

Effect of Grogs on in the Performance of Ceramic Water Filters

Faustine Abiriga, MSc¹; Sam Obwoya Kinyera, PhD²

¹Assistant Lecturer, Dept of Physics, Kyambogo University, Kampala Uganda

²Associate Professor, Dept of Physics, Kyambogo University, Kampala Uganda

Accepted 7th September, 2014

Abstract

We have attempted an experimental study on the effects of introducing grog in different proportions to the composition of ceramic water filters (CWF). The different compositions of clay, sawdust mixed with grogs were compacted to cylindrical discs at high pressures and then fired to 850 °C. The effectiveness of the filters was measured based on the rate of water percolation through the filters, turbidity of the filtrate and e-coli removal efficiency of filters. The introduction of grogs was found to improve the filtration rates of filters, although if so much proportion of it is added the quality of filtrate is lowered.

Keywords: *Grogs; hard wood sawdust; water percolation; water turbidity; e-coli removal efficiency.*

1. Introduction

Most Ugandans living in rural and semi-urban areas obtain water for domestic use from open water sources (WHO/UNICEF, 2010), which are often contaminated with dissolved minerals and pathogenic organisms. These pathogenic organisms are highly infectious and disease-causing (Kosek et al., 2003). Once ingested through consumption of the contaminated water, the pathogenic organisms cause diseases like cholera, typhoid, amoebic and bacillary dysentery and other diarrheal diseases.

Although there are other methods for treatment of contaminated water in developing countries such as boiling, pasteurization, chlorination, flocculation disinfection, solar disinfection, biosand filter etc. [Clasenet al.2007; Fewtrell et al. 2005; Sobsey et al. 2008], point-of-use filtration is one of the most promising solutions available (Sobsey et al.2008). Ceramic water filters (CWFs) are especially appealing because of their low cost, ease of fabrication and use, and their ability to filter out bacteria from water very effectively. A study by Brown and Sobsey (2006) shows that ceramic water filters are effective in reducing the exposure of users

to contaminated water, and hence lowering the occurrence of diarrheal related diseases over an extended period of time.

The basic material for making CWFs is clay, which is quite abundant in Uganda. The pores through which filtration takes place are formed when organic materials such as sawdust or rice husks mixed with clay in predetermined ratios burns out during firing leaving behind cavities in the filter. The ratio of clay to burn-out material in the clay is important in establishing the flow rate and effectiveness of the filters. Although porous CWFs have been used successfully in the field (Albert et al. 2010; Brown et al. 2009; Dies 2003; Hwang 2003; Lantagne 2002; Lee 2009; Oyanedel-Craver and Smith 2008; Swanton 2008; Van Halem 2006) for over a decade, scientific understanding of the effects of porosity on water flow rate and microbial filtration efficiency is still very limited. Therefore, there is a need for scientific studies of the effects of porosity on the water filtration properties of CWFs.

This paper presents the study of effect of introducing different proportions of grogs to mixtures of clay and sawdust on the rate of water percolation and quality of water filtered by ceramic filters.

2. Material and Methods

2.1. Materials

The major raw materials used in making the CWFs include sawdust and clay minerals. The clay mineral preferred had high silicon content, exhibit high plasticity and greater dry mechanical strength when fired (Prajapati and May, 2002). Thus, the clay mineral used was collected from Ntawo, Mukono District with chemical compositions determined by Obwoya, 2006, as shown in Table 1:

Table 1:Chemical composition of Ntawo ball clay minerals (dry wt %)

Mineral	Dry weight %
SiO ₂	65.73
Al ₂ O ₃	26.35
Fe ₂ O ₃	3.94
TiO ₂	1.65
K ₂ O	0.87
MgO	0.39
CaO	0.30
Na ₂ O	0.20
ZrO ₂	0.06
P ₂ O ₅	0.08
Cr ₂ O ₃	0.04
MnO	0.05
ZnO	0.02
Au ₂ O	0.01
CuO	0.02
NiO	0.01

Mahogany hard wood sawdust, obtained from a nearby timbre workshop, was preferred because it does not cause the filter to bloat and it also leads to formation of uniformly distributed pores with fewer defects in the filter (Katherine et al. 2000).

2.2. Processing of ceramic filters

Powdered clay particles and hardwood sawdust of sizes 1mm were prepared through standard procedures. The two powders were mixed in the ratios of 4:3, 3:2 and 5:3 by volume of clay to sawdust and then thoroughly shaken by hand. Water was added to the mixture up to 20% by weight to improve on the workability of the mixture.

Group A ceramic water filter discs were made by compacting 90g of each of these mixtures to a pressure of 200kN into cylindrical discs of diameter 8cm and thickness 5mm using a hydraulic laboratory press-PW40. The green bodies were air dried after which they were fired gradually to 850oC. This temperature was maintained for six hours to allow the body to mature into a finished ceramic product.

After cooling, some of the group A filter discs were crashed and sieved through a 1mm sieve to produce the powder of porous grogs.

Thereafter, powders of clay, grog and sawdust were mixed in different proportions to generate group B and group C filters.

The proportion of clay to grog to sawdust in the formulation of group B filters taken is 4:1:2, 5:1:2, 3:1:1, 4:2:1 and 5:2:1 by volume, respectively. These ratios were derived from group A filters by maintaining the proportion of clay as in group A while the amount of sawdust was varied to allow for the introduction of grog.

Group C filters were made using a mixture of clay to grog to sawdust in the ratios of 3:1:3, 2:2:3, 2:1:2, 4:1:3 and 3:2:3 by volume, respectively. Similarly, group C filters were derived from group A filters by maintaining the proportion of sawdust while varying the amount of clay to enable the introduction of grog.

Each of the mixtures of group B and group C filters were thoroughly shaken and water was added to the mixtures up to 20% by weight to improve on their workability. 90g of each of the mixtures were then compacted to 200kN into discs of diameter 8cm and thickness 5mm in a hydraulic laboratory press-PW40.

The green bodies were air dried and then fired gradually to 850oC. This temperature was maintained for six hours to allow the body to mature into finished ceramic filter discs.

2.3. Experimental design

Each of the filters was fixed in a polyvinyl chloride (PVC) pipe of diameter 8cm using an adhesive as shown in Fig. 1.

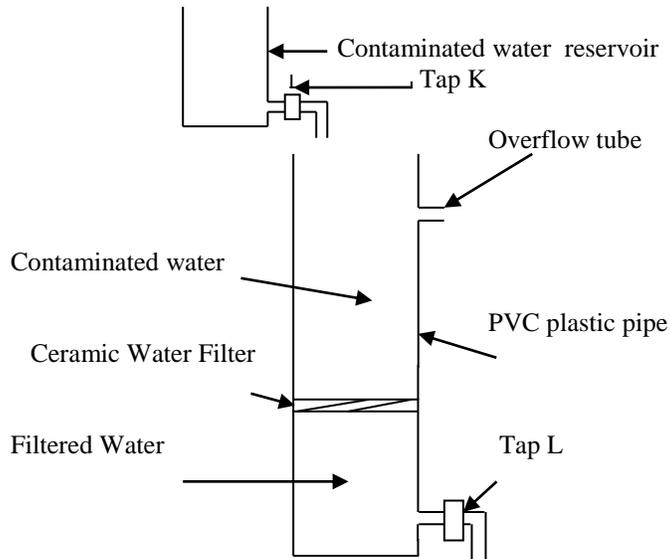


Figure 1: Experimental set up

Contaminated water in the reservoir is let into the space above the ceramic water filter by the use of tap K. The overflow tube ensures a constant overhead water pressure above the filter. The filtered water was collected in the space below the filter and could be drained out of the container through tap L.

2.4. Mechanisms of water flow through CWF

Water flows through the filter by the action of gravity using any one of the following processes: permeability, diffusion and capillarity (Skyer 2005). The tiny pores through which water passes in the ceramic filters can be idealized as a network of conduits and then modeling the conduits as cylindrical tubes, the rate of flow of water, Q , through the porous filters was assumed to follow Darcy's Law, which is given by equation (1)

$$Q = \frac{kA}{\mu L} \Delta P, \quad (1)$$

where; k = permeability of the material, A = surface area, L = thickness of the material, μ = dynamic viscosity of water, and ΔP = pressure difference from the top to the bottom of the surface. The pressure change ΔP , between the surfaces is equal to the hydrostatic pressure of the water (as the flow is very slow, a quasi-steady approximation is appropriate). For the flow through the bottom, the change in pressure from

the inside bottom surface to the outside bottom surface (the distance of porous media through which the water flows) is equal to the hydrostatic pressure of the fluid at that time given by

$$\Delta P = \rho g h(t), \quad (2)$$

where $h(t)$ is height of water above the base of the filter at any given time, ρ is density of water, and g is acceleration due to gravity. Permeability of disk is related to the rate of flow by equation

$$K_w = \frac{V d \rho_w g}{t A (h_1 - h_2)} \quad (3)$$

where K_w is permeability, A is cross section area, d is thickness, $(h_1 - h_2)$ is pressure difference, ρ_w is the density of water and t is the flow rate. According to Dies (2003), the theoretical flow rate is related to the properties of the ceramic disk filter by

$$Q = \frac{\pi d^2 K_w \rho_w g H}{4 \mu L} \quad (4)$$

where H is the water head and L is the disk thickness.

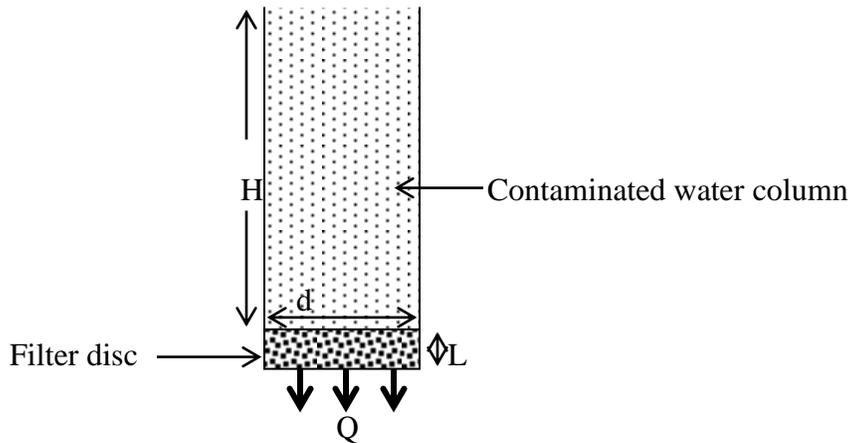


Figure 2: Mechanism of water flow through a ceramic filter disc

2.5. Water turbidity and e-coli removal efficiency

Turbidity is an optical characteristic which gives a measure of relative clarity of a liquid by expressing amount of light that is scattered by suspended material in a liquid when light is passed through the liquid sample. Higher turbidity manifests in higher intensity of scattered light. Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing and represents a health concern. Turbidity provides food and shelter for pathogens including E-coli. This promotes re-growth of pathogens in the distribution system, leading to waterborne disease outbreaks, which have caused significant cases of gastroenteritis throughout the world according to United States Environment Protection Agency (USEPA).

Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa. The particles of turbidity provide "shelter" for microbes by reducing their exposure to attack by disinfectants. Microbial attachment to particulate material has been considered to aid in microbe survival. Thus, due to their undesired health effects both the E-coli and other suspended particles need to be removed from domestic water before use. The Filtration efficiency of the filters is therefore a measure of the ratio of the upstream suspended solids concentration compared to the downstream suspended solid concentration which has passed through the filter. The percentage e-coli removal efficiency was calculated from the raw data equation

$$\text{Percentage Removal Efficiency} = \frac{\text{Untreated} - \text{Treated}}{\text{Untreated}} \times 100\% \quad (5)$$

Where Untreated refers to microbial (e-coli) concentration in the raw water sample (Neat) in cfu/ml and Treated refers to microbial (e-coli) concentration in the filtered water sample in cfu/ml. These were obtained by counting the number of e-coli forming units.

3. Results and discussion

3.1. Test Results for Rate of Water Percolation

The results for the rate of water percolation through the study filters are presented in Fig.3, Fig 4 and Fig 5 for set A, set B and set C filters, respectively.

3.2. Test Results for Water Turbidity

The test results for water turbidity for the filtrate through the study filters are presented in Table 2, Table 3 and Table 4 for set A, set B and set C filters, respectively.

3.3. Test Results for E-coli Removal Efficiency

The percentage e-coli removal efficiencies for the filtrate through the study filters are presented in Table 5, Table 6 and Table 7 for set A, set B and set C filters, respectively.

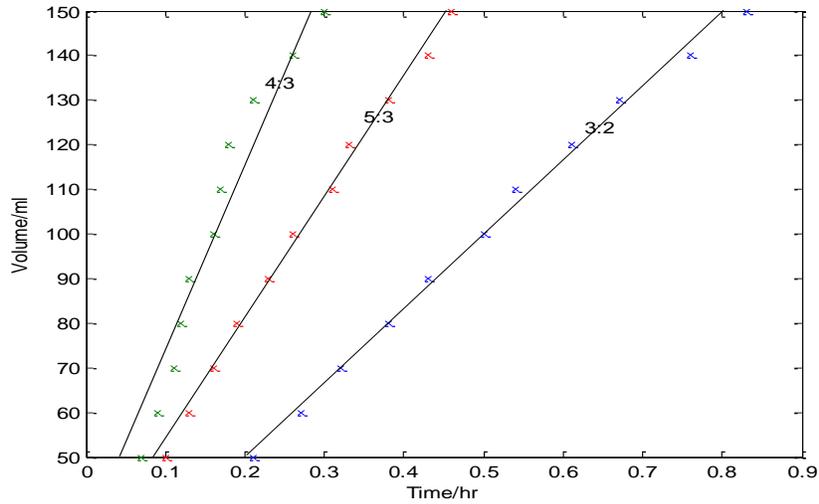


Figure 3: Rate of water percolation through set A filters

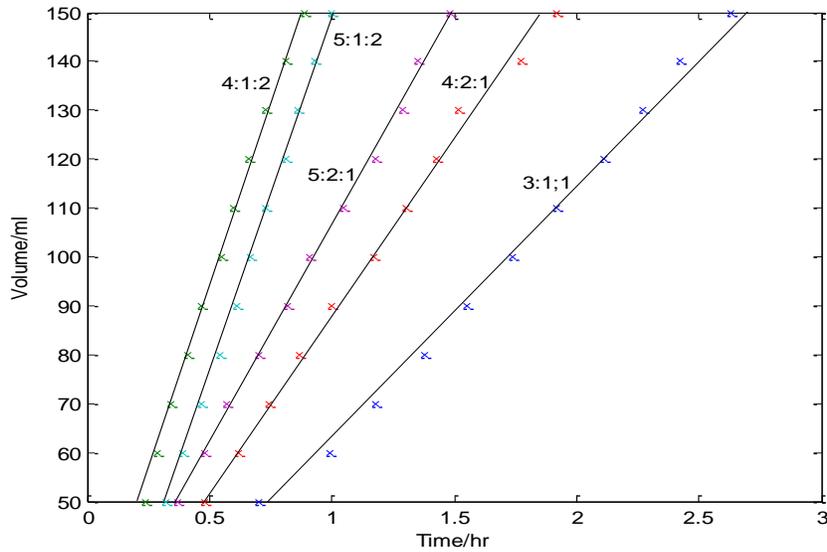


Figure 4: Rate water percolation through set B filters

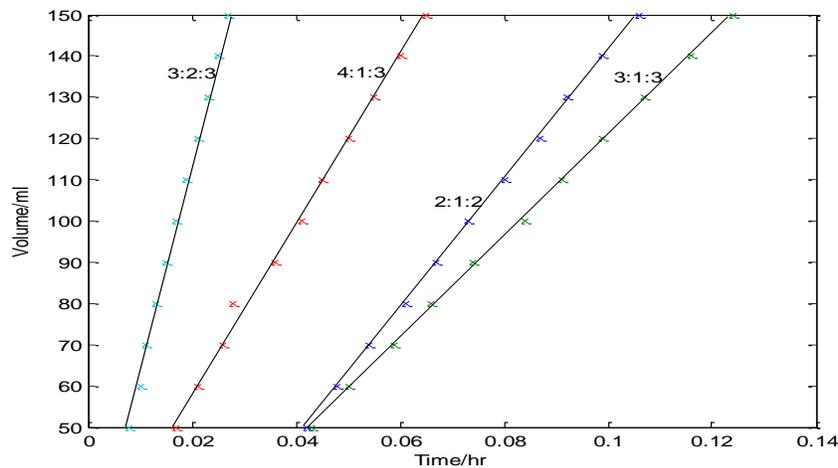


Figure 5: Rate of water percolation through set C filters

Table 2: Test Results for water turbidity for filtrate through set A filters;

Composition ratio (clay:sawdust)	Water turbidity in FNU per 10ml of water filtered through set A filters
4:3	10.50
3:2	09.30
5:3	08.73

Table 3: Test Results for water turbidity for filtrate through set B filters;

Composition ratio (clay:grog:sawdust)	Water turbidity in FNU per 10ml of water filtered through set B filters
4:1:2	2.14
5:1:2	2.09
3:1:1	2.12
4:2:1	1.47
5:2:1	1.19

Table 4: Test Results for water turbidity for filtrate through set C filters;

Composition ratio (clay:grog:sawdust)	Water turbidity in FNU per 10ml of water filtered through set C filters
2:1:2	10.10
3:1:3	08.40
4:1:3	08.44
3:2:3	13.40

Table 5: Results for e-coli removal efficiency for filtrate through set A filters;

Composition ratio (clay:sawdust)	Percentage e-coli removal efficiency for set A filters (%)
4:3	76.3
3:2	93.7
5:3	96.7

Table 6: Results for e-coli removal efficiency for water filtered through set B filters;

Composition ratio (clay:grog:sawdust)	Percentage e-coli removal efficiency for set B filters (%)
4:1:2	100.0
5:1:2	099.6
3:1:1	100.0
4:2:1	100.0
5:2:1	098.7

Table 7: Results for e-coli removal efficiency for water filtered through set C filters;

Composition ratio (clay:grog:sawdust)	Percentage e-coli removal efficiency for set C filters (%)
2:1:2	94.0
3:1:3	99.3
4:1:3	86.5
3:2:3	30.0

3.4. Rate of water percolation through the study filters

Fig. 3 shows that among set A filters, the average rate of water percolation decreased with increased clay to sawdust ratio. For example, set A filter with composition ratio of clay to sawdust of 4:3 had the highest percentage by volume of sawdust (42.9%) in the mixture and it exhibited the highest rate of water percolation of 467.19ml h⁻¹, whereas, the filter with composition ratio of 5:3 had the least percentage by volume of sawdust (37.5%) and it exhibited a lower rate of water percolation of 298.51ml h⁻¹. According to Clair, 2006 and Dies, 2003, when green filters are fired, the sawdust in their composition burns out leaving behind pores or voids through which water is filtered. Hence, filters with a higher percentage of sawdust leave behind more pores after firing and hence greater porosity which is evidenced by a higher water percolation rate.

Among set B filters, the filter with clay to grog to sawdust composition ratio of 4:1:2 had the highest percentage of sawdust (29%) in its composition and they exhibited the highest rate of water percolation of 161.29ml h⁻¹. On the other hand set B filters with clay to grog to sawdust composition ratio of 5:2:1 had the lowest percentage of sawdust (12%), and hence, they exhibited lowest rate of water percolation of 90.91ml h⁻¹. Note that in set B filters the percentage of burn-off material was reduced implying that fewer voids were created after firing the filters (Clair, 2006 and Dies, 2003). Similar observations were made for set C filters. To the composition of set B and set C filters grog was added. In set B filters, grog was added by reducing the amount of sawdust while in set C filters, grog was introduced by reducing the amount of clay mineral, all are in comparison to set A filter composition. These resulted in the following observations:

Set A filter (3:2) and set B filters (3:1:1) both had 60% composition by volume of clay in their textures, but set A filters had 40% composition by volume of sawdust, while set B filter had 20% composition by volume of sawdust and 20% composition by volume of grog. Set A filters had a water percolation rate of 476ml h⁻¹ while the corresponding set B filters had a percolation rate 53.19ml h⁻¹ which is about eight (8) times less than the previous. In this case, the introduced grog is seen to reduce the rate of water percolation. This is because grog has fewer and smaller pores than those which would otherwise be created by the reduced burn-off material. In addition, grog is a clay material itself which does not burn-off during firing. Set C filter (2:1:2) had a 40% composition by volume of sawdust in its texture similar to set A filter (3:2). However this set C filter exhibited a percolation rate of 1,280ml h⁻¹ while the corresponding set A filter exhibited a percolation rate of 476ml h⁻¹. The increase in percolation rate is quite significant and can be attributed to the creation of more voids as a result of introducing the grog. In addition to the voids created by the 40% sawdust during the firing, as the clay shrinks away from the grog which does not shrink, it forms

bridges with the grog thus leaving behind a slightly more porous ceramic media. These bridges have voids which increase on the final porosity of the filters (Sagara, 2000).

It should be noted that set C filters were formed by reducing the percentage of clay in their texture and grog was introduced to complete their composition. In this case, the set C filter with composition ratio of 2:1:2 was derived from the set A filter with a composition ratio of 3:2, which also had a 40% composition by volume of sawdust in its texture. This set A filter exhibited a percolation rate 166.67ml h⁻¹. These results showed that although the two filters had the same percentage composition by volume of sawdust (40%) in their texture, the set C filter (composition ratio 2:1:2) had a higher rate of water percolation compared to the set A filter (composition ratio 3:2). Therefore, the introduction of grog is seen to increase the rate of water percolation through set C filters by a factor of eight (8) compared to the corresponding set A filters with the same percentage composition by volume of sawdust. The highest rate of water percolation through set A, set B and set C filters were 500.00ml h⁻¹, 277.78ml h⁻¹ and 11,100.00 ml h⁻¹, respectively. These results show that set C filters were the most porous due to the presence of grog and a high percentage of sawdust (Clair 2006, Dies 2003, Sagara 2000). Set B presented the lowest rate of water percolation due to the high content of clay both from the ball clay and the grog. Hence fewer voids were created explaining the low percolation rates obtained. This correlation between the percentage composition of sawdust and rate of water percolation through the filters is seen to be consistent with all the sets of filters (A, B and C).

The low percentage of clay minerals in the texture of set C filters coupled with the high percentage of sawdust and the presence of grog in their texture, made set C filters to exhibit the least cohesion of particles, least mechanical strength and highest porosity. In fact, the clay to grog to sawdust composition ratio of 2:2:3 was very weak with very low cohesion of particles that when immersed in water, it just disintegrated into suspensions of smaller particles. Set C filter with composition ratio of 3:2:3 had 63% composition by volume of grog and sawdust altogether. This was the highest possible composition ratio for manufacturing the water filters that could withstand the water pressure. Since this composition ratio had a low percentage composition by volume of clay that provides the plasticity necessary to bind the filter particles together. This filter was mechanically weak and very porous with the highest rate of water percolation of 5,670ml h⁻¹.

3.5. Water turbidity test results and e-coli removal efficiencies

The water turbidity for the filtrate through set A filter with composition ratio of 4:3 is 10.50FNU while that for the set A filter with composition ratio of 5:3 is 8.73FNU. Although both belong to set A filters, the composition ratio 4:3 had

more sawdust in its composition (43%) compared to the composition ratio 5:3 (37%). Therefore after firing, the combustion of the sawdust left behind more pores in the composition ratio 4:3 than in the composition ratio 5:3 (Kabagambe, 2010). This explains why more suspended particles were able to filter through the filter with composition ratio 4:3 compared to that with composition ratio 5:3. It was for the same reason that the e-coli removal efficiency for filter composition ratio 4:3 was 76.3% much lower than that for filter composition 5:3 of 96.7%.

The processes of ceramic filtration mechanisms include direct interception or sieving, bridging and inertial impaction. During the direct interception or sieving process, when a particle of size $0.5\mu\text{m}$ and larger "runs into" a pore at the topmost layer of the ceramic filter that is smaller than the particle, it is captured as with absolute pore rated synthetic dead-end membranes as illustrated in Fig. 6 (Farahbakhsh and Smith, 2004). This filtration mechanism retains particulate matter not only on the surface of the filter but also at the inside of the filter.

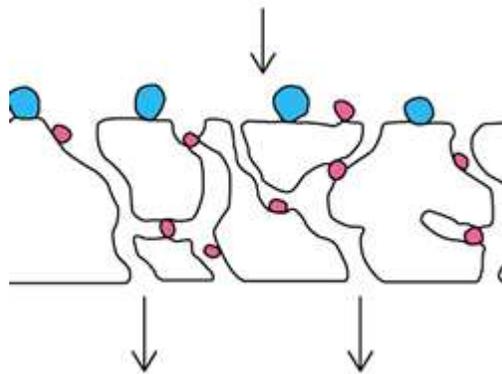


Figure 6: Direct interception or sieving

Particles of sizes smaller than $0.5\mu\text{m}$ may be too small to be intercepted. However, during the bridging process, when two smaller particles hit the obstruction at the same time, they will form a bridge across the pore by adhering to each other. Bridged particles may not block the pore but create an even smaller pore gradually forming a "filter cake". This "cake" creates a finer filtration for subsequent interception at the cost of decreased flow rate and eventually no flow rate. When a particle flowing through the filter hits a non-porous surface barrier, it becomes captured (Kenneth, 2008) while the water flows around the barrier. This phenomenon is called inertial impaction and is more prevalent with smaller particles in range of $0.1\mu\text{m}$ to $0.4\mu\text{m}$ size as these particles are easily affected by molecular bombardment.

Due to the above filtration mechanisms, the range of water turbidity for the filtrate through set A, set B and set C filters were 8.73FNU to 10.50FNU, 1.19FNU to 2.14FNU and 8.40FNU to 13.40FNU, respectively. These results showed that set B filters registered the lowest water turbidity values which were within the standards of 5.00FNU for drinking water turbidity recommended by USEPA and WHO guidelines. Note that set B filters had the least percentage composition by volume of sawdust compared to set A and set C filters. Set B filters, therefore, had the least number of voids after firing due to the low percentage of burn-off in their composition (Clair 2006 and Dies 2003).

In addition, the high percentage of grog in the composition of set B filters increased the intricate maze of labyrinths through which the particle laden water had to navigate (Crittenden J. C et al. 2005).

This led to the suspended particles, including e-coli, to be intercepted within the ceramic depth by the depth filtration mechanism. During this mechanism, the particles that may have penetrated the topmost layer become trapped within the structure as they pass through the filter pores that twist and turn through sharp angles due to the complicated ceramic structure. Small particles, like e-coli, can combine with other particles to form a cluster of particles large enough to become trapped as a group or individual in dead end cavities. Weak Van der Waals forces also attract the small suspended particles to the ceramic structure, causing them to be adsorbed onto the wall of the ceramic material. It is a result of this intricate maze of labyrinths through which the particle laden water had to navigate and the depth filtration mechanism that the percentage e-coli removal efficiency of set B filters with composition ratios of 3:1:1 and 4:2:1 was 100%. This result was excellent according to USEPA and WHO guidelines which recommend that drinking water should have zero e-coli colony forming.

Results from table 4 and Table 7 show that set C filters, which had the highest percentage composition by volume of sawdust and grog, had the highest water turbidity values and the least e-coli removal efficiency ranging between 8.4FNU to 13.4FNU and 30.0% to 94.0%, respectively. These values suggest that bigger pores were created in set C filters due to the high sawdust content in their composition. Hence many of the suspended particles were able to filter through them since the filtration mechanisms of direct interception or sieving were rendered ineffective.

These results were also observed to be above the standards of drinking water turbidity recommended by USEPA and WHO guidelines. Results obtained also showed that the percentage e-coli removal efficiency for the set A, set B and set C filters ranged from 50.3% to 96.7%, 91.6% to 100.0% and 27.3% to 99.3%. These results are in line with the finding of Kabagambe (2010). They also showed a direct relationship between the e-coli removal efficiency of the filters with the composition of the filters, the higher the percentage by volume of sawdust in the composition of the filters the less the effectiveness of the filter in removal of pathogens.

4. Conclusion

This paper presents the results of experimental study on the effect of introducing grog to the composition of ceramic water filters and shows how the filters are made by sintering of well controlled mixtures of clay, sawdust and grogs. The best quality water was obtained for set B filters when the filter composition ratio for clay: grog: sawdust was 4:1:2, 3:1:1 and 4:2:1. At these filter composition ratios, the water turbidity in FNU per 10ml of water filtered were measured to be 2.14, 2.12 and 1.47 respectively. The same composition ratios exhibited excellent e-coli removal efficiencies of 100% (Table 9).

These results were within the standards of drinking water turbidity recommended by USEPA and WHO guidelines. Set C filters indicates an increase in the rate of water percolation however, such mixtures compromised on the quality of the water obtained. Therefore it is important that colloidal silver would be essential to kill the pathogens in the filtered water. Thus, we conclude that presence of grogs greatly affects the performance of the ceramic water filters. Much more proportion of sawdust improves on the filtration rate, but at the expense of the quality of water filtered and high proportion of grog and clay improves on the quality of water filtered at the expense of the rate of filtration.

Acknowledgements

The research is supported by Physics Department, Kyambogo University; Uganda Industrial Research Institute (UIRI), Physics Department, Makerere University and Faculty of Veterinary Medicine, Makerere University.

References

1. Albert J, Luoto J, and Levine D (2010). "End-user preferences for and performance of competing PoU water treatment technologies among the rural poor of Kenya." *Environ. Sci. Technol.*, 44(12): 4426-4432.
2. Clair Matteiletea 2006. *House hold ceramic filter evaluation using three simple low cost methods: membrane filtration, 3m Petri film and Hydrogen sulphide bacteria in Northern region Ghana*. Mscthesis. Massachusetts Institute of technology (USA).
3. Clasen T Schmidt, WP Rabie, T Roberts I and Cairncross S (2007). "Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis." *BMJ*, 334(7597): 782-791.
4. Crittenden JC et al. 2005. *Water treatment: Principles and design*. 2nd edition; John Wiley & Sons. Inc., New Jersey.
5. Dies RW (2003). "Development of a ceramic water filter for Nepal." M.Eng. thesis, Massachusetts Institute of Technology, Cambridge, MA.
6. Farahbakhsh K and Smithe DW (2004). *Removal of Coliphages in Secondary Effluent by Microfiltration-Mechanism of Removal and Impact of operating Parameters*. Walter Research, 38: pp. 585-592.
7. Fewtrell L Kaufmann, RB Kay, D Enanoria, W Haller L and Colford JM Jr (2005). "Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis." *Lancet Infect. Dis.*, 5(1): 42-52.
8. Hans-wolf Ranhardt and Martin Jods 1998. *Permeability, Diffusion and Capillarity absorption of concrete at elevated temperatures*. Otto-Graf-Journal, 9: 34-47
9. http://en.wikipedia.org/wiki/water_supply_and_sanitation_in_Uganda; accessed on 20th December 2010.
10. Hwang REY (2003). "Six-month field monitoring of point-of-use ceramic water filter by using H\2082S paper strip most probable number method in San Francisco Libre, Nicaragua." M. Eng. thesis, Massachusetts Institute of Technology, Cambridge, MA.
11. Jawetz, Melnick & Adelberg (2010). *Medical Microbiology*, 24th Edition by Vishal. The McGraw-Hill Companies.
12. Kabagambe Musa (2010). *Performance of ceramic water filters made from selected Ugandan clays for point-of-use*. Masters dissertation. Makerere University, Kampala.
13. Katherine L Clopeck and Lauren E Foster (2000). *Implementation of an appropriate house-hold water purification system in Tourou*,

- Cameroon.www.sys.virginia.edu accessed on 17th November 2010.
14. Kenneth D Kerri (2008). *Water Treatment Plant Operation Volume 1.6th edition*. California State University (USA)
 15. Kingery, Bowen and Uhlmann (1976). *Introduction to ceramics* 2nd edition, John Wiley & Sons, Inc. New York
 16. Kirabira John Baptist (2005). *Properties of Ugandan minerals and fireclay refractories*. PhD Thesis in material science. Stockholm, Sweden.
 17. Kosek M, Bern C and Guerrant RL (2003). *The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000*. Bull World Health Organ, 81: 197–204.
 18. Lantagne DS (2006). *Investigation of the Potters for Peace colloidal silver impregnated ceramic filter: Report 2: Field investigations*. Boston: Alethia Environment. [Accessed: 6 April 2010].
 19. Lantagne D Klarman, Mayer M, Preston A, Napotnik K J andJ ellison K (2010). "Effect of production variables on microbiologicalremoval in locally-produced ceramic filters for household water treatment."Int.l J. Environ. Health Res., 20(3): 171–187.
 20. 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).
 21. Matovu Fred (2012). *The expenditure review for Uganda 2012*. Directorate of Social Protection Gender Ministry, Kampala.
 22. ObwoyaKinyera Sam (2004). *Effects of microstructure on mechanical strength of selected clays from Uganda*.Ph.D. Thesis. MakerereUniversity, Kampala.
 23. Oyanedel-Craver VA and Smith JA (2008). "Sustainable colloidal silver-impregnated ceramic filter for point-of-use water treatment."Environ. Sci. Technol., 42(3): 927–933
 24. Prajapati HG (2002). *Madhyapur Clay Crafts*.Email correspondence with Jason Low.
 25. Ragland KW, Aerts DJ and Baker A J (1991).*Properties of wood for combustion analysis*.Bio-resource technology, 37: 161-168.
 26. Republic of Uganda; Ministry of Finance, Planning and Economic Development.*Poverty Eradication Action Plan (2004/5-2007/8)*; p. 182-188.
 27. Robert W Dies (2003). *Development of a ceramic water filter for Nepal*.Dissertation for Master in Civil and Environmental Engineering, MIT.
 28. Rugang Chen, Hong Chen and Robert W Besant (2004). *Properties required for moisture transport by capillary, gravity and diffusion in potash beds*. Ind. Eng. Chen. Res, 43: 5365-5571.
 29. Sagara J (2000). *Study of filtration for Point-of-Use Drinking Water in Nepal*.Master of Engineering in Civil and Environmental Engineering, Massachusetts Institute of Technology.
 30. SkyerMcallister (2005). *Analysis and comparison of sustainable water filters*.EPD397 Technical report.<http://pottersforpeace.org> accessed on 28th November 2010.
 31. Sobsey MD (2002). *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*. Geneva: World Health Organization (WHO/SDE/WSH/02.07).
 32. Sobsey MD, Stauber CE, Casanova LM, Brown JM, and Elliott MA (2008). "Point of use household drinking water filtration:A practical, effective solution for providing sustained access to safedinking water in the developing world." Environ. Sci. Technol., 42(12): 4261–4267.
 33. Swanton AA (2008). "Evaluation of the complementary use of theceramic (Kosim) filter and Aquatabs in Northern Region, Ghana."M.Eng. thesis, Massachusetts Institute of Technology, Cambridge, MA.
 34. WHO/UNICEF, (2010).*Meeting the MDG Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress*. Geneva and New York: World Health Organization and UNICEF.
 35. Van Halem D (2006). "Ceramic silver impregnated pot filters for household drinking water treatment in developing countries." M.S. thesis,Delft Univ. of Technology, Delft, Netherlands.