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DESIGN OF A PORTABLE TUBULAR FILTER PIPE FOR BOREHOLE WATER PURIFICATION SYSTEM

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ABSTRACT

The aim of this work is to design a portable tubular filter pipe for borehole water purification system. The materials used in the portable tubular filter pipe (sand layer depth of 0.15m of size 0.8 – 2mm and coarse gravel layer of 0.02m of size 5-8mm) were sourced locally. The coarse aggregate (gravel) layer served as support and distribution of water while the sand layer served as the filter medium. The diameter of the portable tubular filter pipe was assumed to take 4 inches PVC diameter pipe (0.1016m). The design reveals that the filter area is $0.0479m^2$, the flowrate in the filter is $8 X 10^{-5}m^3/s$, the filter volume is $0.02m^3$ and the headloss in the filter is 0.5m. Tests were carried out on borehole water and system filtered water. The results show that the portable tubular filter pipe performed relatively well in purifying borehole water. The model constructed for the tests was a prototype.

Keywords: *Design, Portable, Tubular-filter, Borehole, Purification*

INTRODUCTION

Water (H_2O) is a chemical compound formed from Hydrogen and oxygen. Water occupies a major part of the earth crust and is described as a universal solvent. Living things cannot exist without water. It takes about two-third of the human body. The two main sources of water are surface and underground water. Ground water is a major source of borehole water in most regions.

According to many literatures (Bilge, 2019; Cecen, 2011; Custodio, 2013; Chauhan and Talib, 2017; Edet, 1993; Etu-efeotor and Akpokogie, 1990; Fawell et al., 2006; Gleick, 1993; Kulshreshtha, 1998), untreated borehole water contains many impurities. Theses impurities consist of suspended particles (fine silts and clays), biological matter (bacteria, plankton, spores, cysts or other matter) and floc. Some of the dissolved impurities or substances (like Iron, Manganese, etc) in the water may result to bad taste, odour, turbidity, colour, hardness, and excessive carbon dioxide, corroding concrete and metal parts in the distribution system. Typical water treatment processes are shown schematically in Figure 1.

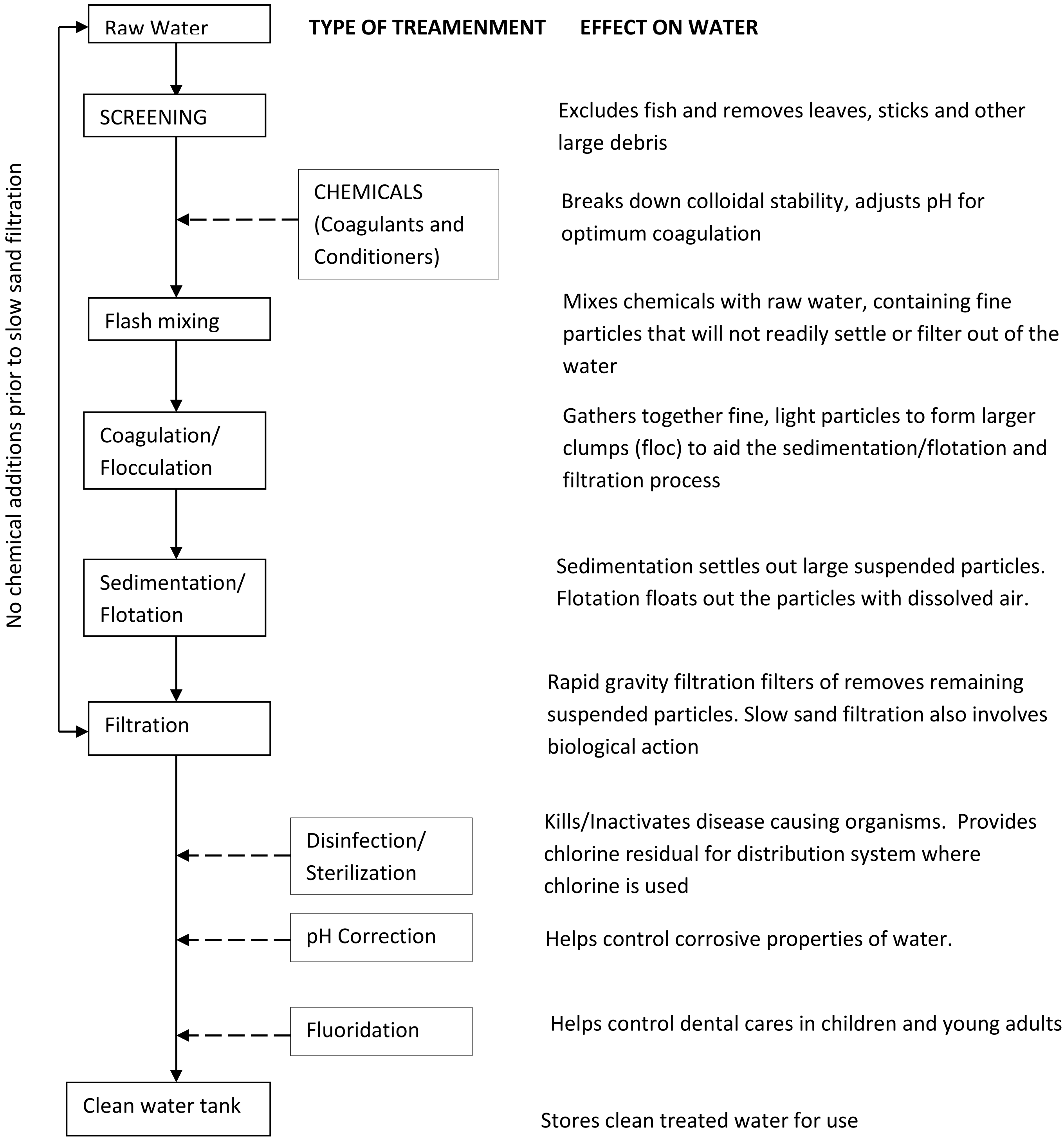

Figure 1: Typical water treatment processes (Noel et al., 1995)

Filtration is the process of passing water through material to remove particulate and other impurities, including floc, from the water being treated. The material used in filters for public water supply is normally a bed of sand, coal, or other granular substances like activated carbon. Filtration is a solid-liquid separation process in which the liquid passes through a porous medium to remove as much fine suspended solids as possible. Water or wastewater containing suspended matter is applied to the top of the filter bed. As the water (or wastewater) filters through the porous medium, the suspended matter in the fluid is removed by a variety of mechanisms. These mechanisms are: *Straining, Sedimentation, Impaction, Interception, Adhesion, Adsorption, Flocculation, Biological growth (Bilge, 2019).*

(i) **Straining:** Particles with pore space of filtering medium are strained out mechanically and also are trapped in filter by chance contact.

(ii) **Sedimentation:** Particles settle on the filter medium.

(iii) **Impaction:** Heavy particles will not follow the flow streamlines.

(iv) **Interception:** Particles moving along in the streamline are removed when they come in contact with the surface of filtering medium.

(v) **Adhesion:** Flocculants particles become attached to the surface of the filtering medium as they pass by.

(vi) **Adsorption (chemical or physical or both):** Once a particle has been brought in contact with the surface of the filtering medium or with other particles.

(vii) **Flocculation:** Large particles overtake smaller particles, join them, and form still larger particles. These are than removed by one or more of the above removal mechanisms.

(viii) **Biological growth:** Biological growth within the filter will reduce the pore volume and may enhance the removal of particles with any of the above removal mechanisms. Substances collected on the surface of the filter medium and available nutrient will result to organisms begin to grow on the surface of filter. A mat is formed containing slimy "*zoogleal*" organisms known as " *Schmutzdecke*". This helps in the straining action of the filter, but must be removed when the headloss through the filter is high. It is undesirable in rapid sand filter because it encourages formation of mud balls during backwashing.

According to *Bilge, 2019,* Filtration is classified as follows:

(i) ***ACCORDING TO ACTUAL FILTRATION OR NOT***

(a) ACTUAL FILTRATION (process by which the water is cleaned) or

(b) BACKWASHING (cleaning of filter medium).

(ii) ***ACCORDING TO DEEP FILTRATION OR NOT***

(a) DEEP BED FILTRATION (DEPTH FILTRATION) - Solids are removed within a bed of porous material. e.g. Rapid granular bed or

(b) CAKE FILTRATION – Particle removal occurs largely at the surface of the media through formation of a filter cake e.g. Pre-coat filtration (diatomite, diatomaceous earth) Slow sand filters

(iii) ***ACCORDING TO TYPE OF GRANULAR MEDIUM USED***

(a) SINGLE MEDIUM (SAND OR ANTHRACITE)
(b) DUAL MEDIA (ANTHRACITE AND SAND)
(c) MULTIMEDIA (ANTHRACITE, SAND, GARNET)
Dual media filters are better, having longer filtration run and available pore volume is maximum at the top of filter and gradually decreases to a minimum at the bottom of filter.

*(iv) **ACCORDING TO FLOW THROUGH MEDIUM***

(a) GRAVITY FILTERS: They are open to the atmosphere. Flow through the medium is achieved by gravity.
(b) PRESSURE FILTERS: Filter medium is contained in pressure vessel. Water is delivered to the vessel under pressure.

*(v) **ACCORDING TO RATE OF FILTRATION***

(a) RAPID SAND FILTERS
(b) SLOW SAND FILTERS

*(vi) **ACCORDING TO FILTER FLOW CONTROL SCHEME***

(a) CONSTANT RATE (constant head or variable head)
(b) DECLINING RATE (constant head or variable head)

A number of properties of filter media are important in affecting filtration performance. These are size, size distribution, slope, density and porosity

- ***Grain size and size distribution***

The smaller the size of granular media, the smaller the pore openings through which the water must pass. Small pore openings increase filtration efficiency. Uniform granular media will permit deeper penetrations of floc better utilization of the storage capacity of the bed. Moreover; during backwashing (cleaning of media with water in reversal direction of flow) bed of nonuniform medium will stratify with smaller particles→ smaller pore openings at the top.

The size of filter media is specified by EFFECTIVE SIZE. The uniformity of filter media is specified by UNIFORMITY COEFFICIENT. Effective size (d_{10}) and Uniformity coefficient (d_{60}/d_{10}) are determined by SIEVE ANALYSIS.

- **Grain Shape**

The shape of filter grains is important because it effects

(i) Backwash flow requirement of medium
(ii) Fixed bed porosity
(iii) Headloss for flow through medium
(iv) Filtration efficiency
(v) The ease of sieving

- **Sphericity and Porosity**

One useful measure of shape is sphericity (ψ) *(Bilge, 2019)*. Sphericity is given by

$$\boldsymbol{\psi} = \frac{\text{surface area of sphere having same volume with particle/Vs}}{\text{surface area of particle/Vp}} \qquad (1.1)$$

Since Vs = Vp

$$\boldsymbol{\psi} = \frac{\text{surface area of sphere having same volume with particle}}{\text{surface area of particle}} \qquad (1.2)$$

This implies that $\frac{A_p}{V_p} = \frac{6}{\psi d}$ (1.3)

(Where s represents sphere and p is particle, V is volume, A is area and d is diameter). As the particles become less spherical, porosity of a given volume increases. Porosity depends on how well particles fit together. Porosity could be fixed bed porosity (compacted – bed porosity) or Loose bed porosity.

The aim of this work is to design a portable tubular filter pipe to purify the untreated borehole water from the aeration tank before sending it to the treatment tank or to purify further the treated water from the water treatment tank in a water purification system. Figure 2 shows a typical borehole water purification system. The raw water from the ground (borehole) is taken by a water pump (submersible or surface) and it is sent to the open tank (aeration tank) through the open air for oxidation of iron and manganese. The water found in the open tank is toxic and contaminated as it is untreated. The untreated water from the open tank is sent to the treatment tank by gravity fall. The treatment tank contains sand, activated carbon and gravel in layers from the top to the bottom. The treatment tank is also chlorinated for further disinfection. Valves are attached at various points to control flow rate and direction. The efficiency in choosing the treatment techniques depends on the efficiency in reducing turbidity (97-99%), removal of viruses and bacteria (pathogens and protozoa) and other objectionable tasks and odor. Figure 3 shows the possible positions of the proposed portable tubular filter pipe (F). It is either placed immediately after the aeration tank for purification of the untreated water from the aeration tank before the treatment tank or it is placed after the treatment tank for further purification.

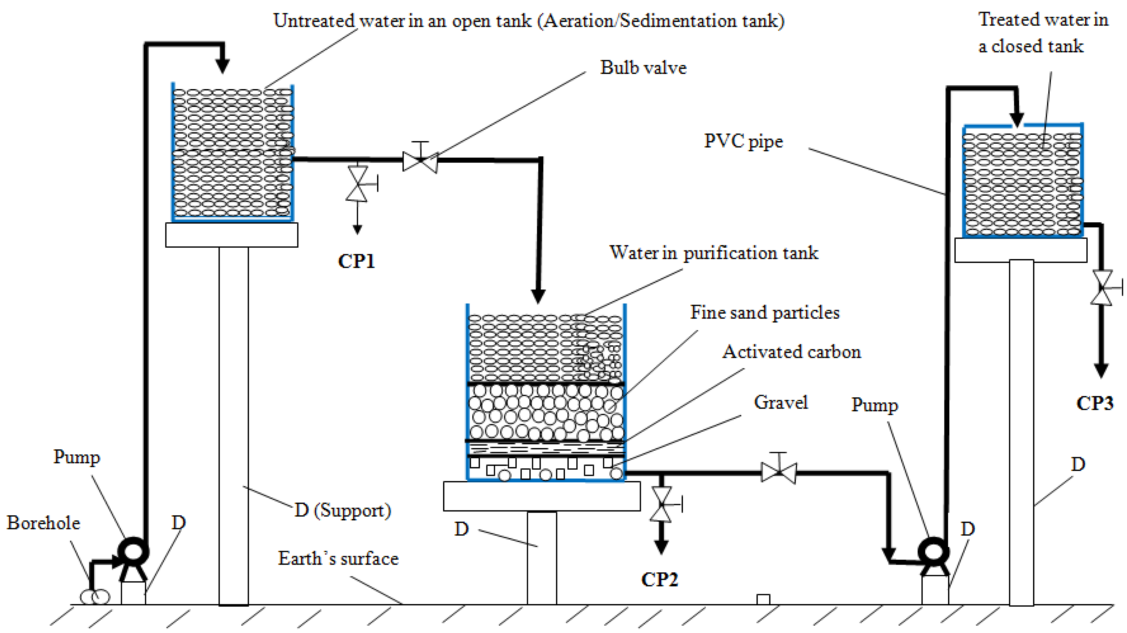

Figure 2: A simplified diagram of a borehole water purification system. CP1, CP2 and CP3 are water collection points. D is a support or stand.

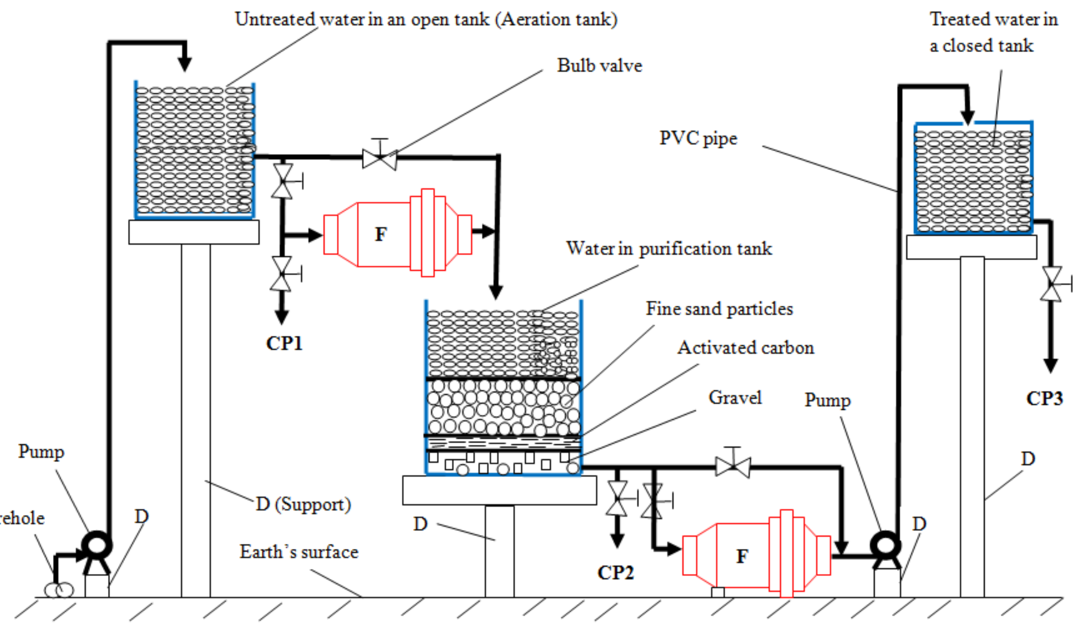

Figure 3: A simplified diagram of a borehole water purification system showing the possible positions of the portable tubular filter pipe (F).

MATERIALS AND METHOD

Reviewed literatures to the design of the portable tubular filter pipe

In determining the size and the filtration rates of the filter bed, a review of relevant literature from journals, scientific reports, and academic texts on similar research projects was done [Adekunle and Adejuyigbe, 2012; Mc Cabe et al., 2001; Muna, 2008; Perry et al., 1997; Schmoll et al., 2006; Sharker, 2019; Stephen et al., 2017; WJS, 2014; WHO, 1998 & 2006].

Assumptions for the design

The diameter of the portable tubular pipe is assumed to be the diameter of a 4 inches PVC pipe. The filtration minimum media depth [height] was determined using the Hudson formula to avoid breakthrough of floc as given by Stephen et al., (2017).

$$\frac{Qd^3h}{L} = B_i \text{ X } 29323 \quad (2.1)$$

Where

Q – Filtration rate ($m^3/m^2/h$)

L – Depth of filter bed (m)

h – Terminal head loss (m)

d - Sand size (mm)

Bi – Breakthrough index whose value ranges between 0.0004 to 0.006 depending on response to pre-treatment in the filter unit (dimensionless).

The following assumptions were also made to determine the minimum sand bed depth, L:

(i) Bi = 4×10^{-4} for poor response to filtration and average degree of pretreatment and;

(ii) Terminal head loss = 0.25 m as given by Stephen et al., (2017).

From the effective sand size determined, the depth was checked against breakthrough of floc by calculating the minimum depth required.

Aeration-sedimentation tank calculations

This calculation determines the volume of the aeration-sedimentation tank, (V) in order to achieve a retention time, (t) of 30 minutes having a maximum flow rate, (Q) of 16 l/min.

$$V = Q \times t \qquad (2.2)$$

$$V = 16 \times 30 = 480\ L = 0.48\ m^3$$

Hence, the required size of the aeration-sedimentation tank should be approximately 0.5 m^3.

Water from the aeration-sedimentation tank will flow by gravity to the portable tubular filter pipe when full using the valves as appropriate. The filter area has the capacity to accept water flow from the aeration-sedimentation tank as calculated below. The first layer to receive the water is coarse aggregate [gravel] layer with grain size 5-8 mm with a bed depth of 0.02m and the second layer to receive the water is sand layer with grain size 0.8-2 mm with bed depth 0.15 m and the third layer is coarse aggregate [gravel] layer with grain size 5-8 mm with a bed depth of 0.02m. The water moves by downward flow through the layers from top to bottom by gravity to the outlet tap at the bottom part of the portable tubular filter pipe thus discharging the treated water. The gravel layers at the top (1^{st} layer) and bottom layer (3^{rd} layer) help as support and distribution of water, therefore, the effective filter diameter used in design is that of the sand layer, effective diameter (d) is 4 inches PVC diameter pipe (0.1016m)

Filter capacity calculations

The flow out from the aeration-sedimentation tank or any pretreatment unit is equal to the flow that enters the Portable tubular filter pipe, therefore,

$Q_{in} = Q_{out}$ (2.3)

$Q_{in} = 16$ l/min $= 0.016$ m^3 /min $= 2.67 \times 10^{-4}$ m^3 /s

The formula for flow rate through the filter media which is dependent on the filter:

Area, (A) is given by Darcy's equation Stephen et al., (2017):

$Q = k \times A \times I$ (2.4)

For vertical flow rate the hydraulic gradient, i, is 1 which gives;

$Q = k \times A \times 1 = k \times A$ (2.5)

The hydraulic conductivity, k, for sand size ranging between medium and very coarse according to Stephen et al., (2017) is:

$k_{ave} = 5.00 \times 10^{-3}$ m^{-3}/s

The hydraulic conductivity is divided by a safety factor of 3 due to clogging of the filter thus giving:

$K_{ave} = \frac{5.00 \text{ X}10^{-3}}{3} \text{m/s} = 1.67 \text{ x } 10^{-3}$ m/s

The filter area is tubular and is given by

$A = 2\pi rl = 2\pi \frac{D}{2} l$ (2.6)

Where, r = radius, D = diameter = 0.1016m and l = the sand filter depth = 0.15m

This implies that $A = 2\pi rH = 2\pi \frac{D}{2} h = 2 \ x \ 3.1428 \ x \ \frac{0.1016}{2} \ x 0.15 = 0.0479 \ m^2$

With the filter area, A = 0.0479 m^2 and then using Darcy's equation to calculate the flow rate of the portable tubular filter pipe

$Q = k \times A = 1.67 \times 10^{-3}$ x 0.0479 = 8×10^{-5} m^3 /s

This flow rate of the portable tubular filter pipe is smaller than the flow rate of the aeration/sedimentation tank (2.67 x 10^{-4} m /s).
Therefore, the size of the filter is adequate and thereby enabling the filter unit delivers the same amount of water as the hand pump.

Sand bed depth

Stephen et al., (2017) recommended a sand bed depth of 20 cm and effective sand size of 1.4 mm. The sand bed depth was checked against breakthrough of floc through the bed by calculating the minimum depth required. The minimum depth of sand required to avoid breakthrough of floc is 13.5 cm. Hence the sand depth used in this work is 15cm (0.15m).

Filtration component head loss calculations

Darcy's law was then used to calculate the head loss in the filter as follows:

$$Q = k.A \frac{\Delta h}{\Delta L} \quad (2.7)$$

$$\Delta h = \frac{Q \Delta L}{K.A} \quad (2.8)$$

For design purposes and simplicity, the calculations were based on filter media consisting of one layer [design scenario is sand with grain size of 1.4 mm] and L being the sand bed depth. The area, (A); the flow rate, (*Q*) and hydraulic conductivity, (k).
With A = 0.0479 m^2, Q = 2.67 × 10^{-4} m^3 /s, k = 8 × 10^{-5} m^3 /s and L = 0.15 m, the head loss is:

$$\Delta h = \frac{2.67 \times 10^{-4} \times 0.15}{1.67 \times 10^{-3} \times 0.0479} = 0.5m$$

Filter volume calculations

For the effective working of the filter, a filter surface area of 0.0479 m^2 is necessary to deliver filtered water at a rate of approximately 8 $\times 10^{-5}$ m^3 /s assuming the guidelines on head and filter sand size/depth are adhered to. Given a head loss of 0.5 m, the portable tubular filter pipe will be able to deliver treated water as follows:

Volume, V = 0.5 m × 0.0479 m^2 = 0.024m^3

The design drawing for the proposed small scale tubular filter media is shown in figure 4

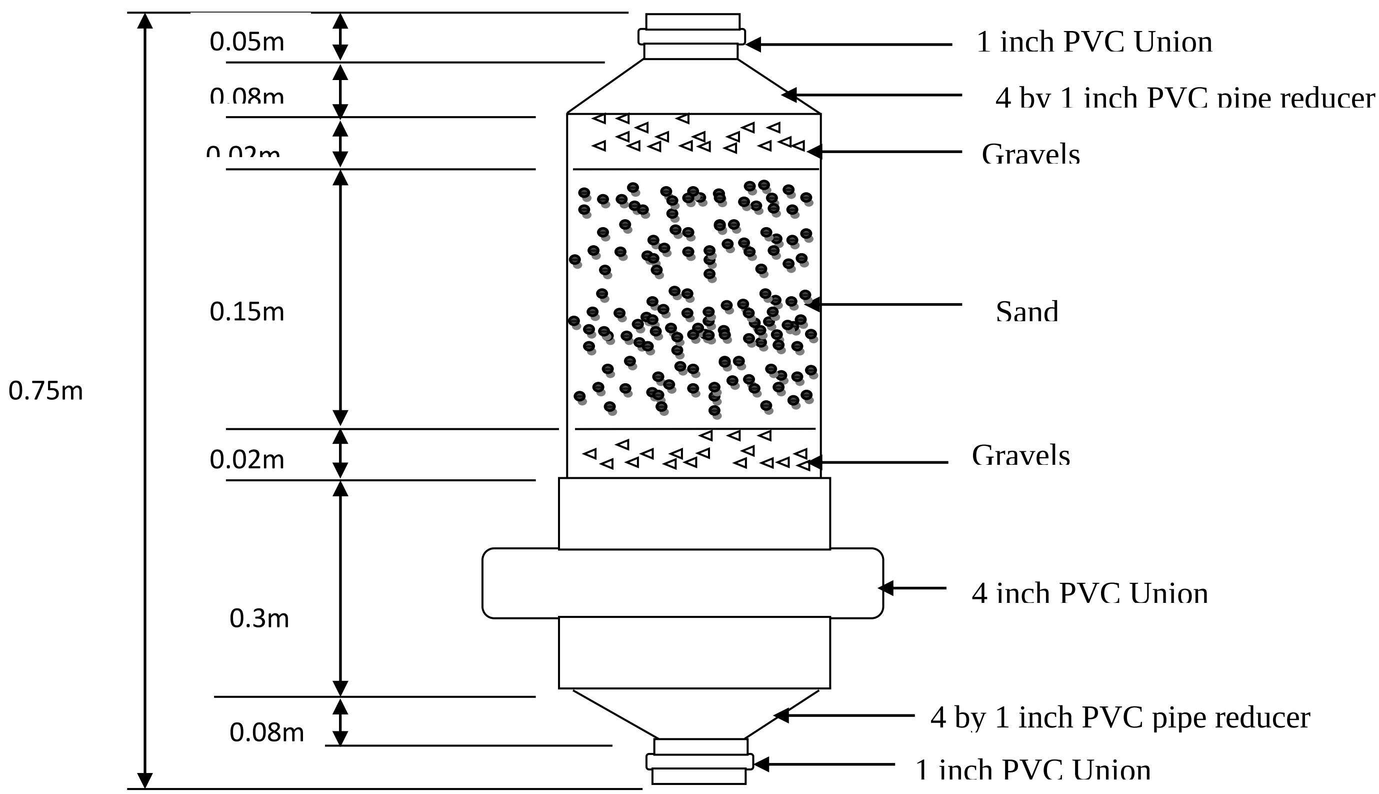

Figure 4: The design drawing of the Portable Tubular Filter Pipe

RESULT

Groundwater Test and Result

The purification process went through various tests to know the level of purity that has been achieved and the results are also compared with world Health organization (WHO) standards for water purification (WHO, 2006). Table 1 shows the results of water samples from the borehole (raw groundwater).

Table 1: Results from raw groundwater sample

S/N	Parameters	P/C Analysis	WHO Standard	Unit
1	General Appearance	Not clear with particles	_____	_____
2	Taste	Objectionable	Unobjectionable	_____
3	Odor	Objectionable	Unobjectionable	_____
4	Temperature	30°C	Ambient	° Celsius
6	Turbidity	2.91	5	NTU
7	P^H Value	6.02	6.5 – 8.5	_____
8	Colour	Brown	_____	_____
9	Total Hardness	123.40 (mg/l)	100	Mg/l
10	Total Alkalinity	41.06	200	Mg/l
11	Total iron	1.22	0.4	Mg/l
12	Total Dissolved solid	118.03	1000	Mg/l
13	Total solid	130.04	500	Mg/l
14	Total suspended solid	12.01	25	Mg/l
15	Chloride	0.00	25	Mg/l
16	Calcium (ca^{2+})	10.42	75	Mg/l

Purified water (without the use of the Portable Tubular Filter Pipe) Test and result

The purified water is also tested in the laboratory to know if it meets up with 'WHO' standard of purified water (WHO, 2006). Table 2 shows the outcome of the results.

Table 2: Results from Treated groundwater sample

S/N	Parameters	P/C Analysis	WHO Standard (maximum permit)	Unit
1	General Appearance	Clear	Clear	____
2	Taste	Unobjectionable	Unobjectionable	____
3	Odor	Unobjectionable	Unobjectionable	____
4	Temperature	25°C	Ambient	° Celsius
5	Electrical Conductivity	24.03	1000	Ms/Cm
6	Turbidity	0.00	5	NTU
7	P^H Value	7.48	6.5 – 8.5	——
8	Colour	Colourless	15	TCU
9	Total Hardness	18.26 (mg/l)	100	Mg/l
10	Total Alkalinity	13.06	200	Mg/l
11	Total iron	0.01	0.3	Mg/l
12	Total Dissolved solid	15.07	1000	Mg/l
13	Total solid	10.40	500	Mg/l
14	Total suspended solid	0.01	25	Mg/l
15	Chloride	6.33	250	Mg/l
16	Calcium (ca^{2+})	10.42	75	Mg/l

Purified water (with the use of the Portable Tubular Filter Pipe) test and result

The final stage of this work was carried out with the use of **the Portable Tubular Filter Pipe** and the result coupled together is shown in the table 3.

Table 3: Results from Treated groundwater sample with the Portable Tubular Filter Pipe

S/N	Parameters	P/C Analysis	WHO Standard (maximum permit)	Unit
1	General Appearance	Clear	Clear	
2	Taste	Unobjectionable	Unobjectionable	_____
3	Odor	Unobjectionable	Unobjectionable	_____
4	Temperature	25°C	Ambient	° Celsius
5	Electrical Conductivity	10.03	1000	Ms/Cm
6	Turbidity	0.00	5	NTU
7	P^H Value	7.00	6.5 – 8.5	_____
8	Colour	Colourless	15	TCU
9	Total Hardness	11.22 (mg/l)	100	Mg/l
10	Total Alkalinity	10.06	200	Mg/l
11	Total iron	0.01	0.3	Mg/l
12	Total Dissolved solid	10.07	1000	Mg/l
13	Total solid	5.40	500	Mg/l
14	Total suspended solid	0.01	25	Mg/l
15	Chloride	5.33	250	Mg/l
16	Calcium (ca^{2+})	9.42	75	Mg/l

DISCUSSION

Table 1 shows the results of water samples from the borehole (raw groundwater). Table 2 shows the outcome of the results after treatment but without **the Portable Tubular Filter Pipe**. Table 3 contains the result of the purification system with **the Portable Tubular Filter Pipe**. It is very clear as one compare and study the results from the tables 1-3 that the quality of the treated water with **the Portable Tubular**

Filter Pipe show an improvement. More study will be done and reported in the next work for how long it will take for **the Portable Tubular Filter Pipe** to be cleaned or renewed.

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