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A Study of Ceramic Pot Filters Made From Clay Body and Sawdust

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Abstract
As a follow-up of an earlier effort to produce ceramic pot filter from locally available materials, studies were carried out towards the development of the filter from clay, laterite and sawdust. As measured by flow rate and water quality tests, the filter having 45% sawdust and 55% clay body by volume was adjudged the best having satisfied the acceptable flow rate (between 1 and 2 litres/hour) and water quality (turbidity less than 5 NTU); in addition, the removal efficiency of suspended solids was 94%.
Keywords: Atamora Pottery Centre, turbidity, suspended solids, laterite, ceramic mould, slurry

1. Introduction

In an earlier study, Oladepo et al. (2017) have shown that clay and combustible materials sourced locally could be used for the production of a ceramic pot filter (CPF); the filter improved the potability of a typical stream water. The background to the study (and indeed, to the current study) is that in Nigeria, despite the challenges of inadequate drinking water supply, the use of CPF has not been reported. This is contrary to widespread use of the technology in other developing nations such as Benin Republic, Cambodia, Guatemala, Dominican Republic, Nicaragua, Tanzania and Sri Lanka (Rayner et al., 2013). The use of CPF has also been reported for Ghana, Kenya and Honduras (van Halem et al., 2009).

Many studies have been reported about CPFs in Nigeria (National Academy of Sciences, 2007; Plappaly et al, 2011; Isikwue and Emmanuel, 2011; Erkuanga et al., 2014), but they have not translated to the availability of the filters in the Nigerian market. According to Oladepo et al. (2017), efforts needed to encourage the local production of CPFs could be seen to consist of three phases, as follows: (a)identification of local sources of clay and combustible materials and evaluation of their suitability for the production of CPF; (b)development of a simple hydraulic press for the production of CPF; and (c)production of the CPF in sufficient quantity for field test on its application and acceptability for water treatment in the rural areas of southwestern Nigeria.

The current study is addressing the subject matter of phase 1. The study was carried out at the Atamora Pottery Centre in 2014. The Centre is located at the Atamora village near Wasinmi on the Ibadan-Ife Express Road, Irewole Local Government Area, Osun State, Nigeria (Onuzulike, 2012). The broad objective is to utilize clay body consisting of clay and laterite (available at Atamora Pottery Centre) and sawdust (obtained from Ile-Ife, also in Osun State) for the production of CPF.

2. Materials and Methods

2.1 Materials

The materials used include clay, laterite, and sawdust. The clay and laterite were procured from the materials stockpiled at Atamora Pottery.

2.2 Production of the ceramic pot filters

The sawdust was sun-dried. A portion of the dried sawdust was separated into four size ranges by using sieves with sizes of openings of 850 µm, 600 µm, and 300 µm. Filters were produced from five categories of sawdust; viz, unsieved sawdust (coded as 0), sawdust retained on sieve with 850 µm opening (coded as 1), sawdust passing sieve with 850 µm opening and retained on sieve with 600 µm opening (coded as 2), sawdust passing sieve with 600 µm opening and retained on sieve with 300 µm opening (coded as 3), and sawdust passing sieve with 300 µm opening (coded as 4).

Clay-to-laterite mix ratio of 3:4 by volume was employed for the study. The clay and laterite were measured into a ceramic trough. Large stones were handpicked from the mixture of clay and laterite in the trough. Water was added to the mixture in the trough to form slurry; this was stirred thoroughly with a shovel. The slurry was poured into a barrel drum which has a plastic sieve placed on top of it. The holes in the sieve have sizes of 6 mm by 4 mm and were meant to remove coarse materials in the slurry. A tap placed at the base of the drum was opened and the slurry was allowed to pass through a sieve with openings of size 150 µm into a concrete tank. The slurry was left in the concrete tank for seven days to enable it to set. The set clay body was scooped from the concrete tank and placed on a floor lined with polythene bags in the vicinity of Atamora Pottery. The set clay body was allowed to dry to the plastic stage so that it could be workable. The clay body was kneaded and piled up to form a hip.

Table 1 shows the parameters that were employed in designing the ceramic pot filters. The filter designs were obtained by combining the five categories of sawdust with varying proportions of clay body as shown in Table 2. Efforts were made to replicate each filter design into three.

A portion of the hipped clay body was cut with cheese wire and weighed. By using Tables 1 and 2, a mix proportion was selected and the corresponding amount of sawdust was also weighed. The clay body and sawdust were slowly and thoroughly mixed to achieve a homogeneous mixture as water was added to it. The mix was thoroughly wedged and kneaded in order to remove all entrained air bubbles and obtain a uniform paste. A ceramic mould was used for the production of the ceramic filters. A slab of 2 cm thickness was prepared from the kneaded mixture. The ceramic mould was then rolled over the slab to mark out the portion required for the forming of the wall of the filter; the portions outside the marks were cut off. Another slab was prepared and the base of the filter was also cut out. The mould was turned upside down and placed on a bat. The cut curved part of the slab was spread around the mould and joined with the hands. The base part was also placed on the mould and joined with the hands as well. After all the joining and mending were done, the filter on the bat was taken to the throwing wheel, centred and dressed. Dressing on the throwing wheel made the entire joints firm and made the filter whole. The filter was removed from the throwing wheel and left for one hour after which the mould was removed. The leftover material was wrapped with polythene bag and it was later used to make the rim of the filter. This procedure was repeated for the production of the other filters. All the filters were tagged for the purpose of identification by using the codes in Table 2. The filters were left in the Atamora studio to dry. The dried filters were fired by using a Mani downdraft kiln at Atamora Pottery for nine hours. The temperature in the kiln during firing was monitored with the aid of a thermocouple. After firing, the kiln was left for 20 hours to cool and the filters were then removed. The filters were taken to the Environmental Engineering Laboratory, Department of civil Engineering, Obafemi Awolowo University, Ile-Ife.

2.3 Flow rate and water quality tests

Each of the filters was weighed and the top diameter was measured, the capacity was also determined. Prior to the determination of the flow rates, the filters were soaked in tap water inside a plastic tank for 48 hours. This was to completely saturate the filters and remove internal bubbles. The constant-head method was used for determining the flow rate (Oladepo et al., 2017). The influent water was collected from a stream behind the Civil Engineering Building (Obafemi Awolowo University, Ile-Ife). At the beginning of the experiment, a sample of the raw water was taken and the pots were filled to the brim with the water. A stopwatch was started and the volume of water filtered by each pot was collected every one hour for five hours. The volume of water collected was measured by using a measuring cylinder. Samples were collected for each pot by using 500-mL covered plastic containers.

Table 1: Parameters for the design configurations of the ceramic pot filters

Sawdust sizes					
Size of sawdust, x (μm)	Unsieved	x>850	600<x<850	300<x<600	x<300
Code	0	1	2	3	4
Clay body-to-sawdust ratios					
Clay body:sawdust proportions by volume (%)	60:40	50:50	40:60	55:45	
Clay body:sawdust proportions by weight (kg)	6:0.8	5:1	4:1.2	5.5:0.9	
Code	A	B	C	D	

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Table 2: Design configurations of the ceramic pot filters

S/N	%Clay	%Sawdust	Size of sawdust, x (μm)	Filter code	Replicates
1	60	40	Unsieved	A0	A01
2	60	40	Unsieved		A02
3	60	40	Unsieved		A03
4	60	40	x>850	A1	A11
5	60	40	x>850		A12
6	60	40	x>850		A13
7	60	40	600<x<850	A2	A21
8	60	40	600<x<850		A22
9	60	40	600<x<850		A23
10	60	40	300<x<600	A3	A31
11	60	40	300<x<600		A32
12	60	40	300<x<600		A33
13	60	40	x<300	A4	A41
14	50	50	Unsieved	B0	B01
15	50	50	Unsieved		B02
16	50	50	x>850	B1	B11
17	50	50	x>850		B12
18	50	50	x>850		B13
19	50	50	600<x<850	B2	B21
20	50	50	600<x<850		B22
21	50	50	300<x<600	B3	B31
22	50	50	300<x<600		B32
23	50	50	x<300	B4	

Table 2: Design configurations of the ceramic pot filters (cont'd)

S/N	%Clay	%Sawdust	Size of sawdust, x (μm)	Filter code	Replicates
24	40	60	Unsieved	C0	C01
25	40	60	Unsieved		C02
26	40	60	Unsieved		C03
27	40	60	x>850	C1	C11
28	40	60	x>850		C12
29	40	60	600<x<850	C2	C21
30	40	60	300<x<600	C3	
31	40	60	x<300	C4	
32	55	45	Unsieved	D0	D01
33	55	45	Unsieved		D02
34	55	45	Unsieved		D03
35	55	45	x>850	D1	
36	55	45	600<x<850	D2	D21
37	55	45	600<x<850		D22
38	55	45	300<x<600	D3	
39	55	45	x<300	D4	D41
40	55	45	x<300		D42

Turbidity of the filtrate was determined by using a desktop turbidimeter (Model Labtech AVI-357). For the total solids, gravimetric method was used with the following procedure: A crucible was dried in the oven and allowed to cool in a desiccator. The initial weight of the dried crucible was determined and recorded as W_1. Then, 50 mL of water sample was measured and poured inside the crucible. The crucible with its content was placed in an oven set at a temperature of 105^{o}C for 24 hours. Thereafter, the crucible was removed, placed in the desiccator to cool and weighed; the weight was recorded as W_2. The total solids concentration was calculated by using Eq. 1.

$$\text{Concentration of total solids (mg/L)} = \frac{W_2 - W_1}{50} \times 10^6 \qquad (1)$$

Suspended solids in the water sample was also determined using gravimetric method with the following procedure: A filter paper was weighed and the weight was recorded as W_1. The filter paper was folded into a funnel and the funnel was placed in a beaker to collect the filtrate. Then, 50 mL of water sample was poured into the filter and the water was allowed to drain off. The filter paper with the residue was removed gently from funnel and placed inside an oven and allowed to dry. The dried filter paper and the residue were then weighed and recorded as W_2. The suspended solids concentration was calculated by using Eq. 2.

$$\text{Concentration of suspended solids (mg/L)} = \frac{W_2 - W_1}{50} \times 10^6 \qquad (2)$$

Dissolved solids for the raw water sample and filtrate were obtained by subtracting suspended solids from total solids for each sample (Eq. 3).

Dissolved Solids (DS) = Total Solids (TS) – Suspended Solids (SS) (3)

3. Results and Discussion

Figure 1 shows samples of the ceramic pot filters, they are frustum-shaped with a flat base. The internal top diameter ranges between 312 mm and 340 mm while the internal base diameter is 190-197 mm; the average wall thickness is 20 mm and the capacity is 6.5-9.0 litres. Figure 2 shows the variation of cumulative volume of filtrate with time for the CPF having 60% clay body and 40% sawdust by volume with varying particle sizes of sawdust. The filter with sawdust having particle size with code 1 (x>850 µm) produced the largest volume of filtrate while the filter with sawdust having particle size with code 4 (x<300 µm) produced the least volume of filtrate. The reason for this could be attributed to the fact that the combustible material, sawdust, burnt off during the firing process leaving a network of pores; the higher the grain size of the sawdust the bigger the expected size of the pores left behind. Also, as expected, the unsieved sawdust has, in addition to the portion above 850 µm, the finer particles which would produce a network of fine pores; hence the volume of filtrate would be less. Figure 2 shows the variation of cumulative volume of filtrate with time for the CPF having 60% clay body and 40% sawdust by volume with varying particle sizes of sawdust.

Figure 3 shows the variation of cumulative volume of filtrate with time for the CPF produced from varying proportions of sawdust. As expected, the filter having 60% of sawdust by volume produced the highest value of filtrate; in fact, the volume of filtrate is nearly constant for each hour of filtration. For the other filter types (A, B and D), the difference in the proportion of sawdust is very close and the values of the volume of filtrate are very close as well. The reason for this could be attributed to the fact that the sawdust burnt off during the firing process leaving a network of pores; the more the volume of sawdust being burnt off, the more the number of pores that would be left behind in the filter and the higher the flow rate through the filter would be.

From the results obtained for the values of filtrate in the first hour of operation of the filters, only four filters have values in the 1 to 2 litres/hour range as recommended in literature (Wald, 2012). These filters are presented in Table 3 with the results of water quality tests. The turbidity levels reduced as filtration progressed; also, the suspended solids removal efficiency increased. This phenomenon can be explained by considering the pores in the filters as becoming smaller as impurities get deposited in them as filtration progressed. Therefore, the pore openings would be widest at the early period of filtration and more impurities would pass through them, resulting in higher turbidities. The recommended turbidity for drinking water is 5 NTU (WHO, 2007). Though the trend is not consistent, the turbidity was reduced from the initial value of 38 NTU to 4 NTU at the end of the fifth hour of operation. The filters exhibited low efficiency for dissolved solids removal. This could be explained by the fact that the major mechanism of filtration in a ceramic pot filter is mechanical screening of suspended particles that are too large to pass through the pores created from the burnt-off combustible material (van Halem, 2006). From a combination of volume of filtrate produced in the first hour of operation and the performance in turbidity and suspended solids removal, filter D4 gave the best performance. This filter has 45% by volume of sawdust and 55% of clay body, the sawdust has a particle size of less than 300 µm.

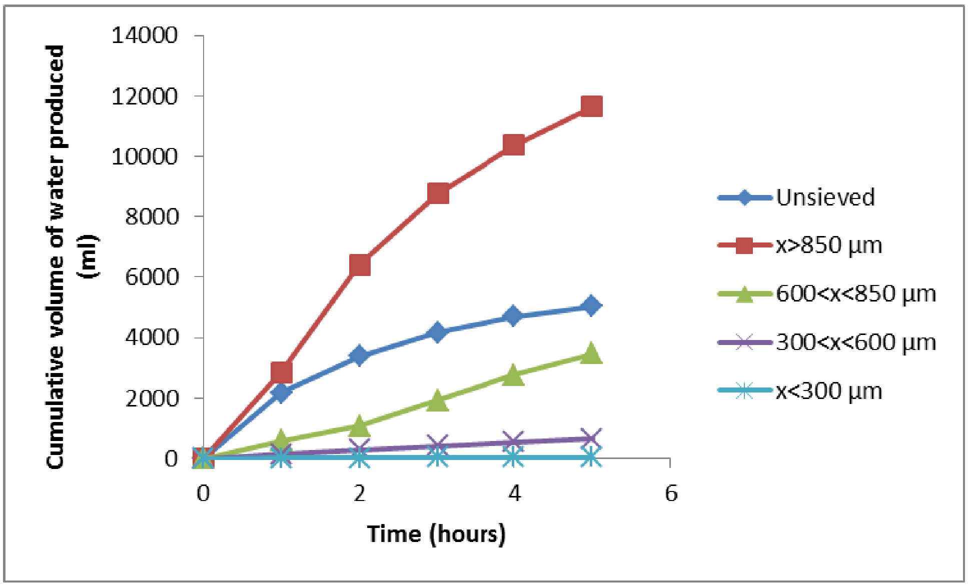

Figure 2: Variation of discharge with particle size of the sawdust

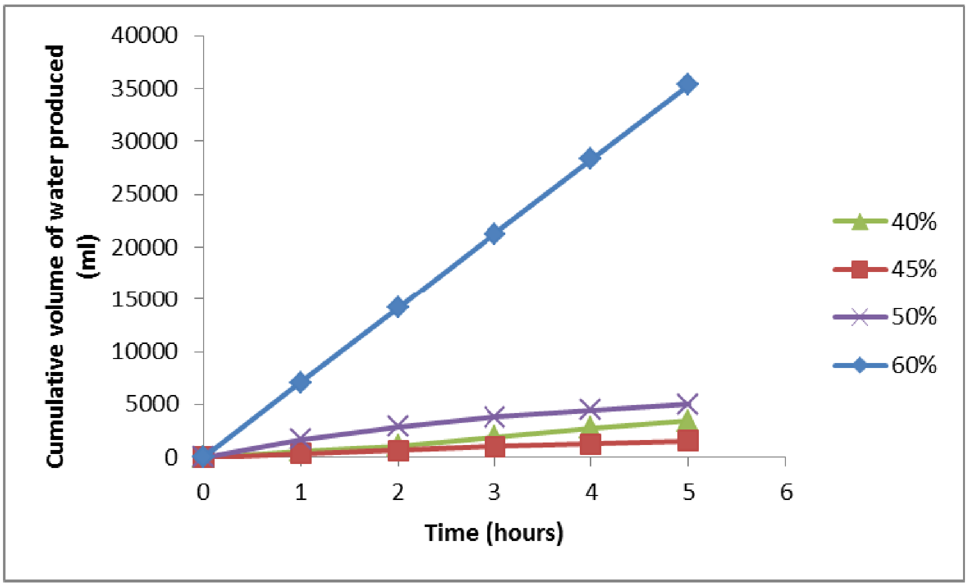

Figure 3: Variation of discharge with proportion of sawdust in the filter

4. Conclusion

Ceramic filters have been produced by using clay body consisting of clay and laterite and sawdust. Four different designs (based on the percentage combination of clay body and the sawdust) and five classes of sawdust based on particle size were considered and their performances were evaluated by using flow rate and water quality characteristics of the ceramic pot filters produced. The flow rates were highest in filters having sawdust with size x>850 and lowest in filters with x<300. Based on the proportion of sawdust, the total discharge within the first five hours of operation was highest for the filter with 60% sawdust and lowest for the filter with 45% sawdust. From the results of flow rate and water quality tests, the filter having 45% sawdust was adjudged the best having satisfied the acceptable flow rate (between 1 and 2 litres/hour) and water quality (turbidity less than 5 NTU); in addition, the removal efficiency of suspended solids was 94%. The next phase of the study is in progress, construction of the hydraulic press is at an advanced stage; this is expected to facilitate the local production of the filters in a sustainable manner.

Table 3: Characteristics of filters having acceptable flow rates

Filter type	Clay body:sawdust Ratio	Size of sawdust, x (µm)	First Hour Discharge (ml)	Time (h)	Turbidity (NTU)*	TSE (%)	SSE (%)	DSE (%)
B1	50:50	x>850	1515	1	7	52	76	25
				2	4	58	76	38
				3	11	64	76	50
				4	7	70	88	50
				5	4	58	65	50
B2	50:50	600<x<850	1700	1	16	62	88	20
				2	19	70	88	21
				3	14	74	83	52
				4	4	70	88	21
				5	4	70	82	37
C0	40:60	Unsieved	1235	1	7	54	77	8
				2	7	67	92	15
				3	11	69	77	54
				4	11	74	69	85
				5	11	72	77	62
D4	55:45	x<300	1850	1	17	83	94	62
				2	10	70	94	23
				3	7	79	94	49
				4	7	74	94	36
				5	4	70	94	23

*Turbidity of the raw water was 38 NTU.

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