International Journal of Academic Engineering Research (IJAER)
ISSN: 2000-001X
Vol. 2 Issue 4, April – 2018, Pages: 1-8

Development of a Deionizer for Water Purification

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Abstract: *Pure water is a basic need for humans, whether for industrial or domestic purposes. Dirty water can be harmful to humans, animals and machines. This work develops a deionization device for water purification. It uses ionization technique which involves the ion exchange method to remove soluble ions in water so as to make it fit for drinking, domestic and industrial uses. The deionizer was designed to accommodate and deionize 40 L of water in 36 seconds. This results in a flow rate of 4* m^3/hr. *The recommended velocity of 1.524 m/s was chosen. Using Lewatit design software, 25 L of Strong Acid Cation (SAC) and Strong Base Anion (SBA) resins were employed for the performance evaluation. This was done by comparing the resistivity of the deionized water and the ionized water using a conductivity monitor. The conductivity and resistivity were discovered to vary with change in the flow rate of water. This indicates that the operational capacity of the deionizer varies with the flow rate.*

Keywords: Water, Purification, Deionizer

1. INTRODUCTION

Water from natural sources contains various substances such as solid, insoluble substances, soluble substances as well as the soluble and non-ionized substances. A de-ionizer removes these soluble ionized substances from water, making it purer and softer. This pure water is much better for drinking and for industrial application. This study involves the development of a de-ionizer, which can be used for the purpose of water purification. It uses ionization technique which involves the ion exchange method to remove soluble ions in water so as to make it fit for drinking, domestic and industrial uses. These soluble ionized substances are present in water as ions. In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions to very low levels through the process of ion exchange. Ion exchange is achieved with the help of ion exchange resins.

One of the most basic human needs and prerequisites for health and sustainability is access to safe drinking water (Schirnding, 2000). World Health Organization (WHO) and United Nation's International Children Emergency Fund (UNICEF, 2004), identified improved water sources as household connection, public standpipe, bore hole, protected dug well, protected spring and rain water collection, while unimproved sources are unprotected well, unprotected spring, river or pond, vendor-provided water, bottled water and tanker-truck water. According to United Nations (2002), about 1.1 billion people representing 18% of the world's population lack access to safe drinking water. The consequence of the failure to provide safe water is that a large proportion of human beings have resorted to the use of potentially harmful sources of water. The implications of this collective failure are dimmed prospects for the billions of people locked in a cycle of poverty and disease (UNEP, 2002). Brown (2003) opined that at any time, more than half of the hospital beds in the world are filled with people suffering from water-borne diseases. Dowdeswell (1996) concludes that about 80% of all diseases and more than one third of all deaths in developing countries are caused by contaminated water. It has been confirmed that with adequate supplies of safe drinking water, the incidence of some illness and death could drop by as much as 75% (UN, 2002). WHO and UNICEF (2004), observed that the quantity of water and the proximity of the supply point to the home are more important than actual water quality in improving health since the quantity collected from such distant source is likely to be too small for effective hygiene. Studies indicate that clean water within a distance of not more than 1 km from the house tends to lead to improved health status, since people tend to use substantially more water for cleaning and washing (Cairncross, 1990; Cairncross and Feachem, 1993). WHO and UNICEF view improved water source as water available from a defined list of technologies, with access to at least 20 litres of water per person per day from source within 1 km of the user's dwelling. The purpose aim of this work is to develop a deionizer for water purification that will enhance strategic water management in Nigeria. An understanding of this will definitely enhance the formulation of policies aimed at ensuring the development of improved and sustainable water system in Nigeria.

Seminar, conferences, discussions and workshops held globally aimed at determining the key elements for strategic water management and how related actions can be effectively implemented for water sustainability. The availability of portable water for domestic and industrial uses at the local level is threatened by water crisis. The resultant effect of this manifests in form of diseases and other related health issues. The novelty of this work will not only reduce water crises at the local communities, but will also increase the ease of accessibility to portable water. The development of the deionizer contributes to knowledge via provision of a portable deionizer at optimum cost for water purification; provision of ionization technique with some filtration processes in its operation for water treatment; provision of an automated stirrer to effectively mix the water and resins and provision of a manual regeneration method to reduce costs.

2. Materials and methods

2.1 Materials

The following materials were used for the construction of the deionizer: ionization chamber; electric motor; water receptacle; water collector; chemical receptacle; ion exchange resin; resistivity monitor; valves; resin bed; filters and stirrer

2.1.1 The ionization chamber

This is the main chamber where ion exchange takes place. This chamber contains the resins responsible for ion exchange. Stainless steel was employed for the fabrication of the ionization chamber because of its excellent corrosion resistance and for the fact that it combines good strength with high formability. The ionization chamber is shown in Figure 1.

Figure 1: The ionization device

2.1.2 Electric motor

This provides the mechanical power for the stirrer (Figure 2). According to Srivastava and Prasad (2000), a 3 kW electric motor will adequately supply the required power for mixing a fluid whose density falls between 850-1000kg/m^3. Hence, a 3 kW electric motor is selected for the required service operation.

Figure 2: The electric motor

2.1.3 Water receptacle

This is where the water is to be fed from. It is fed to the chamber through the chamber inlet.

2.1.4 Water collector

The water collector is used for the collection of deionized water.

2.1.5 Acid and base receptacle

The acid and base are used for regeneration. They are kept in two different receptacles.

2.1.6 Ion exchange resins

These are the main components that facilitate ion exchange in the ionization chamber. They are placed on the resin beds. They are of two types; the anion and cation resins.

2.1.7 Resistivity monitor

This is used for performance evaluation. The less ionic the water is, the more resistive it is to electricity. It will be placed in both water tanks, in order to compare the resistivity and determine the efficiency of the device.

2.1.8 Valves

Valves are used to regulate the flow of water during the process (Figure 3). A 2-inch (0.0508 m) valve is adequate for the required service condition.

Figure 3: The outlet valve

2.1.9 Resin bed

This is the platform that carries the ion exchange resins. It consists of a filter.

2.1.10 Filters

These are used to remove insoluble particles before the water is transported to the ionization chamber. This was made of stainless steel.

2.1.11 Stirrer

The stirrer assembly comprises of the stirrer shaft and a blade to mix the water and the resin effectively (Figure 4).

This is done to facilitate greater efficiency in the ion exchange process. It was made of stainless steel so as to prevent corrosion.

Figure 4: The stirrer

2.2. Methodology

The water is harvested from any source and then fed to the device through the chamber inlet. Filters are included in the chamber inlet. The water is transported from the chamber to the deionized water collector, with gravity. During transportation, the water is passed through the resins where ion exchange takes place. The automated stirrer mixes the water and resins properly, by rotating.

After a certain period of use, these resins decline in efficiency and is regenerated with the use of the regenerants. The regenerants, HCL and NaOH, are stored in separate tanks. During regeneration, the resins are separated with salt solution. The anion resins are then soaked in the HCL while the cation resins are soaked in the NaOH.

Resistivity monitor records the resistivity at the two water receptacles in order to calculate the effectiveness and efficiency of the deionizer.

2.3 Material Selection

The materials selected for the following components and the respective merits are stated in Table 1.

Table 1: Materials used for the components and their merits

S/N	Component	Material used	Merits
1	Ion exchange chamber	Stainless steel	Corrosion resistance
2	Acid tank	Carbon steel	Corrosion resistance, high strength
3	Base tank	Carbon steel	Corrosion resistance, high strength
4	Stirrer	Stainless steel	Corrosion resistance

2.4. Design specifications

The device was designed to accommodate and deionize 40 L of water, which is approximately 2.66 buckets of water, for evaluation. Therefore, the working parameters are:

i. Gross water volume in a day = 0.04 m^3
ii. Gross running time in a day = 0.01 h = 36 s
iii. Gross flow rate = 4 $\frac{m^3}{h}$

2.5. Design calculations

The design calculations was done with Lewatit design software, then verified manually. Some parameters that needed to be calculated before fabrication were:

i. Water velocity
ii. Gravity flow calculation
iii. Resin volume
iv. Regenerant volume
v. Ionization chamber sizing
vi. Stirrer shaft diamter

2.5.1. Water Velocity

The recommended velocity of 1.524 m/s was chosen.

2.5.2. Gravity flow calculation

Using gravity to achieve the flow rate of 4 $\frac{m^3}{h}$, the slope of the inlet pipe must be calculated. The Hazen-Williams equation is given as equation 1.

$$V = kCR^{0.63}S^{0.54} \qquad (1)$$

where

V is velocity (m/s); k is a conversion factor for the unit system (k = 1.318 for US customary units, k = 0.849 for SI units); C is a roughness coefficient = 150 (for PVC pipes); R is the hydraulic radius, (m)

International Journal of Academic Engineering Research (IJAER)
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S is the slope of the energy line (head loss per length of pipe or h_f/L).

Using the equation, we can deduce that:

i. Velocity of water = 1.524 m/s
ii. Pipe slope = 0.07

2.5.3. Resin volume

Using Lewatit design software, the resin volumes were estimated as follows:

i. 25 L of SAC resins
ii. 25 L of SBA resins

Other estimated parameters are:

i. ionic load of 29.7955 meq/l for SAC resins and 30.094 meq/l for SBA resins

2.5.4. Regenerant volume

Hydrochloric acid is used in the regeneration of SAC resins while Sodium hydroxide is used in the regeneration of SBA resins. The parameters of HCL are:

i. Specific consumption = 100 g/L
ii. Concentration as applied = 5%
iii. Volume as applied = 48.8247 L
iv. Portion = 100%
v. Amount = 2.5 kg 100%

The parameters for NaOH are:

i. Specific consumption = 100 g/L
ii. Concentration as applied = 5%
iii. Volume as applied = 47.3058 L
iv. Portion = 100%
v. Amount = 2.5kg 100%

2.5.5. Ionization chamber sizing

The following dimensions used in the design of the ionization chamber are:

i. Wall thickness = 1 mm
ii. Filter diameter = 935 mm
iii. Filter area = 0.69 m^2
iv. Total chamber height = 520.7 mm

2.5.6. Stirrer shaft diameter

Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions (Hall *et al.,* 1980).

Using the relationship

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l} \qquad (2)$$

Where

G is the modulus of rigidity, N/m^2, L is the length of shaft, m, θ is the angle of twist, degree, T is the total resisting torque, N, τ is the maximum shearing stress, N/m^2, J is the polar moment of inertia m/s^4, r is the radius of shaft in m

From the relation in equation 2,

$$\frac{T}{J} = \frac{\tau}{r} \qquad (3)$$

Where;

$$T = \frac{P}{2\pi N} \qquad (4)$$

P is the power rating of the electric motor, (3 kW)
N is the number of revolution per minute (20 rev/min)

Then, the total resisting torque is calculated as 23.87 N. The shaft is solid and the formula for determining the diameter of a shaft having little or no axial loading according to Hall *et al.* (1980) is given in equation 5

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (5)$$

where; M_t is the torsional moment, (Nm), M_b is the bending moment, (Nm), K_b is the combined shock and fatigue factor applied to bending moment, K_t is the combined shock and fatigue factor applied to torsional moment, S_S is the allowable shear stress, (N/m^2) and d is the shaft diameter, (m).

Given the fact that the shaft of the processing tank is to stir fluid whose maximum weight was determined to be 40 kg, using a 3 kW, 20 rpm electric motor, the torsional moment M_t on the shaft is given by equation 6

$$M_t = \frac{kW \times 1000 \times 60}{2\pi rev/min} \qquad (6)$$

From equation 6, torsional moment is calculated as 1432.21 Nm. The shaft length is taken to be 80% of the height of the cylindrical tank. The bending moment is zero since the shaft is vertical.

The shear stress Ss for stainless steel material used for the shaft is given as 55 MN/m^2 and for rotating shaft with minor shock K_b=1.0 and $K_t = 1.0$. These values were introduced into equation 7, as follow;

$$d^3 = \frac{16}{3.142 \times 55 \times 10^6}\sqrt{(1.0 \times 1432.21)^2}$$

$$d = 0.05099 \text{ mm} \qquad (7)$$

The shaft diameter, d for the processing tank is calculated as 50.99 mm. Using a safety factor of 1, the shaft diameter is calculated as 50 mm to the nearest standard size.

Stainless steel was employed for the fabrication of the shaft because of its excellent corrosion resistance and for the fact that it combines good strength with high formability.

2.6. Design Drawings

Figures 5 and 6 show the design drawings of the deionizer.

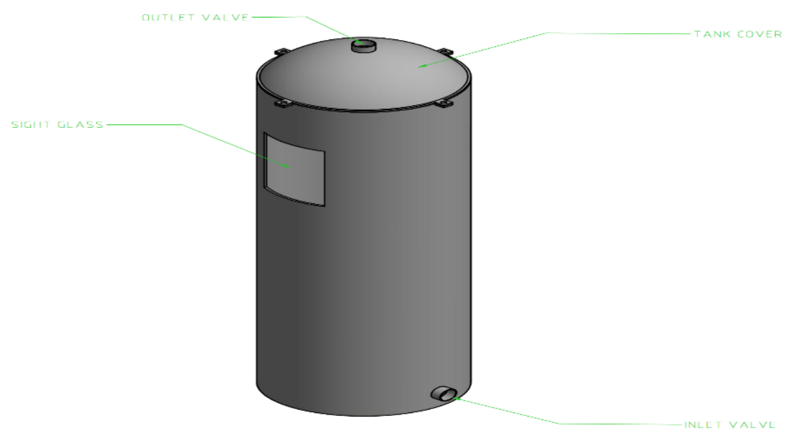

Figure 5: 3D CAD model of deionization device

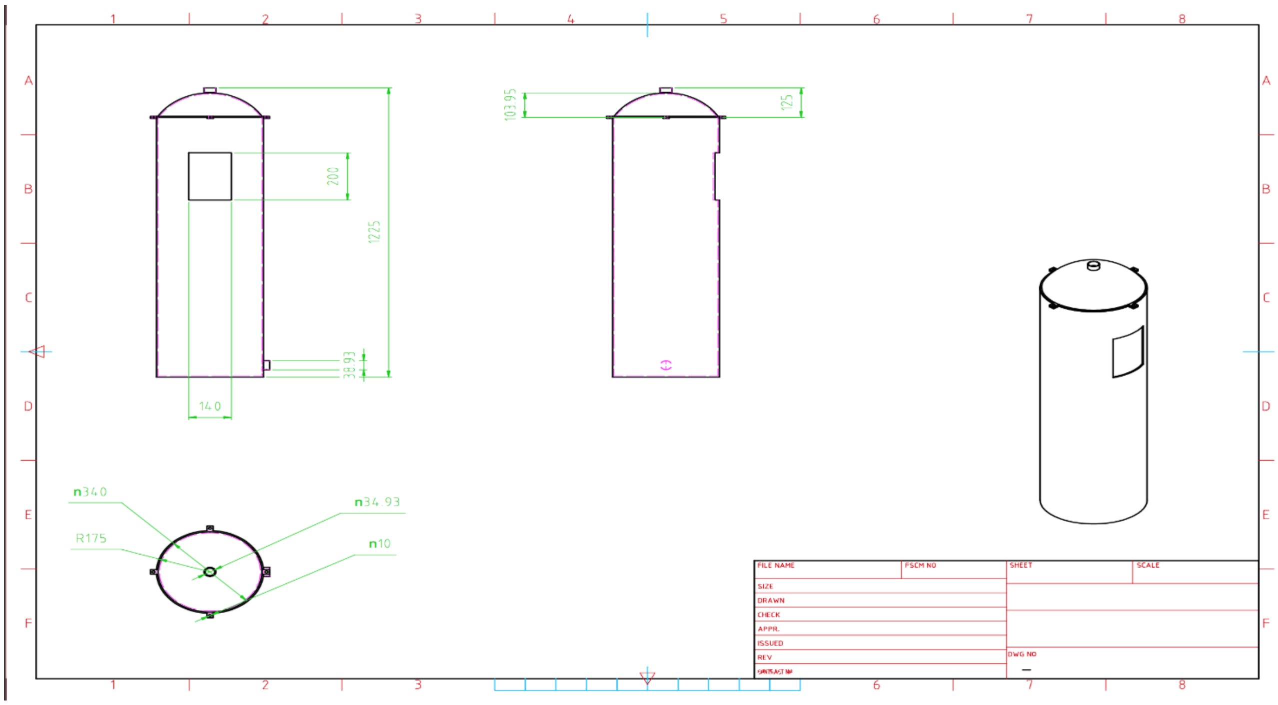

Figure 6: Orthographic and isometric drawing of deionization device

2.7. The fabrication process of the deionization Device

The steps taken during fabrication of the device were:

i. Construction of the cylinder
ii. Construction of the cylinder legs
iii. Assembly of the cylinder and cylinder legs
iv. Installation of mixing unit
v. Installation of fittings, piping and valves

International Journal of Academic Engineering Research (IJAER)
ISSN: 2000-001X
Vol. 2 Issue 4, April – 2018, Pages: 1-8

2.8. Performance evaluation of the developed deionization device

Tests were carried out in order to evaluate the functionality of the device. The results determine the effectiveness and efficiency of the developed device.

2.8.1. Leak test

The procedures for performing the leak test were:

i. The outlet valve was shut off
ii. Water was inserted into the device
iii. The water was allowed to settle for 5 minutes
iv. The body of the device was then visually inspected for any leakage of water

It was observed that there was no water leaking from the device, therefore the leak test was passed.

2.8.2. Evaluation of the deionizer

The procedures involved were:

i. The SBA and SAC resins were poured in the right proportion into the device
ii. The electric motor was left off
iii. Deionized water was poured into the device with the outlet valve open
iv. The conductivity was measured at the outlet
v. The resistivity was calculated from conductivity
vi. Procedures iii, iv and v were repeated with the outlet valve at different positions
vii. The results were analysed and discussed

3. Results and discussion

The device was evaluated at different flow rates and varying conductivity and resistivity were observed. Table 2 shows the results obtained.

Table 2: Flow rates, measured conductivity and derived operational capacity

Flow rate (Cubic meter/hr)	Conductivity (micromho/cm)	Resistivity (ohm/cm)	Parts per million (ppm)	Operational capacity (meq/L)
1521.45	55013.2	1.81775E-05	27506.6	1375.33
2096.64	55842.8	1.79074E-05	27921.4	1396.07
2206.64	58772.4	1.70148E-05	29386.2	1469.31
2352.21	62632.8	1.59661E-05	31316.4	1565.82
2647.64	67311.2	1.48564E-05	33655.6	1682.78

Figure 7 shows the relationship between conductivity and flow rate. Increase in flow rate increases the conductivity and vice versa. This is due to the fact that the water spends less time in the resin bed resulting in limited time for deionization.

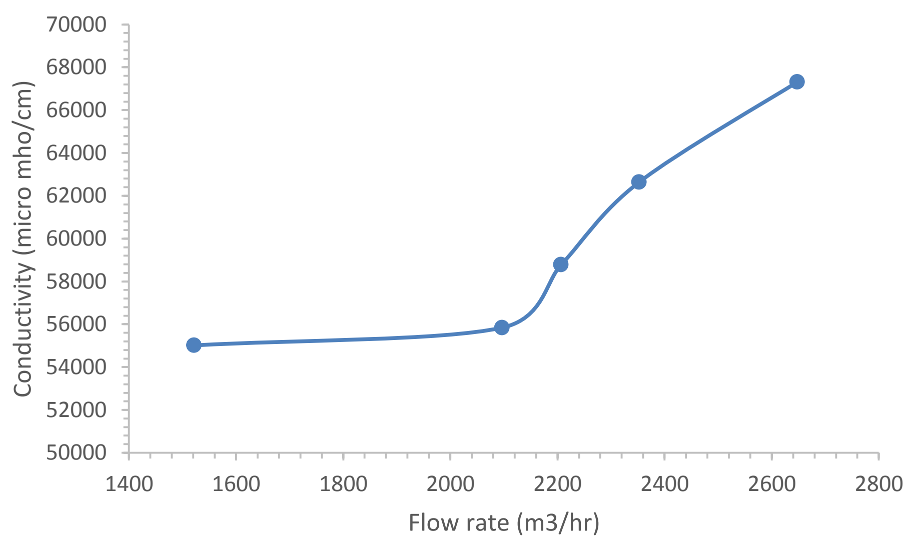

Figure 7: Graph of conductivity against flow rate.

International Journal of Academic Engineering Research (IJAER)
ISSN: 2000-001X
Vol. 2 Issue 4, April – 2018, Pages: 1-8

Figure 8 explains the relationship between resistivity and flow rate. Resistivity is the inverse of conductivity. Hence an inverse relationship exists between Figures 7 and 8. Increase in flow rate decreases the resistivity and vice versa.

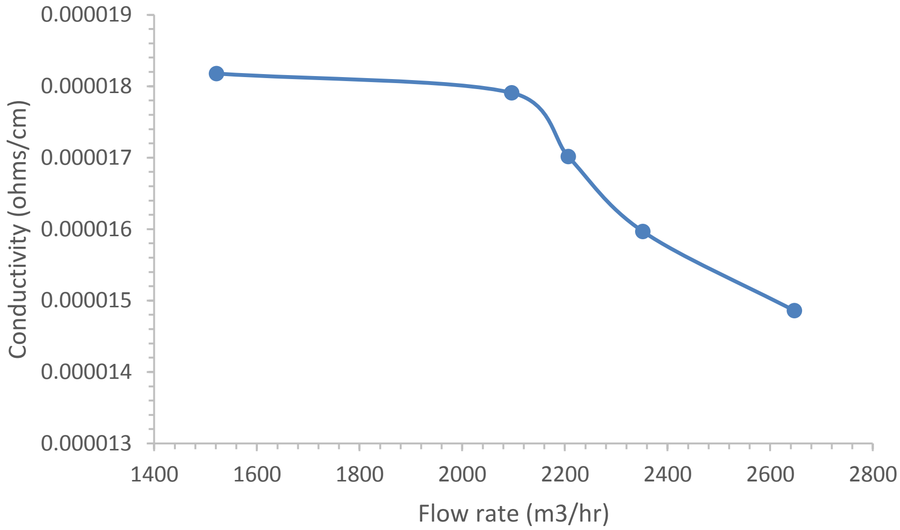

Figure 8: Graph of conductivity against flow rate.

Figure 9 is a graph that shows relationship between operational capacity and flow rate. Operational capacity is a measure of the ion removed per litre and serves as the evaluation parameter with which the efficiency of the device can be measured. The higher the operational capacity the lower the conductivity and higher the resistivity.

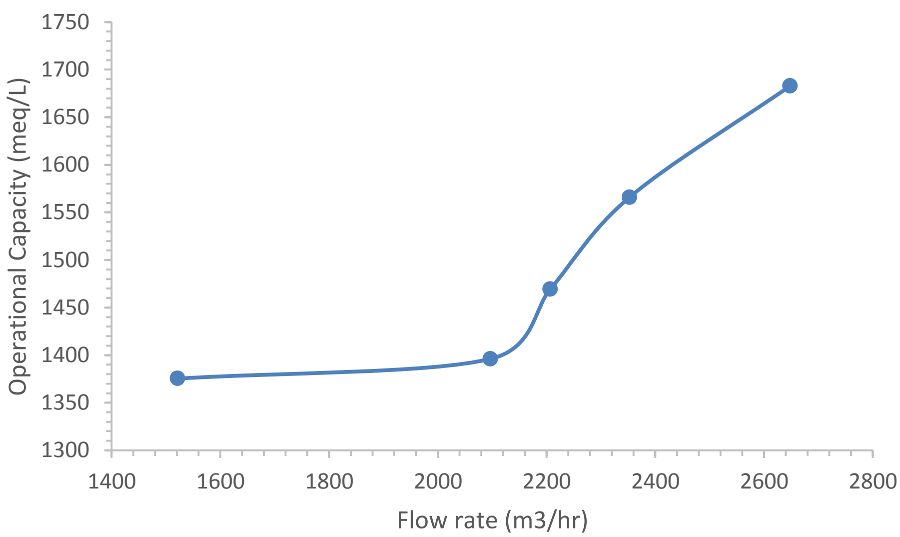

Figure 9: Graph of operational capacity against flow rate.

4. Conclusion

ISSN: 2000-001X
Vol. 2 Issue 4, April – 2018, Pages: 1-8

A deionizer limited to 40 l was designed and the model, fabricated. an optimum flow rate of fluid of 1521.45 m/s was found sufficient for the ion exchange during the water purification with the deionizer.

5. Recommendations

i. The work can be done on a larger scale for cost optimization.
ii. The test rig should be commercialized.
iii. There should be an increased awareness on this area of water purification so as to boost availability of portable water, most especially in local communities.

REFERENCES

Brown, M. M. (2003). "Clean Water an Agent of Change''. Choices 12(1):34.

Cairncross, S. (1990). ''Water Supply and Urban Poor". The Poor Die Young. Edited by Hardoy, J. E. et al., Earthscan Publication, London.

Cairncross, S. and Feachem, R. (1993). Environmental Health Engineering in the Tropic: An Introdcuction Text, 2nd Edition, John Wiley, London.

Dowdeswell, E. (1996). ''Editorial Comments on Water''. Our Planet, 8 (3):1.

Hall, A. S., Holowenko, A. R. and Laughlin, H. G. (1980). Machine Design Purdue University Press: 113-130.

Schirnding, Y. V. (2000). ''Health in the Context of Agenda 21 and Sustainable Development: Meeting the Challenges of the 21st Century, Sustainable Development International: Strategies and Technologies for Agenda Implementation, ICG Publishing Ltd., U.K.

Srivastava, A. and Prasad, R. (2000). Performance of a Diesel Generator Fuelled with Palm Oil. *Fuel Renewable Sustainable Revolution*. 4:105-140.

UNEP (2002). ''GEO 3 at a Glance-Fresh water''. Our Planet, 3(2):18.

UN (2002). ''Facts about Water". Facts Sheet. Johannesburg Summit 2002. Johannesburg, South Africa.

WHO and UNICEF (2000). Global Water Supply and Sanitation Assessment Report, WHO, Geneva.

WHO and UNICEF (2004). ''Joint Monitoring Programme for Water Supply and Sanitation; Meeting the MDG Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress, WHO, Geneva.