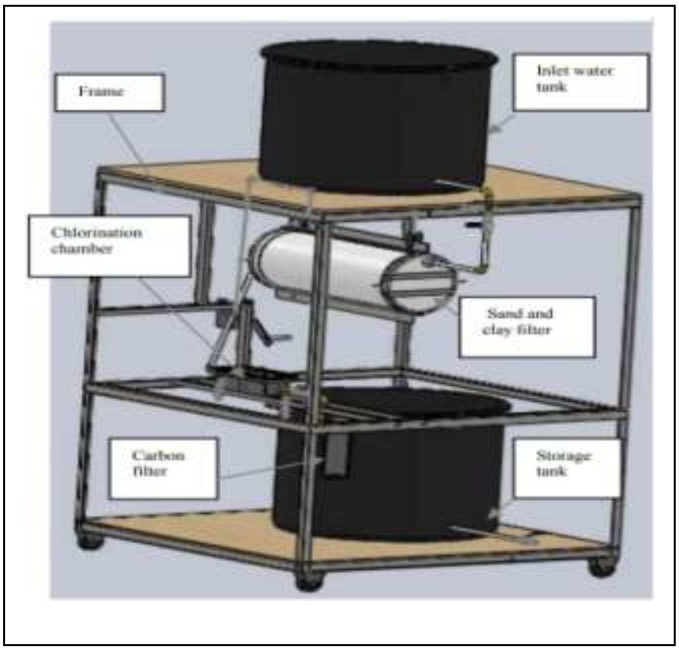

Figure 1: The portable water treatment plant

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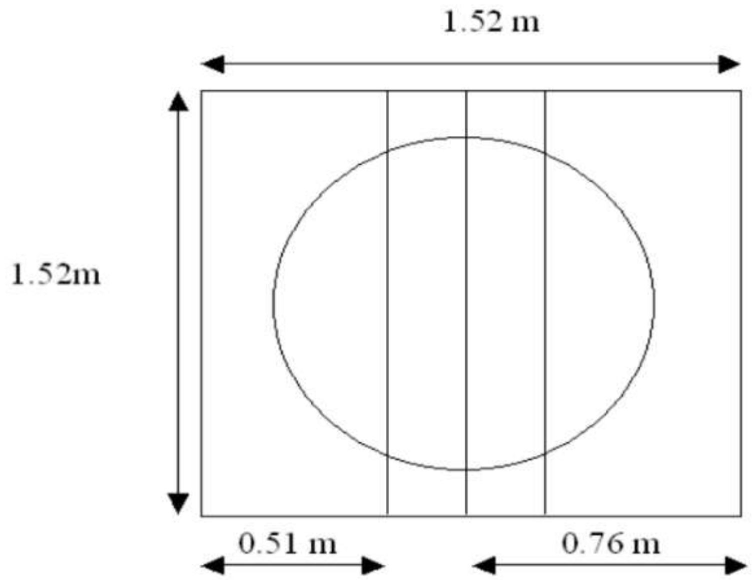

Figure 2: Top layer of the frame

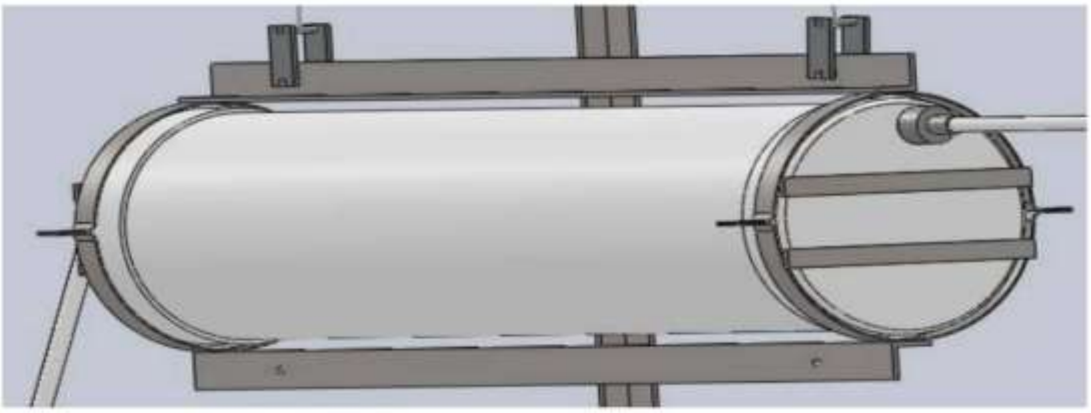

Figure 3: The sand and clay filter assembly

The sand and clay filter (as shown in Figure 3) was made from a 305-mm diameter PVC pipe of length, 0.91m. The ends of the pipe have flat bottom end caps with two 18.75-mm diameter inlet and outlet holes made on each of the end caps. The filter was filled with the following material in the order: 20% - 18.75 mm size yellow pea gravel; 20% - 9.5 mm size yellow pea gravel; 30% - sharp sand and 30% - 70/30 mixture of silica sand and kaolin clay. This proportion of the mixture of 30% clay and 70% silica sand was found to be the best for water filtration by Ekwue and Ramdeen (2004) and was therefore adopted in this construction. The full description of the sand and clay filter was given by Ekwue and Ramdeen (2004).

The middle and the bottom layers of the framework were made from 37.8 mm x 37.8 mm x 6.3 mm iron bars. In the middle layer, there is the addition of two lengths of bars, each 1.52 m length, where a chlorination chamber and a household carbon filter (see Figure 4) were attached as shown in Figure 1.

The total weight of the chlorination chamber and the bars is 332 N. The chlorination chamber was made out of 6.3-mm thick sheet metal and consists of a box of dimensions 305 mm x 100 mm x 100 mm. Around the lip of the box, one-25.4 mm x 25 mm x 6.3 mm size angle iron was attached. The top frame of the box has eight equally spaced holes of 6.3 mm diameter drilled around the box. On the 100 mm x 100 mm faces of the box, 38 mm-diameter inlet and outlet holes were drilled. A cover for the box was made out of Plexiglas of dimensions 355 mm x 178 mm x 6.4 mm. A chlorine tablet kept in its position by the use of separation plates was placed in the centre of the box vertically.

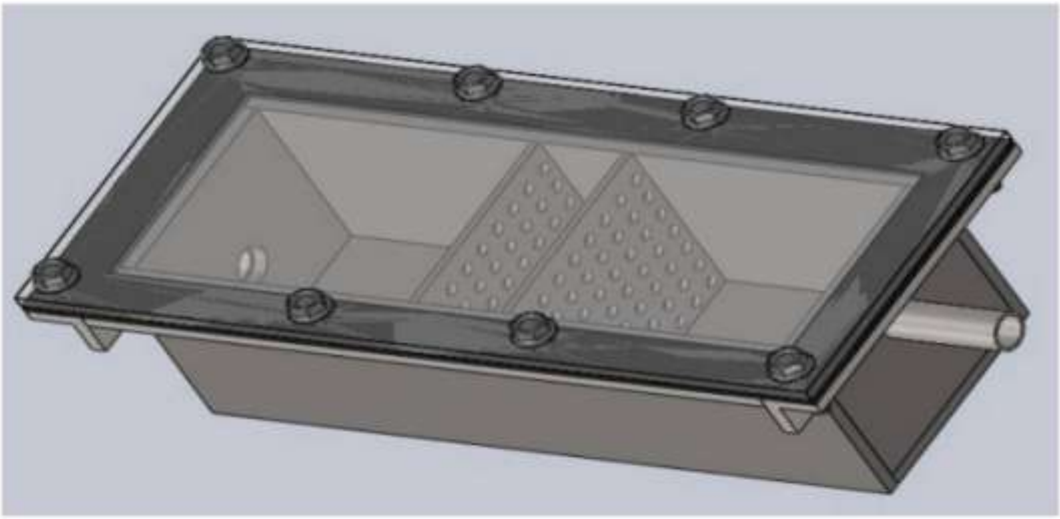

Figure 4: Chlorination chamber

The bottom layer of the frame (see Figure 5) has two supporting bars 0.51 m from each end of the square. The supporting bars were each 37.8mm x 37.8 mm and 6.3 mm size angle iron, holding the storage tank (with 450 L capacity). The storage tank has a float inside it to control the level of water. The total weight of the storage tank and the supporting bars which act on the supporting bars is 4,536 N, meaning that 2,268 N acts on each bar. The total bending stress on each supporting bar was computed as 97 MPa, which is safe since it is less than the design stress of 125 MPa for mild steel.

The vertical frame members comprise of two sections: a top layer with height 1.12 m and a bottom layer, 0.76 m high. The two layers were each made out of four 37.8mm x 37.8 mm and 6.3 mm angle iron. The wheel assembly consists of a 127 mm caster wheel, four-9.5 mm diameter nut and bolts with washers as well as an additional metal 6.3 mm thick plate with 100 mm x 127 mm size. The casters were mounted using 50.8 mm long 9.5 mm diameter nut and bolt with a washer and lock washer. The lock was provided for the safety and stability of the device.

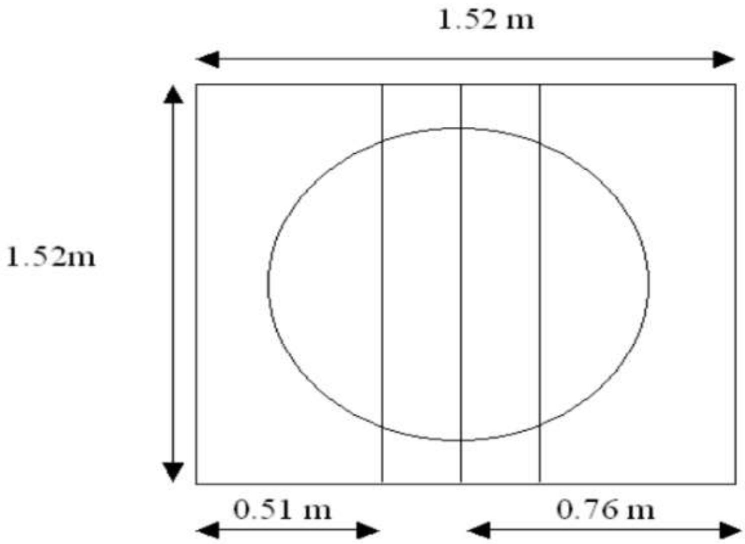

Figure 5: Bottom layer of the frame

The total loads on the wheels (11,256 N) was calculated as the sum of the top layer of the frame (4,846 N); sand and clay filter assembly (1,024 N); middle layer comprising of the chlorination box and the bars (332 N); bottom layer including the bars (4,797 N) and the four vertical posts (257 N). The total load on each of the four wheels was therefore 2,814 N which is 287 kg and 631 Ib. The load capacity of the casters used was 1000 Ib. Hence, the choice of casters is suitable for the design since this allowed for a factor of safety greater than 1.5.

3.2 PEINCIPLES OF OPERATION

This design operates on the process of gravitational flow where water will be directly added to the inlet tank from sources like rainwater runoff from a house roof system or from water addition through a pump system from river or pond. The flow of water in the system depends mainly on the water level in the bottom storage tank which will be maintained by the level of the float. The water from the inlet tank will enters the sand and clay filter and proceeds to the chlorination chamber. The chlorination chamber box will contains a chlorine tablet which reacts with the water as it passes over it. After chlorination, the water will go through a household carbon filter and is then stored in the bottom storage tank. The frame is designed so as to encourage gravity flow due to its vertical design which also allows for a compact and space reduction process.

The stress analysis of the frame posts was also carried out. The total load on each post was 2,814 N and with the area of each post obtained as 0.000444 m2, the stress was computed as 6.34 MPa, which is very safe. Lastly, the force required for possible tipping of the device was computed as 4,164 N. This relatively large force will minimize the chance of tipping of the device. Finally, the steel materials of the water treatment plant were painted in order to reduce corrosion and increase the aesthetics. :

IV. RESULTS AND ANALYSIS

The results of the raw water tests are analyzed thus:

4.1 RAW WATER TEST

The results of the raw water test are follows;

I. Temperature 27^0C
II. pH 6.8 before dosing with aluminum sulphate (AL_2 (S04)
III. T.D.S (total dissolved solids 1500 PPm (per million)
IV. Color (color units)

TABLE 2

S/No	Physical Chemical Analysis	Quality of water Produce	International Standard
I	PH	7.2	7-8.5
II	Turbidity	0.1	≤ 1.5 ppm
III	T.D.S	400ppm	≤ 500 ppm
IV	Color	2	≤ 20
V	Free chlorine	Nil	≤ 0.2
VI	Total hard Ness	100(moderately soft)	Un objectionable
VII	Chloride	15 ppm	≤ 200 ppm

4.2 TESTING OF THE WATER TREATMENT PLANT

4.2.1 EXPERIMENTAL PROCEDURE

Tests will be conducted to investigate whether the constructed plant could treat water from different sources and produce water of acceptable quality for drinking. Water from three sources will be tested. The first one will be rainwater collected from a spouting system from a roof nearby. The second water source will be from any nearby pond around the polytechnic premises. The third source will be water from Talata Mafara River. The raw water in each case will be brought in a tank and pumped into the inlet tank. Ideally, the system was designed to be placed directly beneath the outlet of a spouting system, so that rainwater or any other fresh water could flow directly into the inlet tank of the water treatment plant. Water will then flow into the sand and clay filter which will be tilted at different angles so as to determine the best position for water treatment. Investigation of the angles for positioning the filter will be necessary so as to determine the angle of the inclination of the filter that affect the quality of the water to be produce. The angle of the filter will be easy to vary because of the addition of the winch system on the filter. The valve will be open allowing the water to pass through the sand and clay filter. The water exiting the filter will be allowed to runoff from the system for a period of two minutes in order for excess particles to exit the system which will be made by the movement of the filter. The water will then flow through to the chlorination chamber where it will come in contact with a chlorine tablet and then pass through the household carbon filter and into the storage tank. The raw water and the water effluent to be collected at the storage tank each time after the changing of each tilting angle of the sand and clay filter will be tested in the laboratory.

4.3 QUALITY OF WATER

The plants performance is hinged on the quality of portable water produced, after further dosing unit it appropriate quantities of chlorine (C4 (Oc) 2) and soda ash. (N2 C03) for disinfection and PH correction. The result are show in table 2.

V. CONCLUSSION

The plant which is capable of being constructed and maintained by indigenous personnel has been developed. Its design analysis as well as method of construction is presented in this study and quantity of water produced by the plant compare favorably with international standard.

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