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Fabrication, physico-mechanical properties and turbidity reduction of disk-shaped ceramic water filters made for peri-urban rivers

EBENEZER ANNAN[1], DAVID KONADU[1,*], KEZIAH N GEORGE[1] and ALFRED ATO YANKSON[2]

[1]Department of Materials Science and Engineering, University of Ghana, Legon, Accra, Ghana
[2]Department of Physics, School of Physical and Mathematical Sciences, University of Ghana, Legon, Accra, Ghana
e-mail: dskonadu@ug.edu.gh

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Abstract. Disk-shaped ceramic water filters were fabricated using kaolin and bentonite clays. The pore former was sawdust with three different sizes: 150 μm, 250 μm and 350 μm. The plasticity index of the Saltpond kaolin and Abonko clay in the ratio of 1:1 showed medium plasticity index of 14.9. The volume of water filtered was observed to increase with increasing sawdust particle size for all disks. The volume of filtered water was observed to increase for consistent consecutive run of disk filters. The flow rate in the first hour for disks used for Ahwiam river was 73 ml/hr and that for Ashiyie river was 108.2 ml/hr. The results from turbidity, total suspended solids (TSS) and total dissolved solids (TDS) suggested that the ceramic water disk filters as a household technology showed great potential as a partial treatment for peri-urban communities.

Keywords. Disk filters; clay filters; flow parameters; water treatment and flow rate.

1. Introduction

Ceramic water filters are used by most peri-urban and rural communities in developing countries as water storage system locally called “pots” and recently, as a water treatment system [1]. The use of ceramic water filters is socially, financially, and culturally sustainable. In achieving the Millennium Development Goals (MDG’s), the contribution of ceramic water filters will be significant in the pursuit of targets for Sustainable Development Goals (SDG’s) (SDG3—for good health and well-being, and SDG 6—for clean water and sanitation) [2, 3].

Globally, 80% of wastewaters are released into the environment without treatment. And also, 1.8 billion individuals use contaminated drinking water with faecal particles, which might lead to risk of contracting cholera, dysentery and typhoid [4]. In most Sub-Sahara Africa countries, wastewaters from certain centers are untreated before being discharged into drainage networks. These plants are not designed to remove complex pharmaceuticals particles [5]. Peri-urban communities that do have water bodies depend on these wastewaters, seen as water reservoirs, for various uses. In cases where industrial liquid wastes are not channeled to the water bodies, it competes with other waste materials in degrading the environment. The health of living organisms that depend on this channel of industrial wastewater could be affected. It is therefore, important to engineer affordable, acceptable and sustainable water treatment systems that can offer appreciable contribution to achieve SDG’s [6].

In Ghana, about 60% of water bodies are polluted with most of them in critical conditions [7]. The quality of groundwater and surface water resources keeps worsening. This is mainly due to soaring levels of pollution from “galamsey” (illegal mining), domestic or industrial waste, leachate from chemical fertilizers and pesticides used in agriculture. Others are chemicals from mining, and use of chemicals in fishing coupled with rapid population growth [8]. The quantity and quality of fresh water are still a major problem in most parts of Ghana as people resort to use rainwater, surface water, and shallow groundwater as their drinking water sources [8]. There is urgent need to improve the quality of fresh-water bodies in these areas. The use of affordable, acceptable and sustainable treatment technology should be encouraged, and ceramic water filters are no exception.

Ceramic water filters are basically mixtures of clays, sawdust (combustible materials), and water. The mixture is molded into the required shape and fired at temperatures depending on properties of the clays but usually above 700°C for effective sintering. The combustible material in the mix, burns out at temperatures around 280–350 °C

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*For correspondence

creating pores [9, 10]. Current manufacturing practice suggests that for frustum-shaped ceramic water filter, average minimum flow rate in the first hour should range from 1.0–3.0 l/hr while the average maximum flow rate should be from 2.0–5.0 l/hr [11]. The main factors that affect the flow rate are the size and quantity of the combustible material [12], sintering temperature [13], size and network of pores [14, 15] and nature (size) of clay particles [16–18]. With no guideline for flow rate for disk-shaped ceramic water filters, hydraulic conductivity is mostly relied on by most authors. Bensah *et al* [19] theorized the framework to compute flow from full size filters [19]. Other authors have given various values for their fabricated disk-shaped ceramic water filters [20]. Disk-shaped ceramic water filters have been used for trapping and disinfection of biological contaminants [21–23]. Their effectiveness is mainly due to two mechanisms; mechanical screening and colloidal silver (silver nanoparticles) impregnation. The release of silver into water during treatment has been investigated and reported to be within the WHO guidelines on contaminants in water [24].

Research involving full size ceramic water filters are very tedious considering quantities of materials to be used, large volumes of water required, etc. As such, there have been increasing interest in the use of disk-shaped filters. Various authors have discussed the implications of different materials and other input parameters, and their effect on flow for ceramic water filters [19, 25, 26]. Researchers have demonstrated the anti-bacterial effectiveness of the ceramic water filters through use of disk filters [22, 27]. In this research, we investigated the turbidity removal of rivers in the peri-urban communities and ascertained the effectiveness of the disk-shaped ceramic water filters as complementary filtering partial unit to a household treatment system. The flow and other properties that affect efficiency of household water treatment technology were examined and discussed. This paper has two main objectives; (1) fabricate disk-shaped ceramic water filters using two local clays, and (2) explore the extent to which the choice and particle size of sawdust affect flow and physical quality of water.

2. Materials and methods

2.1 *Materials identification and preparation*

Two locally sourced clays, Abonko bentonite clay and Saltpond kaolin clay were used to fabricate the ceramic disk water filters. Both clays were mined from the Central Region of Ghana and were selected based on their chemical composition. Saltpond kaolin clay has a low-shrink swell capacity and appreciable surface area whereas Abonko clay is highly plastic [10]. The combustible material used was sawdust at different particle sizes; 150, 250 and 350 µm. The sawdust was obtained from a local woodshop on the University of Ghana campus, Legon–Accra. The 425-micron size powders of the clays were obtained through further sizing using ball milling (PQN4 Planetry Mill Across Int., New Jersey, USA) and then screened. The obtained sawdust was first sun-dried and further milled using mortar and pestle to ensure size adherence via series of sieves. The clays were mixed in the ratio 2:2:1 (% by volume) of Abonko, Saltpond kaolin and sawdust.

The water sources for this project were Magbadza River (from Ahwiam henceforth denoted as AHSD) and Ashieyie River (from Ashiyie henceforth denoted as ASSD) in the Ningo-Prampram district and La Nkwatenang district, both in Accra–Ghana respectively and were contaminated. The water samples obtained were characterized through various standard water testing methods. As of the year 2010, the population of the La Nkwatenang district was about 111,926, and 76,386 people for Ningo-Prampram district, Accra Ghana respectively [28].

2.2 *Materials and characterization*

X-ray diffraction (XRD) analysis was carried out on Abonko clay and Saltpond kaolin which were used in the fabrication of the water filters. Using XPERT-PRO diffractometer (PANalytical BV, Netherlands) with 2Θ geometry, the system was operated in a cobalt tube at 35 kV and 50 mA. The goniometer was equipped with automatic divergence Slit and a PW3064 spinner stage. The XRD patterns of all specimens were recorded in the (10°–80°) 2θ range. Qualitative phase analysis was conducted using the X'pert HighscorePlus software (v. 4.8) and with the ICDD PDF-4/Organics 2020 database (PANalytical B.V, ALMELO, Netherlands) [29].

2.3 *Disk-shaped ceramic water filters fabrication*

The filters were compacted using a pressing system with pressure between 3–5 tonnes for various mixtures of the Saltpond kaolin, Abonko clay and sawdust. The various batches for the filters are presented in table 1. The green filters were air-dried at room temperature 25 ± 2°C for two weeks and then fired at 800°C. A disk filter has an average

Table 1. Ceramic water disk filters and batches produced from kaolinite:bentonite clays of 1:1 ratio and fired at 800°C.

Disk filters type	Batch (number of fabricated disk filters)	
Sawdust size	AHSD (disk filters for Ahwiam river)	ASSD (disk filters for Ashiyie river)
150 µm	AHSD1 (5)	ASSD1 (5)
250 µm	AHSD1 (5)	ASSD1 (5)
350 µm	AHSD1 (5)	ASSD1 (5)

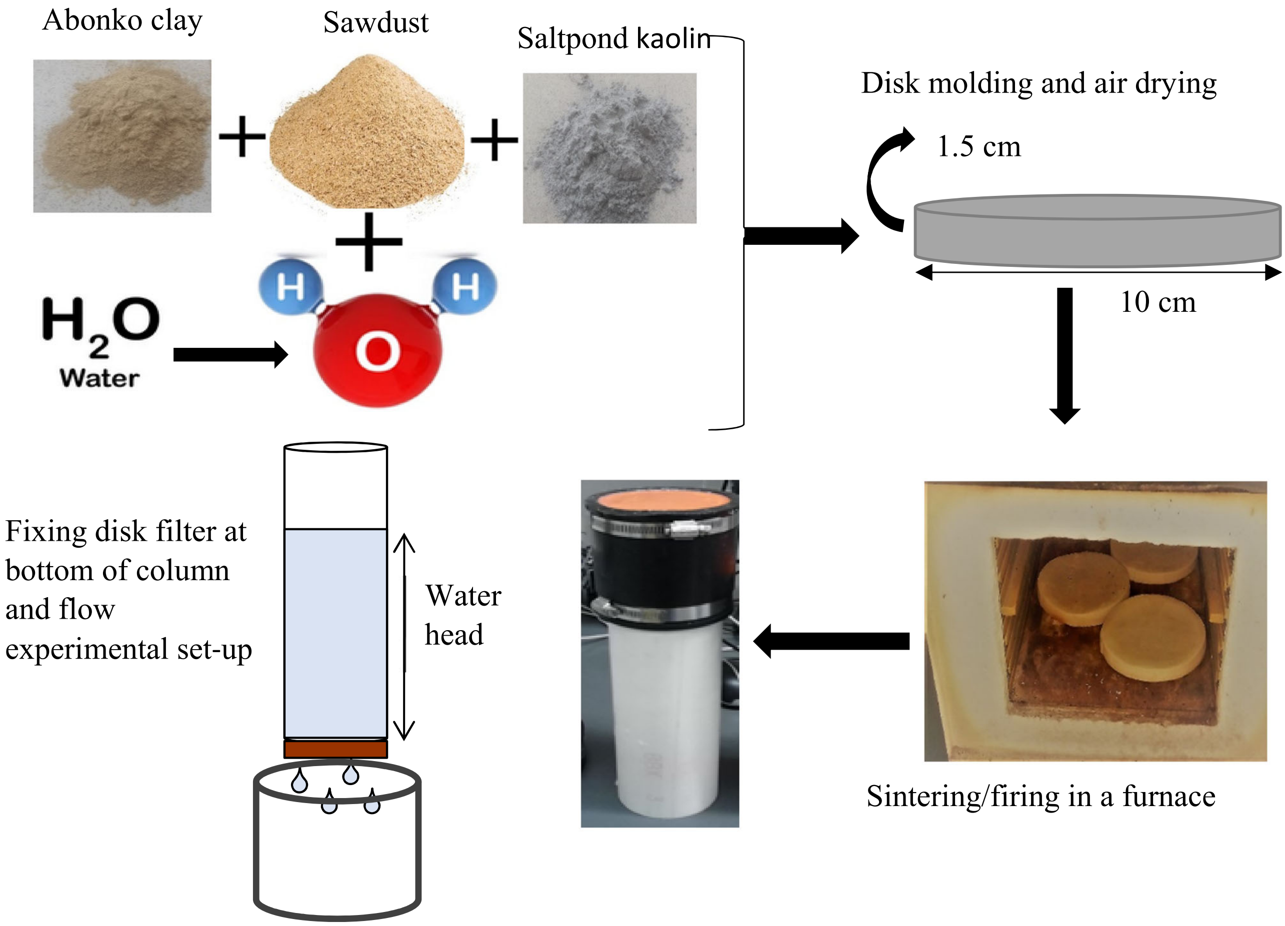

Figure 1. Schematic diagram of experiment.

diameter of 10 ± 0.2 cm and thickness 1.5 ± 0.1 cm. Each batch had five fabricated discs but three disks were used for the experiment. The flow system was filled with 2 L of water sample and allowed to go through the disk filter under gravity. The volume of filtered water was measured after each hour till the eighth (8^{th}) hour. The flow experiment was repeated each hour twice, and the average volume of water was computed.

The pH, turbidity, total dissolved solids (TDS) and total suspended solids (TSS) of the water samples were measured. The pH test and TDS were measured using Jenway 570 pH meter and Hanna Combo pH respectively. The turbidity test of the water samples was measured using 2100P turbidimeter Hach and the TSS was performed with Hach portable datalogging spectrophotometer DR/2010. Other chemical analysis such as iron, magnesium and fluoride tests were ignored and not included in this data because of its values which falls within the WHO limit.

Plasticity index is the difference between liquid limit (LL) and plastic limit (PL). The plasticity index (PI) of the clay samples was undertaken to measure the range of moisture content over which the soil remains plastic. The test was performed using ASTM standard test method D4318. The PI was determined employing the Casagrande instrument and was calculated using equation 1:

$$PI = LL - PL \tag{1}$$

The water of absorption (WA), apparent porosity (AP) and bulk density (BD) were determined using the standard testing method ASTM C373. WA gives an estimated measure of the extent to which the product is susceptible to seepage of water through its pores when immersed in water [30]. Test samples were prepared by mixing Abonko clay, Saltpond kaolin clay and sawdust in the ratio 2:2:1 respectively and adding a little amount (10 ml) of water gradually to coalesce and made into a paste. The mixed samples were transferred into a wooden mold of dimensions 6 cm × 3 cm × 2 cm and pressed into the mold to assume the shape of the mold and finally, air dried for two weeks at room temperature of 25°C. The dried sample was fired to a temperature of 800°C after removing moisture through oven heating. The weight of the fired samples was measured and recorded (Dw). The fired sample was then immersed in a bowl of water for an hour. It was then re-weighed to determine the quantity of water absorbed (Sw). The absorption percentage was calculated using equation (2).

$$\%\text{Water of absorption (WA)} = \frac{Sw - Dw}{Dw} \times 100\% \quad (2)$$

AP is the proportion of the bulk volume represented by the spaces or pores communicating with each other and with the outside atmosphere [30]. The same procedure for the measurement of WA was followed and the sample was weighed, Wa.

Fired test piece was placed in a 1 L beaker into which water was poured until the water level in the container was about 3 cm above the topmost test pieces in the container. The setup was boiled on the burner for five (5) hours while continuously adding water to ensure the 3 cm level was maintained due to evaporation. After 5 hours, the sample was taken out and weighed (Wb). All the water droplets were cleaned from the sample and then weighed in air (Wc). AP was calculated based on equation (3).

$$\%\ \text{Apparent porosity (AP)} = \frac{Wc - Wa}{Wc - Ww} \times 100\% \quad (3)$$

Bulk density is the weight of soil in each volume or mass per unit volume of a material [31]. The sample obtained after following the same procedure for the measurement of WA was weighed after firing the test piece (Wa), the volume (V) of the test piece was determined using the dimensions of the mold and the bulk density (BD) was calculated using equation (4)

$$\text{Bulk Density (BD)} = \frac{mass}{bulk\ volume} = \frac{Wa}{V} \quad (4)$$

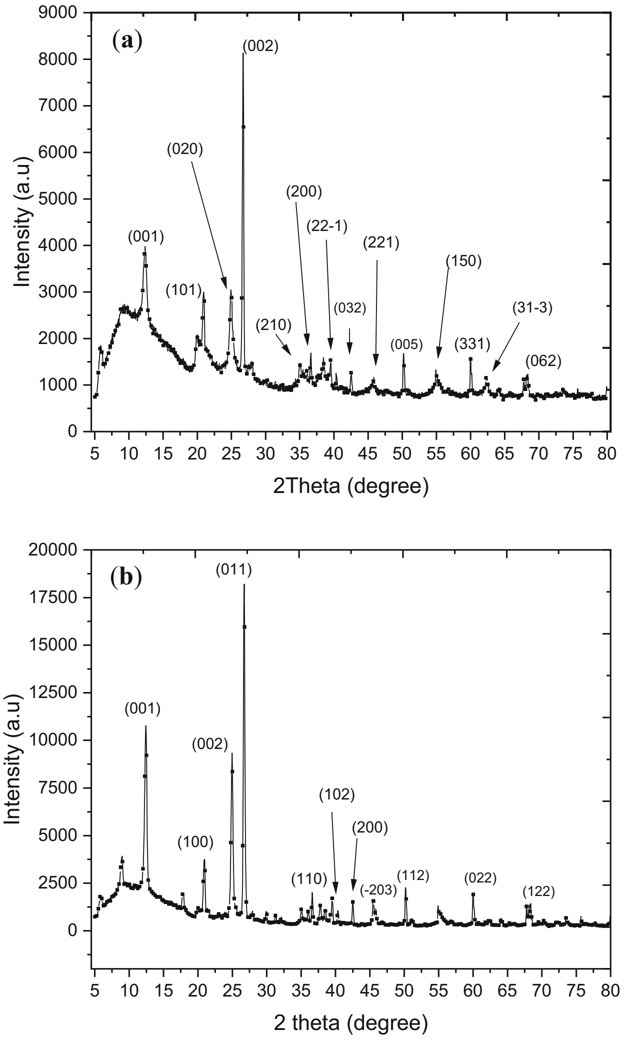

Figure 2. XRD spectra of (a) Abonko clay and (b) Saltpond kaolin.

Table 2. Identified list of XRD pattern for Abonko clay.

Reference code	Score	Compound name	Chemical formula
00-058-2034	49	Potassium Aluminum Silicate Hydroxide	$K\ Al2\ (Si, Al\ )_4\ O10\ (O\ H\ )_2$
00-058-2004	43	Aluminum Silicate Hydroxide	$Al2\ Si_2\ O_5\ (O\ H\ )_4$
01-085-1054	61	Silicon Oxide	$Si\ O_2$

Table 3. Identified list of XRD pattern for Saltpond Kaolin.

Reference code	Score	Compound Name	Chem. Formula
00-029-1488	48	Aluminum Silicate Hydroxide	$Al2\ Si_2O_5\ (O\ H\ )_4$
98-006-8698	40	Kaolinite 1A	$H4\ Al_2\ O_9\ Si_2$

Table 4. Turbidity of water samples.

Water sample	Treatment	Turbidity (NTU)
AHW (Ahwiam river)	Before	273.00
ASW (Ashiyie river)	Before	39.20
AHW	AHWA, with Alum	10.90
AHW	AHSD1 - Disk filter, 150 µm sawdust size	1.58
AHW	AHSD2 - Disk filter, 250 µm sawdust size	2.55
AHW	AHSD3 - Disk filter, 350 µm sawdust size	6.79
ASW	ASWA - Alum	3.05
ASW	ASSD1 - Disk filter 150 µm sawdust size	0.88
ASW	ASSD2 - Disk filter 250 µm sawdust size	0.87
ASW	ASSD3 - Disk filter 350 µm sawdust size	1.12
TAP WATER	As obtained from laboratory	0.99
WHO GUIDELINE (2008)		5.00

Table 5. Total suspended solids (TSS), total dissolved solids (TDS) and pH of water samples.

Water samples (description)	TSS (mg/L)	TDS (ppm)	pH
AHW	228	148	6.47
ASW	161	195	5.97
AHWA	86	201	3.76
AHSD1	23	212	7.11
AHSD2	46	208	5.21
AHSD3	79	172	5.93
ASWA	16	300	3.88
ASSD1	13	506	6.33
ASSD2	27	260	5.19
ASSD3	56	471	6.13
TAP WATER	0	5	7.03
WHO GUIDELINES FOR DRINKING WATER (2008)	500	1000	6.5 – 9.2

2.4 *Flow experiments*

The set-up for the flow experiment is shown in figure 1. 2 L of river sample was poured into a vertical column and then allowed to flow under gravity. The vertical column has a height of 25 cm and diameter of 4 inches (10.16 cm). The permeability and flow rates at various times were computed. The filtered water was decanted, and the physio-chemical analysis of the water sample was undertaken. The flow experiment was carried out over eight (8) hours and for each hour, the flow rate was computed. For each disk filter, three flow (over 8 hours) were undertaken, thus for disk filters: AHSD1, AHSD2, AHSD3 and ASSD1, ASSD2, and ASSD3, each had a flow experiment undertaken three times (henceforth referred to as 'run') and the flows were continuous. It was important to note that each filter batch had five fabricated discs (and three were used) and the flow experiment was done for the three different particles sizes of 150 µm, 250 µm and 350 µm. Each disk for a particular batch was tested for the three runs separately. Different disks but same configuration was adopted for each run.

The hydraulic conductivity values of the disc filters were computed using Darcy's equation of flow through porous media. The Darcy equation is given by

$$Q = kA\frac{\Delta P}{\mu L} \tag{5}$$

Where Q is the discharge from the porous media, A is the surface area which holds the water, ΔP is the pressure-head of water dependent on height Δh, K is the hydraulic conductivity of the porous structure and L is the thickness of the porous media through which the water needs to percolate.

The hydraulic conductivity K, term is defined as

$$K = \frac{\gamma k}{\mu} \tag{6}$$

Where µ is the viscosity of water at a given temperature, γ is the specific gravity of water at that temperature, and k is the intrinsic permeability defining the porosity and interconnectivity of the porous media.

3. Results and discussion

3.1 *X-ray diffraction studies*

The XRD analysis results of the clays are shown in figure 2 with tables 2 and 3 giving the various compounds present. Basically, the compounds silicon dioxide and aluminium silicate hydroxide were the same in both clays, but Abonko clay showed more mineral quartz (silica) content. The percentage ratio of silica to alumina has influence on plasticity index of the clay mixture. The Saltpond kaolin was found to be far less plastic than Abonko clay (which is a bentonite) and hence the mixing of the two clays in the 1:1 proportions produced an intermediate plasticity index,

Table 6. Plasticity index data.

Sample identification	Atterberg test (%)			PI description (ASM D4318-10)
	Liquid limit	Plastic limit	Plasticity index	
Saltpond Kaolin	40	27	13	Low
Abonko Clay	60	25	35	High
Kaolin and Abonko	42.6	27.7	14.9	Intermediate

Table 7. Water of absorption, apparent porosity and bulk density of the disks.

Sample Code	Combustible type (size)	Composition K:A:C (by volume)	Fired weight (%)	Soaked weight (%)	Water of absorption (%)	Bulk density (g/cm^3)	Apparent porosity
Avg. BSD300	Sawdust (350)	2:2:1	31.27	45.91	46.88	0.87	0.44
Avg. BSD250	Sawdust (250)	2:2:1	29.40	41.68	41.78	0.82	0.42
Avg. BSD150	Sawdust (150)	2:2:1	28.20	39.17	39.90	0.78	0.40

which optimized pressing and thermal shock resistance for ceramic water filter fabrication and application [10, 32].

The XRD plots of both clays showed diffraction peaks that are observed in literature and database to conform to kaolin and bentonite. Tables 2 and 3 give the major phases in the analyzed samples, which were kaolinite and quartz (silica). This was observed after comparing the plots peaks with the ICDD in the match protocol in HighscorePlus in the XRD equipment indicated in section 2.2. The miller indices for the planes as indicated on the XRD plots in figure 2 were undertaken via the references [33–35].

3.2 *Analysis of water samples*

Tables 4 and 5 show the results obtained for some physical and chemical tests undertaken on the water samples. The two water sources, Ahwiam and Ashiyie were found to have high turbidity values of 273 and 39.2 Nephelometric Turbidity Unit (NTU), which were far above the WHO limit of 5 (table 4) but that of Ahwiam was very high. All the disks were found to lower the turbidity within acceptable WHO limits, except AHSD3 with a value of 6.79 NTU. This might be due to the pores which were generated because of using sawdust particle sizes of 350 μm. The 6.79 NTU might also be due to the high turbidity value of the Ahwiam river. This suggests that the 350 μm disk-shaped ceramic filter will not be good for people using that river. The results indicated that the smaller the particle size of the combustible material, the lower the turbidity level and therefore the filtered water will be complaint to WHO standards. The residents in these communities depend on 'alum' (aluminum sulphate) to treat these waters. From table 4, it was also observed that the filtration of the ceramics disks performed better in the Ashiyie river compared to the Ahwiam river. This was expected. as the turbidity was high for the Ahwiam river comparatively. The turbidity of the two water samples were reduced to 10.9 and 3.05 for Ahwiam and Ashiyie rivers respectively using alum. Chemical aspects on water treatment using alum are exhaustively considered by Van Benschoten *et al* [36]. It is interesting to note that ASSD1 and ASSD2 revealed lower values of turbidity compared to tap water values (table 4).

The results obtained for TSS, and TDS are presented in table 5. The results showed that the TSS values after treatment of the water were further reduced for all forms of treatment and disk filter used. It is important to note that the TSS values prior to treatment for both water samples were also compliant to WHO guidelines. The TSS value for Ahwiam water sample was greater than the Ashiyie water. It was observed that the disk filters used for Ahwiam water samples were more effective in reducing the TSS compared to same type of disk filters used for Ashiyie waters. This might be attributed to the water source as the values obtained before treatment was higher for the Ahwiam water sample compared to the Ashiyie water sample since the ceramic disks are the same (table 5). The turbidity and TDS values obtained for the ceramic disk filters confirmed literature [25, 37].

For the TDS data, all the treatment forms adopted were found to increase the TDS values, though far below the WHO guidelines. Another observation was that the disks used for Ashiyie water samples were found to have TDS values nearly twice its pre-treatment value. This may be due to spalling from the disk edges or surfaces. Probably,

Table 8. Hydraulic conductivity values for fabricated disc filters.

Disk filter configuration	Hydraulic conductivity (x 10^{-5} cm/s)
AHSD1	8.70
AHSD2	8.77
AHSD3	8.03
ASSD1	8.33
ASSD2	8.22
ASSD3	7.77

the sintering temperature of 800°C should be increased for proper adhesion of particles to avoid the spalling [17, 38]. This sintering temperature was the highest the furnace used could attain. This probable spalling of the disks does not affect the filtered water since even when the turbidity was twice its original value, it was below WHO guidelines. Again, it was important to reassess the PI of the disk to ensure the ceramic will not disintegrate from its parent matrix [39, 40].

The residents in these locations use alum as their main water treatment method. The use of alum was found to increase the acidity of the treated water with a pH of 3.76 and 3.88 for Ahwiam and Ashiyie water samples respectively. The increase in acidity of the alum-treated water samples is attributed to hydroxide complex formation by chemical reactions during coagulation [36, 41].

3.3 *Physical properties and strength of filters*

The fired ceramic disk water filter can be seen in figure 1. It was observed that the filters had a disk shape with the dimensions as given in the experimental procedure. The results obtained for the PI for various mixtures are given in table 6. All filters were fabricated using the moderate range plasticity index of clay mixtures. The results for WA, AP and BD are presented in table 7. It can be seen that, generally the WA increases with an increase in the particle size of carbonaceous materials. For sawdust with particle size 350 µm, the average WA was 46.88% which happened to be the highest among the various carbonaceous materials. This was followed by sawdust with particle size 250 µm and 150 µm with WA averages of 41.78%, and 38.90% respectively. This showed that the bigger the sawdust particle sizes, the more water the disks filtered which can be related to the pore sizes within the ceramic disks.

It was observed that for sawdust with particle size 350 µm, the average AP was 0.44 which happens to be the highest among the various carbonaceous materials. This was followed by sawdust of particle sizes 250 µm, and 150 µm with average AP values of 0.422 and 0.401 respectively. This could also be attributed to the larger pores generated by the larger sawdust particles [17]. It also showed that the pores were connected during firing and might be due to proper mixing of the mixture during preparation.

3.4 *Bulk density and strength of filters*

The bulk density increased as the pore sizes decreased, though minimal. The BD results obtained for the various batches are represented in table 7. It can be inferred from the results that, BD is generally decreasing from BSD350, BSD250 and to BSD150 (table 7). The mechanical robustness of the filters can be deduced to be highest for smallest particle size of combustible materials provided all other sintering conditions remained the same. The particle size of the combustible materials affected the porosity of the ceramic disk filter. It also affected the mechanical robustness of the disk filters since increased quantity of the sawdust resulted in greater number of pores and reduction in the plasticity of the clay mix [10, 39]. Furthermore, it is important to note that the quantity and size of the sawdust affected the flow characteristics as well. Therefore, the particle size of the sawdust should not be chosen without theorizing its effects on strength and flow characteristics of the filters. In this investigation the same quantity of sawdust was used for all disk filters produced, only the particle size of the sawdust was varied.

3.5 *Flow analysis and implications*

Flow rate in the first hour of filtration is crucial. The magnitude is dependent on the nature of the filter before use. When the filter is not pre-soaked in ‘clean’ water, the system will require a time transient to achieve equilibrium in flow. The magnitude of the first flow rate has been observed to be greater in situations where the filter is pre-soaked than when it was not. In this investigation, the filters were not soaked prior to flow experiment. The average flow rate for disks used for Ahwiam river (AHSD filter set) was 73 ml/hr and disks for Ashiyie river (ASSD filter set) was 108.2 ml/hr. The average flow rate of disks was found to be 74.3 ml/hr, 80.5 ml/hr and 117 ml/hr for disks made from 150 µm, 250 µm and 350 µm particle sizes of sawdust respectively. It is important to note that irrespective of the water physico-chemical nature, the flow for first three runs revealed an increasing flow with sawdust particle size. The results showed increasing flow rate with increasing sawdust particle size used in the disk filters production [17, 25, 26]. This observation can be linked to the turbidity removal level of the disks. The Ahwiam water was more turbid than the Ashiyie river and the filtration of the ceramic disks followed the order of lower turbidity values for the Ashiyie river compared to the Ahwiam river. Similar observations concerning disks efficiency could be seen for TSS and TDS data before and after treatment.

Table 9. Flow parameters of filters with Ashiyie River at the eighth hour.

Flow parameters Average values	ASSD1	ASSD2	ASSD3
Volume (cm^3)	434.67 ± 21.73	460.33 ± 23.02	495.67 ± 24.78
Water Head Loss (cm)	5.36 ± 0.27	5.68 ± 0.28	6.11 ± 0.31
Flow Rate (cm^3/hr)	54.33 ± 2.72	57.54 ± 2.88	61.96 ± 3.10

Table 10. Flow parameters of filters with Ahwiam at the eighth hour.

Flow parameters average	AHSD1	AHSD2	AHSD3
Volume (cm^3)	324.67 ± 16.23	326.33 ± 16.32	414.67 ± 20.73
Water head loss (cm)	4.00 ± 0.2	4.02 ± 0.201	5.11 ± 0.256
Flow rate (cm^3/hr)	40.58 ± 2.03	40.79 ± 2.04	51.83 ± 2.59

Note – SD is sawdust.

The results obtained for the hydraulic conductivity values of the various disc filters are computed and given in table 8. The flow characteristics for the combustible materials of particle sizes: 150 µm, 250 µm, and 350 µm for filter batches ASHDn and ASSDn are given in tables 9 and 10. The total average volume of water filtered at the eight-hour experiment for ASSD1, ASSD2 and ASSD3 was 434.67 ml, 460 ml and 495.67 ml respectively. The water-head loss is in increasing depth from ASSD1 to ASSD3. The flow rate values of the ASSDn set also agrees with water-head loss and total volume filtered. The flow rate for AHDn set filters was in the order, AHSD3>AHSD2>AHSD1. This can be explained by the values obtained for water-head loss and hydraulic conductivity. The higher the hydraulic conductivity value, the more volume of water that can be filtered [17, 19].

Also, the particle size of the sawdust determined the pore size of the sintered filters. The pore size and number of pore distribution largely affected the flow rate of the filter. The more inter-connected pores in the filter, the higher the volume of water that could be filtered within the same filtration period [17, 26]. In cases where isolated pores are more than the inter-connected pores, the water head loss will be less and thus, volume of water filtered may be obviously less. Water molecules that may be trapped in isolated pores may affect the mechanical robustness of the disk filter. It was therefore important to ensure proper mixing of combustible materials with parent clays to ensure uniform but much inter-connected pores. The results generally revealed that the flow rate decreased with decreasing saw dust particle size, thus suggesting that the mixing of the mixture was good.

Furthermore, to understand flow through disk ceramic filters during continuous usage, each disk was run three times continuously with each time stretching the eight-hour period. The computed flow rate data for the disk filters the water samples for eight-hour successive runs is provided in figure 3. The data showed equal volume of water produced for each hour in both respective disks for the water samples. The volume of water for disk AHSD3 and ASSD3 for both river samples were higher than the first two—showing increasing volume from disk 1 to disk 3. This may be due to the pore distribution and size that was produced by the sawdust. The flow rate for disks filters was found to be decreasing with time for all runs. This is due to decreasing pressure head of water in the column and possible clogging of pores [17, 25]. Again, for each run, the flow rate was found to be decreasing. This was the case for all disk filters for both water samples.

The values obtained for the flow rates were lower than that published in works by Zhao *et al* [42] but comparable to Heylen *et al* [38]. Zhao *et al* [42] reported 124 mL/hr and 119.3 mL/hr for the ceramic water filter disk produced. The difference in this flow value may be due to properties of the disk filter. For instance, although they both have same diameter (10 cm) the thickness of the disk filters by Zhao *et al* [42] was 1 cm as compared to 1.5 cm (in this work) whereas in Heylen *et al* [38] the disk diameter was 8 cm and at 880 °C and 950 °C firing temperatures. Increase in the thickness of the disk ceramic water filter is associated with decrease in the flow rate. Other properties such as, pore size, hydraulic conductivity and waterhead are key factors in the determination of flow rate as demonstrated by Shuaib-Babata *et al* [37].

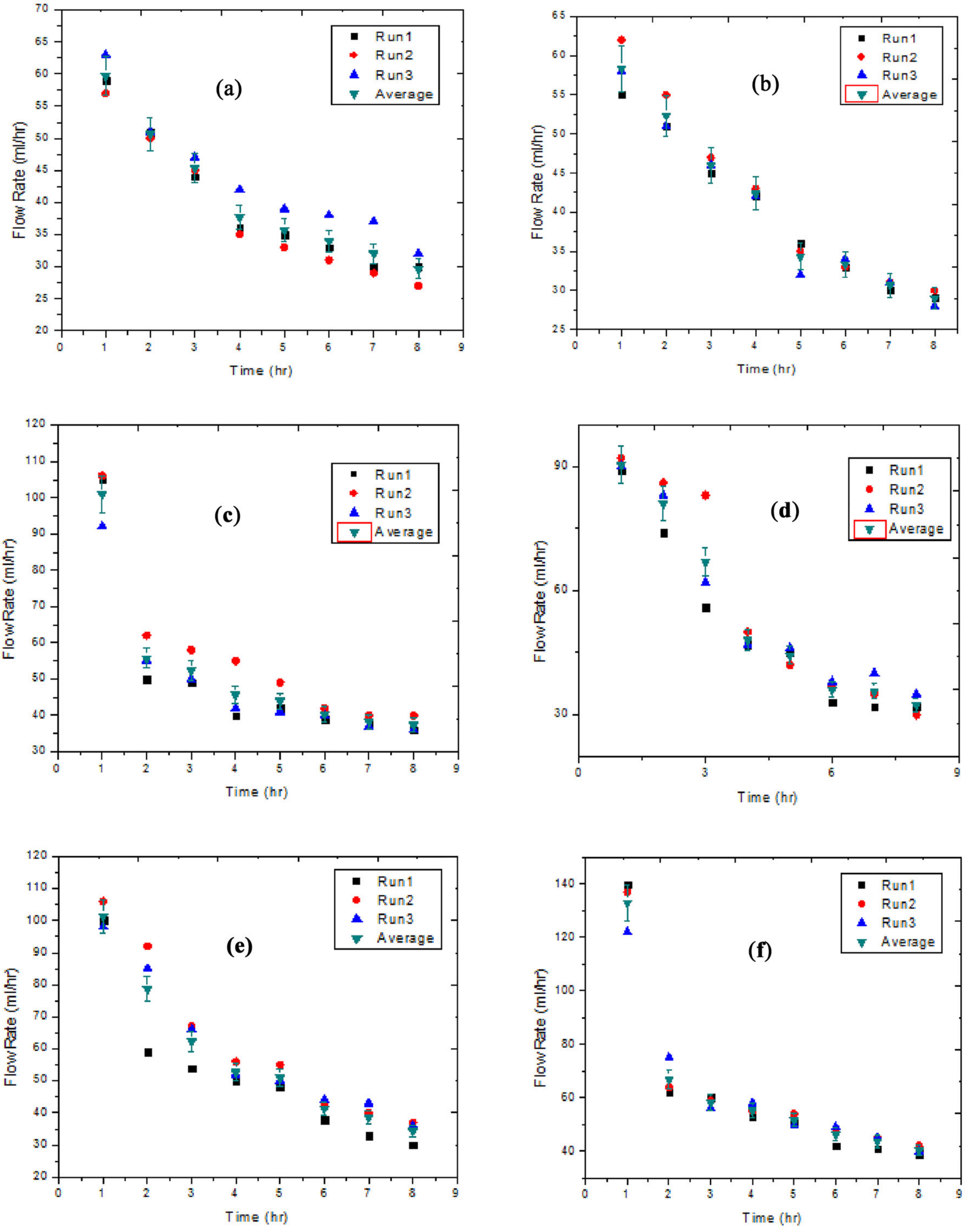

Figure 3. Flow Rate Analysis of (a) AHSD1 (b) AHSD2 (c) AHSD3 and (d) ASSD1(e) ASSD2 (f) ASSD3.

4. Conclusion

- The flow rate in the first hour for disks used for Ahwiam river was 73 ml/hr and that for disks used for Ashiyie river was 108.2 ml/hr for 150 μm of sawdust particle.
- The hydraulic conductivity values were found to range from (8.03–8.77) × 10^{-5} cm/s for disks filters used for Ahwiam river and (7.77–8.33) × 10^{-5} cm/s for disks used for Ashiyie river.
- The volume of water filtered was found to increase with increasing particle size of the sawdust. The

mechanical robustness of the filter erodes with increasing particle size considering the bulk density values, though with increasing filtered water.

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