Evaluation of the Hydraulic Conductivity and Water Quality of a Natural Water Purifier using Ceramic Waste Aggregate as Filter Layer

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Abstract

The ceramic industry is known to generate large amounts of wastes each year. So far a huge part is used in landfills. Reusing these wastes in water filtration could be a profitable and eco-friendly aspect. The project focuses on the improving the quality of water by using the ceramic layer in the filter medium and to obtain an optimal Hydraulic Conductivity for the filter medium. For the determination of water quality, four tests have been assessed which are pH, Turbidity, Dissolved Oxygen, and Total Dissolved Solids. Four Samples of Filtered water are examined with the different ceramic concentration of 0, 12.5, 25 and 40 percentage in the filter medium of the water purifier in each case and the Hydraulic Conductivity with the addition of ceramic is tested in Constant Permeability Head Apparatus. Test results have shown with the addition of ceramic, the quality of water has been improved under low temperature and an optimum value of Hydraulic Conductivity is obtained under the desired range for a filter medium of a water purifier.

Keywords — *Ceramic; Hydraulic Conductivity; Constant Permeability Head Apparatus; Turbidity; Dissolved Oxygen; Total Dissolved Solids; pH ; Water Purifier*

1. INTRODUCTION

In this latest generation economic scenario, profit making societies are asked to mitigate undesirable impacts of their activities on the environment. This is particularly right for those industrial organizations which generate harsh and adverse global environmental impacts. Ceramic industries produce a large amount of wastes which are discarded and unprocessed without any further treatment. These solid waste lead to severe environmental pollution, degradation, and significant land occupation [2] .The ability to cope with these wastes depends on the sector and geographic location of the industry, availability of resource, size of the company and strategic attitude. A Huge amount of ceramic waste materials in the form of powder and pellets is produced in different stages such as cutting, grinding, polishing and dressing inside the industrial plant. They lead to severe environmental harsh effects and problems. Natural resources are facing a decline with time due to excessive use. It is worth noticing that the progress in Environmental Technology Advancement might be a useful way to reduce the use of natural resources by recycling the ceramic wastes coming out from the industries. Recycling and reuse of waste materials help in cost reduction, energy saving, possible superior products and less or no hazards to the surrounding environment. Ceramic waste materials may have a profitable effect if used in the filtration of water because ceramics are resistant to corrosion, abrasion and have high chemical resistance, making them suitable for engineering applications that require filtration of challenging media. Ceramic materials have water attaching properties that can be adjusted for specific applications by tailoring their surface zeta potential through the material chemical composition. A better hydrophilic membrane material will promote the clean water flow through its structure while repelling other fluids, such as gelatinous and oily liquids. This improves the rate of filtrate through the membrane and enhances its selectivity properties. Additionally, newly developed ceramic membranes can achieve great and sustainable compactness due to their versatility in structure. These design specifications also contribute to the energy efficiency of such systems. Environmentally, it is a fact that by recycling ceramic waste, landfilling is reduced while more natural resources are protected. Therefore, the integration of this stable ceramic waste for some useful applications like in Aquifer layer or in filtration of water may offer economic, technical as well as environmental benefits.

II. PREPARATION OF FILTER MEDIA

It's a description about the various quantities of materials that are needed to make the filtration system. The materials that are used for making the system in the first case where the filtration system does not involve the use of ceramic and is a miniature version of the groundwater aquifer. It involves layers of filter cloth (10micro pore size), activated charcoal of (600IV,0.5-1mm), Filter Sand (0.6-1mm), gravel

(3-10mm), silex (0.5mm), Ceramic (15mm), course aggregate (3-4mm), Pebbles (6-12mm) in the same sequence as they have been mentioned above.

Fig 1: Filter Media

The other three samples require the application of ceramic with different percentages of it being used with respect to the overall weight of ceramic taken at the start. The second sample involves the usage of 12.5% of ceramic and then the third sample has 25% of the ceramic, and fourth sample has 40% of ceramic. The addition of ceramic has been done in each of the samples has been done right after the placing of the second filter paper in the filtration system. A tabulation describing the sequence of addition of materials, and the quantity of materials added is given in it:

Table I

Filter Media Specification

Filter Media	***Size (mm)***	***Thickness (mm)***	***Sample 1(No ceramic) (kg)***	***Sample 2 (ceramic-12.5%) (kg)***	***Sample 3(ceramic-25%) (kg)***	***Sample 4(ceramic-40% (kg)***
Filter Cloth	0.01	0.5	0.001	0.001	0.001	0.001
Activated Charcoal	600IV 0.4-1	70.0	0.798	0.798	0.798	0.798
Filter Sand	0.6-1	20.0	1.517	1.517	1.517	1.517
Gravel	3-10	10.0	1.676	1.676	1.676	1.676
Silex	0.50	50.0	4.6531	4,6531	4.6531	4.6531
Filter Cloth	0.01	0.5	0.001	0.001	0.001	0.001
Ceramic	15.0	5-15	0	0.358	0.700	1.120
Gravel	3-10	5-10	1.676	0.838	0.496	0.100
Course Agg.	3-4.0	60.0	3.740	3.740	3.740	3.740
Gravel	3-10	10.0	1.676	1.676	1.676	1.676
Pebble	6-12	60.0	4.000	4.000	4.000	4.000

III. PREPARATION OF HYDRAULIC CONDUCTIVITY MEDIA

It's a description about the various quantities of materials that are needed to make the Hydraulic Conductivity media. It involves layers of Hydraulic Conductivity media described from bottom to top layer of the media which are activated charcoal of (600IV,0.5-1mm), Filter Sand (0.6-1mm), Gravel (3-10mm), Course Aggregate (3-4mm), Gravel (3-10mm), Ceramic (15mm), Gravel (3-10mm), Pebbles(6-12mm). The table below describes the layer arrangement of the Hydraulic Conductivity Media along with the thickness and weight of each layer

Table II

Hydraulic Conductivity Media Specification

Hydraulic Conductivity Media	***Size (mm)***	***Thickness (mm)***	***Weight (kg)***
Activated Charcoal	600IV 0.4-1	25.6	0.291
Filter Sand	0.6-1	7.3	0.533
Gravel	3-10	3.67	0.615
Course Agg.	3-4.0	5.00	0.398
Gravel	3-10	3.67	0.615
Ceramic	15.0	22.0	1.371
Gravel	3-10	3.67	0.615
Pebble	6-12	39.0	2.550

IV. WATER QUALITY TEST

A. ph Test

The determination of pH of all these samples has been done with the help a pH meter. First, there is need to calibrate the instrument with a standard solution of known pH .We took a standard sulphuric acid solution of (pH -3) and the after calibration the value of pH meter is set to standard by calibration scale provided on the device, by placing the filtrate in the flask and then placing the electrode into the filtrate the device gives the value of pH on the scale. Thus we obtained the pH value of all samples.

B. Turbidity

The device that has been used for the above is a turbidity meter. The device needed to be calibrated and so we used for that purpose a standard formazin solution (40NTU) which was prepared as follows-

1 gm of hydrazine sulphate was diluted to 100ml, 10gm of hexamethylene Tetramine was taken and diluted to 100ml.Now we mixed 5ml of each of the two mentioned solutions in 100ml volumetric flasks and allowed it to stand for 24hrs at about 25

and dilute it to 1000ml. This has a turbidity of 40NTU.

C. Dissolved Oxygen

For determination of DO of the filtrate samples the following procedure is followed:

*1) **Preparation of Manganous Sulphate Solution:*** It requires the dissolution of 48gm of $MnSO_4.4H_2O$ in distilled water and dilutes to 1000ml.

*2) **Preparation of Alkali Azide Iodide Reagent:*** It requires the use of 70gm of KOH and 13.5gm of NaI and dilutes to 60ml. Add 1gm of Sodium Azide (NaN_3) dissolved in 40 ml of distilled water.

*3) **Preparation of Standard Sodium Thiosulphate Solution:*** We dissolve 6.205gm of Sodium Thiosulphate ($Na_2S_2O_3.5H_2O$)in freshly boiled and cooled distilled water and dilute to 1 liter .We preserve it by an addition of 5ml of chloroform or 0.4gm of NaOH/L.

*4) **Procedure:***

We took a standard BOD bottle of 300ml capacity and filled it with filtrate samples completely then placed the stopper of BOD bottle and remove the excess sample. Removed the stopper and added 2ml of $MnSO_4$ followed by 2ml of alkali iodide Azide solution. The stopper was placed again and the air bubbles were excluded by inverting of the bottle many times. We allowed the precipitate to settle sufficiently (approximately half of the bottle) to give a clear supernatant above the manganous hydroxide floc. Now add 2ml of concentrated sulphuric acid and we put the stopper back, the solution is mixed thoroughly by inverting it several times until dissolution was completed. Then we took 203ml of the sample into the conical flask and titrated the sample using standard sodium thiosulphate solution until solution attains a pale straw yellow color was obtained. We added few drops of starch indicator and continued the titration until the blue color disappears. We noted down the value of Sodium Thiosulphate solution consumed and that gives the value of Dissolved Oxygen in filtration samples.

Calculation of the Dissolved Oxygen is done by the formula:

$$D.O. = \frac{0.2 * 1000 * \ ml\ of\ Na_2S_2O_3 consumed}{203}$$

D. Total Dissolved Solids

The value of the Total Dissolved Solids was measured by a TDS meter device is works on the principle of determination of electrical conductivity which thereby gives the quantity of TDS. This was done by simply placing the device into the sample and the device gave the value of TDS. The tabulation below shows the results of the water quality tests of the samples.

Table III

Water Quality Test

Experimental Sample	***pH***	***Turbidity (NTU)***	***Dissolved Oxygen (mg/l)***	***Total Dissolved Solids (ppm)***
Standard Drinking Water	6.5-8.5	≤ 5.0	5-9	0
VIT Tap Water	6.2	5.0	7.68	0
Water Filtered Sample-1 (No ceramic)	6.7	3.0	8.07	0
Water Filtered Sample-2 (12.5% ceramic)	6.95	2.6	9.14	0
Water Filtered Sample-3 (25% ceramic)	7.01	2.3	9.13	0
Water Filtered Sample-4 (40% ceramic)	7.02	2.3	9.13	0

The following column diagram depicts the change in values of the water quality tests carried on the samples. Hence it would give an insight of how much change is required to improve the quality of water into drinkable standards.

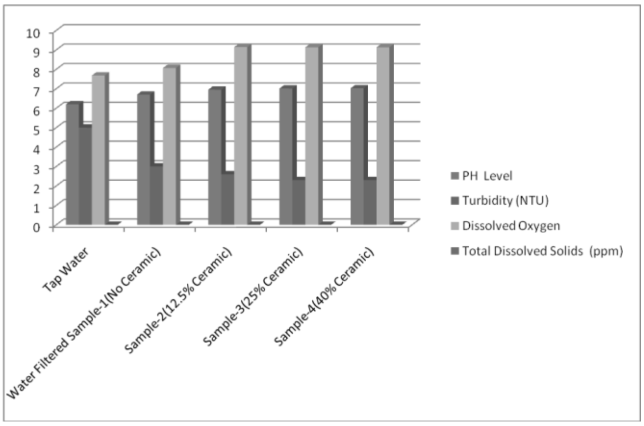

Fig 2: Column Diagram of the Water Quality Test

In the Fig. 2. The First bar from the left represents the pH Level which is at 6.2 for VIT tap water. After the addition of ceramic the pH Level rises to 7.02 at Sample 4 with 40% ceramic addition. Beyond which the pH level remains a constant indicator. The Middle bar represents the Turbidity (NTU) which is at 5.0NTU for VIT tap water. After the addition of ceramic, the Turbidity goes on decreasing up to 2.3NTU at Sample 4, beyond which it undergoes no change in the value after the addition of ceramic. The Light Grey bar represents the Dissolved Oxygen which is at 7.68 mg/l for VIT tap water. After addition of ceramic, it rises initially till Sample 2 at 9.14 mg/l then with the further addition of ceramic it undergoes a decrease in Dissolved Oxygen value to 9.13 mg/l at Sample 4 with 40 %

ceramic addition. Beyond which the Dissolved Oxygen value remains fixed. The Last bar represents the Total dissolved solids. In this case, the Total Dissolved solids for the entire experiment is found to be 0 i.e. the water in VIT has no dissolved solids in it thus indicating free of organic matter in the water. Since the organic matter has high reactivity they can form by-products that do not contain nutrients can be made and have the capability of inducing biofouling which can clog the water filtration system in water purification as these by-products are larger than the membrane pore size. But clogging can be treated with the addition of chlorine as a disinfectant which can break down the residual matter the clogs the filter medium. However, these may also lead to the production of disinfection by-products which is not recommended for a good water quality.

V. DARCY'S LAW

Darcy's (1856) law forms the foundation of quantitative groundwater hydrology and was given by the French hydraulic engineer Henry Darcy [5]. It states that the velocity of flow (v) through a porous medium is directly proportional to the hydraulic gradient, i.e.

$$v \alpha - \frac{dh}{dl} \approx -\frac{\Delta h}{\Delta l} \qquad (1)$$

Where the $\frac{\Delta h}{\Delta l}$ refer to gradient of definite difference in the head and the distance along the flow direction or

$$v = -k \frac{dh}{dl} \qquad (2)$$

where k is the constant of proportionality known as the hydraulic conductivity (m/d) in the direction of flow, and v is Darcy's velocity. The rate of flow across the area A can, therefore, be expressed as:

$$Q = vA = -kA \frac{dh}{dl} \qquad (3)$$

Darcy's Law is valid only for laminar flow, whose limit is defined by R_e<10, where Reynold's number $R_e = vd_{10}/v$, where d_{10} is the average mean grain diameter of the porous media (90% retained on the sieve) and v is the kinematic viscosity of the water (=0.01cm^2/s at 20^{O}c).

The above table depicts the Hydraulic Conductivity (m/d) of some common materials.

Table IV

Hydraulic Conductivity (m/d) of common materials	
Material	***Range***
Lime Stone	0.0000004-0.00008
Sand Stone	0.00012-1.2
Clay	0.00004-0.04
Silt	0.04
Very Fine Sand	0.4-4
Fine Sand	4-40
Medium Sand	40-100
Coarse Sand	180-260
Very coarse sand	260-320
Very fine gravel	320-450
Fine Gravel	450-640
Medium Gravel	640-900
Coarse Gravel	900-1200
Very coarse gravel	1200-1600

Table V

The table below depicts the hydraulic conductivity (m/d) of an aquifer considering the various layers of aquifer formation.

Hydraulic Conductivity (m/d) of Aquifer Formation	
Aquifer formation	***Hydraulic Conductivity (m/d)***
Clay soil (surface)	0.01-0.2
Deep clay bed	10^{-8}-0.01
Loam soil	0.1-1
Fine Sand	1-5
Medium Sand	5-10
Coarse Sand	20-100
Gravel	100-1000
Sand+gravel mix	5-100
Clay+sand+gravel mix	0.001-1
Sand Stone	320-450

The Sand + gravel mix is the ideal aquifer layer formation with hydraulic conductivity ranging from 5-100 m/d. Hence the water filter media should have closer value to the range of the Sand + gravel mix.

VI. HYDRAULIC CONDUCTIVITY TEST

It is done by a device called the constant head permeameter .It has a cylindrical glass tube filled with the sample to be tested. Hydraulic head is maintained constant across the tube. The flow rate across such a sample is given by Darcy's Law. The procedure involved in the above is as follows:

We noted down the dimensions of the permeability mould. We took a miniature version of our filtrate samples in the mould by scaling them by say (1/5th). We placed a filter paper on the top of the soil and then a porous stone was placed for the purpose of compaction of the soil. The top plate and base plate was secured by suitable clamps and rubber gaskets to make the entire assembly in the entire assembly watertight. See Fig.2. [3]

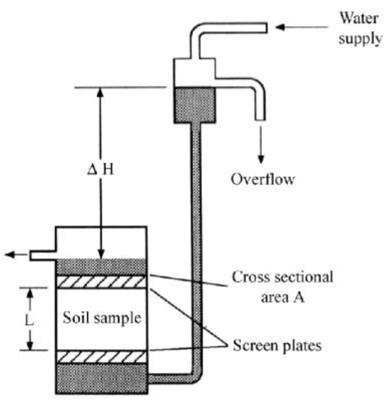

Fig 3: Constant Head Permeameter

We placed the assembly in a shallow metal tray with an outlet. The tray was then filled with water to submerge the base plate completely. The constant head water tank as then attached with sliding bucket to a vertical stand. One of the openings was connected to the water supply source, the second to an overflow rate and the third to the inlet valve provided on the cap of the permeameter. The sample was then allowed to saturate. This was checked by getting concordant values of discharge collected over a given time under a given head. This was done to make sure that the sample was fully saturated. After that, we recorded the time required to collect sufficient quantity of water (20-30ml) using a 100ml container. The coefficient of hydraulic conductivity was measured by the formula:

$$k = \frac{QL}{Aht} \quad (4)$$

Where k is the coefficient of permeability (hydraulic conductivity), Q is the measured discharge, A is the cross- sectional area of the filtration specimen, t is the time taken for collection and h is the head causing the flow [1].
Sample cores can be taken from 3 to 4 depths of the aquifer, can also be taken in any direction if the bore hole is a large diameter. It is important that no air is entrapped in the system. Use of desired water and saturating the sample from below is recommended. When saturated from below, water moves under capillary action, when saturated from the top it moves due to the force of gravity and may miss some pores [4].

VII. RELATION BETWEEN PRESSURE HEAD-HYDRAULIC CONDUCTIVITY

The relation between Pressure Head (m) and Hydraulic Conductivity (m/s) is studied. Using the constant head permeameter, the hydraulic conductivity is determined for a particular pressure head taken one at a time which ranges from 0.1 to 0.4 with a common difference of 0.05 and taking seven consecutive reading from the range including the lower and upper limit. It is observed that after the sixth reading with an increase in pressure head, the hydraulic conductivity rises and then becomes either constant or has small marginal change. Hence beyond that if the Pressure Head is increased there will be no as such significant change in the hydraulic conductivity of the sample.

The table below depicts the relation between the Pressure Head (m) and Hydraulic Conductivity (m/s).

Table VI

Pressure Head-Hydraulic Conductivity		
Sl no.	***Pressure Head (m)***	***Hydraulic Conductivity (m/s) * (10^{-4})***
1	0.10	1.388
2	0.15	1.196
3	0/20	0.864
4	0.25	0.364
5	0.30	0.288
6	0.35	0.279
7	0.40	0.277

In order to measure the hydraulic conductivity, we need to scale down the quantities of materials used for the actual experiment in order to use the constant head permeameter. So we get the value of hydraulic conductivity as 0.479×10^{-4} m/s which is evidently in the range of the optimum hydraulic conductivity for proper flow. The value obtained can also be determined by the graph with Pressure Head as the abscissa and Hydraulic Conductivity as the ordinate. In the slope of the graph, the maximum point is taken beyond which the Hydraulic Conductivity has small marginal change.

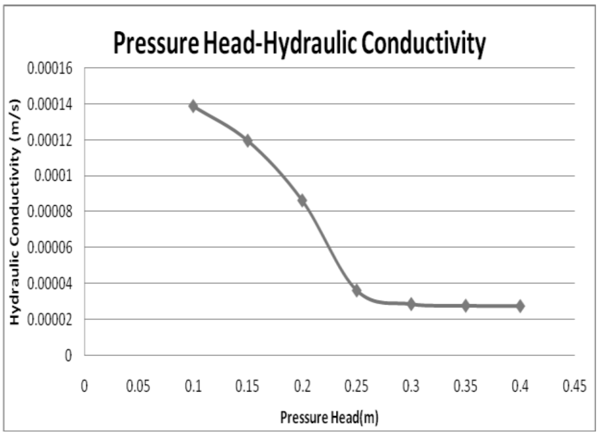

Fig 4: Pressure Head-Hydraulic Conductivity

From the graph, it is understood that the relation between Pressure Head and Hydraulic Conductivity is inversely proportional to each other.

VIII. RESULTS

With the progress of the experiment, it was observed that the pH of the water approached neutrality which is a good sign as the pH of standard drinking water is between 6.5-8.5 and the filtration system provides filtered water in this range. With the progress of the experiment it is observed that with the increase of ceramic % in filtration system its efficiency has also increased in terms of turbidity removal which is evident from the fact that turbidity of the water sample has from 5 NTU initially to 2.3 NTU at the filtrate obtained from the 40% ceramic filtration system. Dissolved Oxygen is showing an increment in its value, also with the condensation of water has served as the method to maintain the DO value as it is. Total dissolved solid is not a very useful factor in our project as the water sample that has been used does not show appreciable TDS. Hydraulic conductivity obtained is well within the optimum range of it which is between 2.77 $x10^{-5}$m/s and $0.138x10^{-5}$ m/s. This goes to show the permeability of ceramic as a filtration material.

The graph below depicts the change in the indicators of the water quality for different Samples and hence the result obtained.

The top line indicates the Dissolved Oxygen change, the middle line indicates the pH change and the third line from top indicates Turbidity change and the bottom line parallel to X-axis indicates the Total Dissolved Solids.

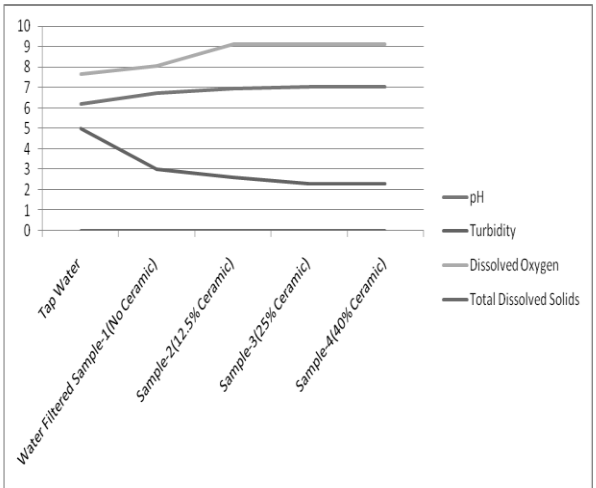

Fig 5: Water Quality Test of Samples

IX. CONCLUSION

In this research work, we have proposed an improvement in the recycling of harmful wastes because a huge amount of solid wastes is generated of which ceramic wastes form a large proportion. So, ceramic wastes are available in abundance and can be used in water filtration medium as a filter layer in the water purification system at low temperatures. Ceramics utilization in filter medium can be beneficial since it brings the filtered water to the range of water drinking standards. This has been proven by determining the p H value, Turbidity, Dissolved Oxygen and Total Dissolved Solids whose data fall under the drinking water standards. The use of ceramic in filter media has also brought the hydraulic conductivity in the desired range for filter media thus proving to be an upcoming new filter media. The future prospects for this development in the making of the filter media by using ceramic will decrease the cost of production in the manufacturing of filter media and also an environmentally friendly method which would help in the management of waste disposal. Further development can be made in setting the filter medium at varied temperature instead of a fixed temperature so to decrease the constraints in setting up the temperature and lower the cost burdens related to it.

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