Production of Clay Filters for Waste Water Treatment

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Abstract-
Water borne diseases have continued to linger and has remained a major challenge facing most developing nations today. This has been caused mainly by lack of access to clean water. The rapid industrialization has led to the discharge of effluents loaded with pollutants into our water bodies that have greatly affected humans, aquatic life and the environment. This work looks into the possibility of improving the quality water through the elimination of (i) inherent contaminants in water using filters made from cheap locally available red clay and biomass (300 microns sawdust) materials and (ii) chemical treatment of industrial and domestic effluents which in itself is a source of environmental pollution. The sawdust-clay materials were first thoroughly dry mixed in four different weight ratios, 6/80 (sample A), 5/80 (sample B) 4/80 (sample C) and 2/80 (sample D) before water was then added gradually and mixed until the clay clumped together completely, softened and workable. It was then wedged by pressing firmly in order to remove bubbles from the inside of the clay and molded into cup--like shape. It was first sun dried then oven dried at 110 0C and then fired in a Muffle furnace at 850 0C to burnout the sawdust biomass and thus create fine pores within the clay matrix. Performance of the sawdust-clay filters for the purification of waste water obtained from two different sources, industrial and kitchen effluents, was investigated. Results obtained from the study showed that the four filters (A, B, C and D) proved to be moderately effective for the treatment of the two effluents. All the filters reduced the total dissolved solids (TDS) to 120 and 110 mg/L of the industrial and kitchen waste water respectively, to acceptable levels which is less than 500mg/L, set by the World Health Organization (WHO). Conductivity values obtained after the treatment of the water samples were lower than the 1000 μs/cm limit set by WHO. And with the exception of filter D, others greatly reduced the turbidity of water samples as values less than 5 NTU as set by WHO were obtained. The pH values or acidity reduced for the industrial waste water from 4.5 to 7.02 and for kitchen waste water from 5.1 to 7.02 which met the specification set by WHO. Some of the heavy metals detected in the water samples were effectively reduced to acceptable levels. The filtration rates were 140, 100, 50 and 20 ml/min for filters B, A, C and D respectively. The rates rapidly reduced to about 2.7, 1.7, 1.0 and 0.7 ml/min for A, B, C and D respectively after 30 minutes of filtration. This implies that the filters were effective and should thus be developed for industrial and domestic waste water treatment applications.

Keywords: Clay filters, industrial and kitchen effluents, water borne diseases

1. Introduction
Fine filters are easy to make, less expensive and effective when deployed and used for water filtration. They depend on the micro-pore of small-sized pores of clay [1, 2] or ceramic materials made from made from weight mix of local terra-cotta clay and sawdust or other combustibles,
such as rice husks to separate or filter out debris, dirt, and microbes or bacteria from water. After mixing, they are then milled, fired to temperature of up to nearly 860 °C and while the particulate biomass materials are burnt out, creating tiny pores within the filters. The clay filters sometimes undergo filtration rate test to ensure they conform to standard and may then be film-coated with colloidal silver (Ag) in such a way that it doesn’t leak away. The combined effects of the bactericidal properties of the colloidal Ag and fine pores help to produce very effective clay or ceramic filters. The silver helps to kill or incapacitate bacteria and prevent the growth of mold and algae in the body of the filter [3]. The fine pore clay filter system is then set up and made to sit on top of a clean plastic or ceramic container or receiver. Contaminated water is poured into a top container. It passes through the filter into the receptacle below. Extraneous matters, dirt or contaminants bigger than the fine pores or holes of the ceramic filter structure will be left on the top half of the unit. The contaminants are then removed from the filter or it is cleaned by using soft brush to remove them and then rinse off using clean water. Sometimes hot soap solution may be used [4]. Just like any other known filtration process, water is carefully poured through one side of the filter, which then acts to prevent the passage of contaminants and extraneous matter larger than its pore size. Usually, microbial cysts, protozoa, and bacteria are removed during the filtration process but depending on the filter type, they are not effective enough to remove viruses since they are smaller than the fine filter pores, they easily pass through to the clean side of the filters [5].

The development of ceramic filter technology in 1981, has been attributed to Fernando Mazariegos of Guatemala [6, 7]. It was aimed at helping developing nations at providing cheap and sustainable technology for the production of high quality potable water especially for rural dwellers. According to the World Health Organization (WHO) and United Nations children’s fund Joint Monitoring Programme [8, 9] there are 1.1 billion people around the world that still lack sustainable access to relatively safe drinking water. This includes people in rural, urban and peri-urban areas. According to the WHO a short-term solution to meet the basic need of safe drinking water can be found in household water treatment and safe storage [10-12]. Water treatment utilities mostly employ disinfectants such as chlorine-based chemicals to kill microbes in bulk water treatment. However, chlorine requires well-treated water (turbidities < 1 NTU) to be effective as a disinfectant [13]. And taking into account that the poor, rural communities who do not have the luxury of treated water supply are mostly affected by bacteria and other-pathogen water related diseases. This is why cheaper and user-friendly household water treatment methods are constantly being sought to avert these problems. Hence the use of suitable home filters (such as ceramic pots) with built-in disinfectant becomes very useful which also helps to avoid the home addition of chlorine to water. This process averts the formation of disinfection by-products and thereby maintaining the taste of the water [4]. Ceramic pot filters can be used to provide an improved quality of drinking water to households in situations where centrally treated water supply is not available or the treated water supply is not of a potable quality [14]. Be that as it may, many factors such as the situation at hand, the quality of the raw water, the available technology, the time frame in which it is to be used, the prevailing customs, preferences and education levels of the local population determine the most appropriate water treatment technology to be used [15, 16].

Generally, clay materials for filter pots are generally classified in terms of the differences in the layered structures that make up the clay material. Clay refers to naturally occurring minerals
mainly made of fine grained minerals that make up colloid fraction (particle size of ~2 μm) which have plasticity when mixed with water and harden when they dry [17, 18]. They have been formed over a long period of time through a gradual process of chemical or natural weathering of silicate bearing rocks [19, 20]. Massive changes in the clay mineral content of the rocks usually produce relatively pure clay deposits that are of very high economic value. [18]. Mineral contents in clay usually have high affinity for water which makes the clay to swell and then double in its thickness after it has absorb water. Most clay minerals have the ability to take up dissolved ions from solutions and release the ions when the prevailing conditions are altered [19]. The cation exchange capacity of the clay, as well as the size and charge of the cations determine the amount of swelling. The greatest amount of swelling is observed with small univalent cations such as Li+ and Na+ while polyvalent cations such as Ca2+ and Mg2+ present an incomplete swelling due to strong interactions between the cations and the water [4]. Clays have high surface areas that previously had been suggested as sites where concentration and catalysis can take place (Jiang, 2004). The diverse clay adsorption capabilities and capacities usually come from an overall or net negative charge on their mineral structure. This is what gives clays the inherent capability to adsorb positively charged ionic molecules. In addition to the aforementioned, the very high surface area and porosity also contribute to clay sorption properties exhibited by them [21].

Three types of clays, bentonite, white and red clays [5] are used for the ceramics such as the body of the filter pots. The main minerals in bentonites are smectite clays such as montmorillonite. They have very high cation exchange when activated with strong acids [22]. The white clay is mainly composed of quartz, montmorillonite and hematite [23, 24]. White clay has excellent working properties and is extensively used in throwing clays that require more plasticity to form the ware [25] while the red clay is mostly made of kaolinite, quartz, montmorillonite, albite and hematite. Iron oxide, Fe₂O₃ is the main colorant in the clays, being responsible for the reddish color after firing [24]. These clays exhibit plastic behaviour when they are mixed with water in certain ratios or proportions [5] and when dry, they become firmly formed and when fired in a furnace or kiln, irreversible physical and chemical changes take place (Hamer, 2005). Recent researches carried out on the absorption/adsorption capacity of clay in diverse applications include the removal of heavy metal contaminants from polluted water and in air purification [26]. This is what this work is set to investigate by deploying the versatile clay properties in fine filters production for treating industrial and domestic waste water.

2. Methodology
The effluents from the industry (flour mill) and cafeteria were first collected for physico-chemical analysis to determine pH, turbidity, temperature, electrical conductivity, TDS, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). The raw water or effluents were also tested for the presence of some heavy metals such as zinc (Zn), iron (Fe), copper (Cu), lead (Pb), manganese (Mn) and cadmium (Cd) using the Atomic absorption spectrophotometer (AAS).

The fine clay filter produced was first placed on a 1000 ml beaker (receptacle). Then 500 ml of the waste water was taken and gradually poured into the filter for filtration to take place. The
filtrate was collected in clean plastic bottles for further analysis. The experiment was repeated with the same water sample but this time using each of the four filters produced. Analyses of the filtrates from the four filters were then carried out based on the physico-chemical parameters and presence of heavy metals as listed paragraph 1 above.

2.1 Material Processing
Proportions of clay and biomass materials are the key factors considered to produce the fine filters. The mass ratios of sawdust to clay used to produce the small sized fine filters were 6/80 (sample A), 5/80 (sample B), 4/80 (sample C) and 2/80 (sample D). The sawdust was first sieved with 300 microns sieve. The clay and sawdust were then thoroughly mixed to have a uniform and consistent mix. Water was added in small amounts until the clay-sawdust mix clumped together completely and became soft and workable. The clay was wedged by pressing firmly in order to remove bubbles from the inside of the clay. The workable clay sample was then molded into small clay pot such that it can sit on a beaker. Extra water was then added at this point to help increase the plasticity and reform cracks that may occur in the pot. The clay pot was then left under the sun to dry to the extent that it could be moved without falling apart. It was then dried at 110 C in an oven for 24 hours. The dried clay pot was fired in an electric furnace at 900 C to churn off the organic matter contained in it leaving behind pores (Bielefeld, 2009). After which the fired clay was then left to cool down at room temperature. Prior to its use, the fine clay filter pot was first soaked in water to ensure the pores are through for the filtration experiments. Filters of other biomass-clay ratios were also produced using the same procedure.

3. Result and discussions
Tables 1 and 2 show the result of analyses before and after filtration of the industrial and kitchen waste water. Also included in the Tables are the World Health Organization (WHO) specifications for the various parameters tested. The performances of the various filters (containing various clay to biomass ratios) have been included.

Table 1 Parameters of Untreated and Treated Industrial Wastewater for Various Clay Filters

| S/N | Test parameters | W.H.O Raw | Filter D | Filter C | Filter B | Filter A |
|-----|----------------|-----------|----------|----------|----------|----------|
| 1   | Turbidity NTU  | 5         | 11       | 5.7      | 4.26     | 4.12     | 4.7      |
| 2   | pH             | 6.5 - 7.5 | 4.5      | 5.89     | 7.22     | 7.08     | 7.01     |
| 3   | Conductivity (us/cm) | 1000 | 2000 | 837 | 753 | 741 | 761 |
| 4   | TDS (mg/L)     | 500       | 1200     | 443.2    | 426.3    | 430.4    | 438.7    |
| 5   | BOD (mg/L)     | 40        | 70       | 40.2     | 39.3     | 39.6     | 39.7     |
| 6   | COD (mg/L)     | 120       | 164      | 122      | 119      | 118      | 122      |
| 7   | IRON (mg/L)    | 2         | 2.8      | 1.9      | 1.82     | 1.9      | 1.78     |
| 8   | Cadmium (mg/L) | 0.1       | 0.17     | 0.64     | 0.5      | 0.56     | 0.49     |
| 9   | Lead (mg/L)    | 0.1       | 0.19     | 0.12     | 0.09     | 0.1      | 0.09     |
| 10  | Zinc (mg/L)    | 5         | 7.89     | 5.58     | 5.01     | 4.96     | 4.99     |
Table 2 Tested Parameters of Untreated and Treated Kitchen Wastewater for Various Clay Filters

| S/N | Test parameters | W.H.O Kitchen Water | Filter D | Filter C | Filter B | Filter A |
|-----|----------------|---------------------|----------|----------|----------|----------|
| 1   | Turbidity NTU  | 5                   | 9        | 6.3      | 4.36     | 4.22     | 4.4      |
| 2   | pH             | 6.5 - 7.5           | 5.1      | 5.9      | 7.05     | 7.07     | 7.06     |
| 3   | Conductivity (us/cm) | 1000 | 1875 | 842 | 772 | 774 | 777 |
| 4   | TDS (mg/L)     | 500                 | 1150     | 448.2    | 437.5    | 435.3    | 432.9    |
| 5   | BOD (mg/L)     | 40                  | 78       | 45.2     | 36.3     | 35.6     | 35.7     |
| 6   | COD (mg/L)     | 120                 | 163      | 152      | 110      | 109      | 112      |
| 7   | IRON (mg/L)    | 2                   | 2.49     | 1.7      | 1.67     | 1.62     | 1.65     |
| 8   | Cadmium (mg/L) | 0.1                 | 0.17     | 0.54     | 0.49     | 0.52     | 0.46     |
| 9   | Lead (mg/L)    | 0.1                 | 0.16     | 0.11     | 0.76     | 0.83     | 0.79     |
| 10  | Zinc (mg/L)    | 5                   | 7.47     | 5.52     | 4.47     | 4.52     | 4.49     |
| 11  | Manganese (mg/L) | 1                  | 1.35     | 0.74     | 0.63     | 0.68     | 0.62     |
| 12  | Copper (mg/L)  | 1                   | 1.3      | 0.77     | 0.61     | 0.64     | 0.65     |

Figure 1. Filtration Capacities of Clay Filter Samples
3.1 The effect of clay filter pots on total dissolved solids (TDS) in industrial and kitchen waste water

Analyses of both the untreated industrial and cafeteria waste water samples showed higher values of Total Dissolved Solids (TDS) compared to the specifications of the World Health Organization (WHO). From Tables 1 and 2 the TDS values gave 500, 1200 and 1150 mg/L for WHO, industrial and kitchen samples respectively. However, the values obtained after treatment with the four filters (A, B, C and D) showed tremendous reduction in the TDS values to acceptable levels (< 500mg/L) for the two water samples. While the TDS for the industrial waste reduced from 1200 mg/L to 435.7, 430.4; 426.3 and 443.2 mg/L using filters A, B, C and D respectively, the TDS for the kitchen waste water reduced from 1150 mg/L to 432.9, 435.3, 437.5 and 448.2 mg/L using the same order of filters respectively. It was observed that the reduction efficiencies, calculated in terms of percentage solid removal, of the four filters for the two processes were nearly the same. The difference was only marginal. These were 63.7, 64.1, 64.5, 63.1 % using filters A, B, C and D respectively to filter the industrial waste water while they were 62.4, 62.1, 62.0 and 61.0 % filtering the kitchen waste waters with filters A, B, C and D respectively. Results from the first run (filtration of industrial waste water) showed Filter C as marginally the best of all the filters used. The trend was however, marginally different when the same filters were washed and used during the second run (filtration of kitchen waste water). The efficiencies using all the filters reduced marginally. This may be attributed to clogged filter pores. The overall solids removal efficiency of 64.5 % as obtained may be greatly enhanced amongst others if (i) biomass particle size of less than 300 microns or Nano-range size is used (ii) at the mixing stage, thorough mixing is carried out for even distribution of biomass particles within the clay matrix (iii) residence time and temperature are adequate for the complete burnout of the biomass, ensuring no residue is left is left within the clay matrix.

3.2 The effect of clay filter pots on conductivity of industrial and cafeteria waste water

From Tables 1 and 2 higher values of electrical conductivity were obtained for the industrial and cafeteria waste water compared with WHO’s specification. The values obtained for the two untreated water samples were 2000 and 1875 μs/cm in comparison the 1000 μs/cm limit set by WHO for effluent water. The conductivity values for the two treated waste water samples using the clay filters (A, B, C and D) showed very much improved effluents with lower conductivity values compared their respective initial values. From Tables 1 and 2, the electrical conductivity decreased significantly for both water samples to lesser values of exchangeable ions estimated in the treated waste water samples. Dissolved ions and TDS are responsible for the initially high electrical conductivities analysed for both effluent samples. The analysed values using the four filters A, B, C and D to treat the industrial effluent were 837, 753, 741 and 761 μs/cm respectively while the values obtained using the same set and order of filters to treat the cafeteria effluent were respectively 842, 772, 774 and 777 μs/cm. The percentage reduction in the conductivity values of the treated industrial effluent using Filters A, B, C and D were calculated to be 58.2, 62.4, 63 and 62 % respectively. It was observed that as the ratio of biomass to clay in the filters decreased, the efficiency or their ability to remove dissolved ions/TDS increased until after Filter C, when it began to decrease. There was however, no established trend in the efficiencies obtained (55.1, 58.9, 58.7 and 58.6 %) using the same but washed set of filters for the treatment of the kitchen effluents. The results generally showed great improvements compared to WHO standard (1000 μs/cm) set for effluent water.
3.3 The effect of clay filters on the turbidity (NTU) of industrial and cafeteria waste water
The tested raw industrial and kitchen waste water failed the minimum specification limit (5 NTU) set by WHO. The values obtained for the raw industrial and kitchen waste water samples were 11 and 9 NTU respectively. However, the treated industrial waste water using the clay filters (A, B, C and D) showed much improved results giving 4.7, 4.12, 4.26 and 5.2 NTU respectively while the treated kitchen effluent gave turbidity values 4.4, 4.2, 4.4 and 6.3 NTU. Filters A, B and C were effective in reducing the high turbidity values of the two effluents to acceptable limits which directly impacts on the water quality since high turbid water is associated with microbial contamination [27] and light penetration through water [28]. Filter D performed the least compared to the other three filters.

3.4 The effect of clay filter pots on BOD and COD in industrial and kitchen waste water
BOD and COD stand for Biochemical Oxygen Demand and Chemical Oxygen demand respectively. The Chemical Oxygen Demand (COD) measures the total organic molecules dissolved in a given waste water sample while Biochemical Oxygen Demand (BOD) gives the amount of the dissolved oxygen needed by aerobic micro-organisms in the waste water for metabolism. The BOD for the measured industrial and kitchen waste water samples were prior to treatment were respectively 70 and 78 mg/l. The specification of WHO (see Tables 1 and 2) for waste water is 40 mg/l. Using the clay filters to treat the industrial waste water sample gave much improved values of 40.2, 39.3, 39.6 and 39.7 mg/L using filter samples D, C, B and A respectively while for the kitchen water the BOD after treatment of the kitchen waste gave 45.2, 36.3, 35.6 and 35.7 mg/L using filters samples D, C, B and A respectively. Thus the effectiveness of treatment using the filters was between 42.5 and 43.9 % for the industrial waste water while it was between 42.1 and 54.4 % treating the kitchen waste water. For the COD the standard set by WHO is 120 mg/L while the COD values for both gave 164 and 163 mg/L respectively for the industrial effluent and kitchen waste water (see Tables 1 and 2). The results obtained from the treated industrial effluent were 122, 119, 118 and 122 mg/L while the treated kitchen waste water gave 152, 110, 109 and 112 mg/L using filters D, C, B and A respectively for the two water samples. It was generally observed that while filter D with 2:80 biomass to clay ratio was particularly not very effective filter B with biomass to clay ratio of 5:50 performed the best. This may be attributed to the number of pores presented and how they are interconnected within the within the filter matrix.

3.5 The effect of clay filter pots on the pH of waste water
Tables 1 and 2 show the effect of the clay Filters (A, B, C and D) on pH of both the industrial and cafeteria or kitchen effluents. It was observed that all the clay filters increased the pH (or reduced acidity) of both the industrial and kitchen waste water samples. This is expected since most of the total dissolved solids and heavy metals were successfully removed by the filters. All the filters reduced the acidity of the industrial effluent from acidic 4.5 to a neutral pH of between 7.01 and 7.22 except for Filter D whose pH increase was almost insignificant (from pH value of 4.5 to a pH of 5.89). The same trend was observed for the kitchen waste water as Filters A, B and C reduced the acidic water from pH of 5.1 to neutral pH value of between 7.01 and 7.07. Filter D could only produce at best, the pH of 5.9. Filter D contains the least quantity (g) of sawdust to clay ratio increase; there was a corresponding increase in the pH or a reduction in the acidity of the two effluent water samples.
3.6 The effect of clay filters on the filtration rate

Figure 1 shows the filtration capacities or filtration rates of four filters. Very high rate of filtration was observed within the first five minutes of filtration. 700, 500, 200 and 100 ml of water were collected after 5 min using filters A, B, C and D respectively. These rates however, rapidly and drastically reduced as the time of filtration increased for the four filters. In 30 min, only 50, 80 30 and 30 ml water could be respectively collected or filtered using filters A, B, C and D. Cumulatively, 1460, 1100, 460 and 270 ml of water was collected in 30 min from the filters A, B, C and D respectively. It was noticed that the higher the biomass contents in the filters the higher the filtration rate. This is expected since very fine pore spaces, in the order of the particle size of the biomass, are created as the clay filters with the highest biomass contents are burnt-off when they are fired in the furnace. This allows easy percolation (especially when the pores are well distributed and interconnected) of water during the filtration process. However, as time of filtration progressed, less volume of water was recovered because the residue from the waste water clogged the pores in all the filters.

3.7 The effect of clay filters on heavy metals in industrial and kitchen effluents

From Tables 1 and 2, six heavy metals namely Iron (Fe), Cadmium (Cd), Lead (Pb), Zinc (Zn), Manganese (Mn) and copper (Cu) with different concentrations (mg/L) were detected in each of the two water effluents. And expectedly the industrial effluent contained higher concentrations of the detected heavy metals (see Tables 1 and 2). Fe, Mn and Cu present in both water samples reduced in concentrations below the WHO set limits after treatment by filtration using filters A, B, C and D. Except for filter D, the other filters A, B and C reduced the Zn concentration to acceptable WHO set limit. The concentration of cadmium (Cd) unexpectedly increased above the concentrations that were detected in the two raw industrial and kitchen waste water samples. The detected Cd concentration in the industrial and kitchen effluents was 0.17 mg/L. However, after treatment of the effluents with the four clay filters, the detected concentrations were observed to have increased to 0.64, 0.5, 0.56 and 0.49 mg/L for the industrial waste water and 0.54, 0.49, 0.52 and 0.46 mg/L for the kitchen effluent using filters D, C, B and A respectively. It is suspected that the starting clay and or sawdust samples may contain Cd ions which were leached from the clay filter matrix during the filtration experiment. Characterization and treatment of clay and biomass samples are therefore imperative and must form an integral part in the making of clay filters for water treatment.

4. Conclusion

The performance of the four filters in the treatment of the two effluents (industrial and kitchen), was very good. The order of performance of the four filters was assessed by the level of removal or reduction of the pollutants detected in the two effluents. TDS, conductivity, turbidity and some heavy metals (Fe, Mn and Cu) were reduced to below the limits set by WHO. Filter A produced the best performance compared to the other three samples. This was closely followed by B, then C and the least D. The effectiveness of treatment using the four filters was reflected in the reduction of the BOD on the average, by 43.2 % for the industrial waste water and 48.3 % treating the kitchen waste water. The COD correspondingly reduced on the average, by 20 % treating the industrial waste water and 26.9 % treating the kitchen waste water. It was observed that performance of the four filters increased as the ratio of sawdust to clay increased from 2 to 6 g per 80 g of clay. Thus the development of comprehensive clay filters considering different clay type, biomass materials, and particle size distribution of the biomass, kneading
process, kneading time and microbe inhibition will lead to the production of cheap, good and efficient filters that are environment friendly and affordable to all, especially to the rural dwellers where access to portable water is still an uphill task.

5. **Recommendation**

The production and use of the clay-biomass filters was effective in the treatment of industrial effluent and should thus be developed further for portable water production by the inclusion of microbes inhibiting chemicals into the filter matrix of Nano-pore size.

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**Reference**

[1] Adeoye, J. B., Omoleye, J., Ojewumi, M. E., & Babalola, R. (2017). Synthesis of Zeolite Y from Kaolin Using Novel Method of Dealumination. *International Journal of Applied Engineering Research, 12*(5), 755-760.

[2] Babalola, R., Omoleye, J. A., Adefilia, S. S., Hymore, F. K., & Ajayi, O. A. (2017). Analysis of zeolity from Nigerian clay vis-avis standard grade. *Journal of Emerging Trends in Engineering and Applied Sciences, 8*(6), 229-232.

[3] Hillie T., Munasinghe M., Hlope M., and Deraniyagala Y., "Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks."

[4] Watters T. T. R., (2010) "The effect of compositional and geometrical changes to the bending strength of the Ghanaian ceramic pot filter," Massachusetts Institute of Technology.

[5] Sobsey M. D., Stauber C. E., Casanova L. M., Brown J. M., and Elliott M. A. (2008) "Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world,". *Environmental science & technology, 42*, 4261-4267.

[6] Varkey A. and Dlamini M., (2012) "Point-of-use water purification using clay pot water filters and copper mesh," *Water SA, 38*, 721-726.

[7] Yakub I., Plappally A., Leftwich M., Malatesta K., Friedman,K. C., Obwoya S. et al., (2012) "Porosity, flow, and filtration characteristics of frustum-shaped ceramic water filters," *Journal of Environmental Engineering, 139*, 986-994.

[8] UNICEF and UNICEF, "World Water Day, commentary," UNICEF Television, Accessed on, vol. 7, 2007.

[9] Biswas A. K., (2010). "Water for a thirsty urban world," *The Brown Journal of World Affairs, 17*, 147-166.

[10] U. Who, (2010). *Progress on sanitation and drinking-water, 2010 Update*: World Health Organization Geneva.

[11] W. H. Organization, (2008). *Progress on drinking-water and sanitation*: World Health Organization.

[12] Bartram J. and Cairncross S., (2010) "Hygiene, sanitation, and water: forgotten foundations of health," *PLoS medicine, 7*, p. e1000367.

[13] Clasen T., Nadakatti S., Menon and S. (2006). "Microbiological performance of a water treatment unit designed for household use in developing countries," *Tropical medicine & international health: TM & IH, 11*, 1399-1405.
[14] Bielefeldt A. R, Kowalski K. and Summers R. S. (2009). "Bacterial treatment effectiveness of point-of-use ceramic water filters," Water research, 43, 3559-3565.

[15] Linn S. (2007). "Ceramic water filters improve water quality for rural communities in Myanmar," ed: Unicef.

[16] Naing W. (2007). "Ceramic water filters improve water quality for rural communities in Myanmar Yangon, Myanmar."

[17] Oyanedel-Craver V. A, Smith and J. A (2007). "Sustainable colloidal-silver-impregnated ceramic filter for point-of-use water treatment," Environmental science & technology, vol. 42, pp. 927-933.

[18] Lee C. (2009). "Investigation into the Properties of Filtron," Univ. of Strathclyde, Glasgow, UK, http://www.edc-cu.org/pdf/scotland%20study.pdf (Nov. 7, 2009).

[19] Franz A. (June 2005) "A performance study on Ceramic Candle filters in Kenya including tests for Coliphage removal, Masters of Engineering Thesis," ed: MIT, Department of Civil and Environmental Engineering, Cambridge, Ma.

[20] Simonis J. J. and Basson A. K. (2011). "Evaluation of a low-cost ceramic micro-porous filter for elimination of common disease microorganisms," Physics and Chemistry of the Earth, Parts A/B/C, 36, 1129-1134.

[21] Ngai T. K., Shrestha R. R., Dangol B., Maharjan M. and Murcott S. E. (2007). "Design for sustainable development—Household drinking water filter for arsenic and pathogen treatment in Nepal," Journal of Environmental Science and Health, Part A, 42, 1879-1888.

[22] Plappally A., Chen H., Ayinde W., Alayande S., Usoro A., K. C. Friedman, et al., (2011). "A field study on the use of clay ceramic water filters and influences on the general health in Nigeria," Journal of Health Behavior and Public Health, 1, 1-14.

[23] Berg P. A. (2015). "The world's need for household water treatment," Journal-American Water Works Association, 107, 36-44.

[24] McCarton L. "Household Water Management in Sierra Leone, Dublin Institute of Technology," ed, 2009.

[25] Bain J. and Highley D. (1979). "Regional appraisal of clay resources-a challenge to the clay mineralogist," in Developments in Sedimentology. 27, 437-446.

[26] Duke W. Nordin R., D. Baker and Mazumder A. (2006). "The use and performance of BioSand filters in the Artibonite Valley of Haiti: a field study of 107 households," Rural Remote Health, 6, 570.

[27] Wole M. and Ayanbode O. (2009). "Use of indigenous knowledge by women in a Nigerian rural community," Indian Journal of traditional knowledge, 8, 287-295.

[28] Montgomery M. A. and Elimelech M. (2007). "Water and sanitation in developing countries: including health in the equation," ed: ACS Publications.