Current Journal of Applied Science and Technology

22(6): 1-10, 2017; Article no.CJAST.34740
Previously known as British Journal of Applied Science & Technology
ISSN: 2231-0843, NLM ID: 101664541

Suitability of Using Ipetumodu Potter's Clay for the Production of Ceramic Pot Filters

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Authors' contributions

This work was carried out in collaboration between all authors. Author KTO designed the study and wrote the first draft of the manuscript. Authors SOF and ASO managed the experimental work and prepared the tables. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2017/34740
Editor(s):
(1) Saeed Khorram, Eastern Mediterranean University, Famagusta, Cyprus.
Reviewers:
(1) A. J. Varkey, University of Swaziland, Swaziland.
(2) Rafael Marín Galvín, Universidad de Córdoba, Spain.
(3) Dejanira de Franceschi de Angelis, UNESP, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/20337

Original Research Article

Received 8th June 2017
Accepted 23rd July 2017
Published 3rd August 2017

ABSTRACT

Ceramic filtration is one of the household water treatment methods of providing potable water to rural dwellers in developing nations. This study reports an effort to produce ceramic pot filters from locally available clay using rice husk and sawdust as the combustible materials; the fractions of the combustible material used in preparing the pots were 10%, 20%, 30%, 40% and 50% by volume. The filters were tested for flow rate and effectiveness in the removal of turbidity, suspended, dissolved and total solids. The filter that contains 20% rice husk was found to be the most efficient because of its acceptable flow rate and effluent water quality; the first-hour flow rate was 1.66 litres per second while the turbidity of the effluent was reduced from 38 NTU to 4 NTU after five hours of filtration. The efficiency of suspended solids removal ranged between 67 and 89%. The next phase of the study, which is in progress, involves the construction of a hydraulic press to facilitate the production of the filters in a sustainable manner.

Keywords: Ceramic filter; household water treatment; clay; rice husk; sawdust.

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1. INTRODUCTION

Water is essential for maintaining life on Earth; but water can also serve as a medium for hazardous substances and pathogenic organisms, posing substantial health threats to human beings [1]. It has been established, [2], that inadequate provision for water, sanitation and drainage contributes to very large disease burdens and hundreds of thousands of premature deaths each year. In 2015, it was estimated that 663 million people worldwide did not have access to improved drinking water sources; about half of this number lived in sub-Saharan Africa [3]. In Nigeria, 57 million people don't have access to safe water while around 45,000 children under five years old die every year from diarrhea caused by unsafe water and poor sanitation [4]. It was also pointed out that eight out of ten people still live in rural areas without improved drinking water source [3]. According to the 2015 edition of the United Nations World Water Development Report [5], the year 2015 marked a critical milestone on the road to sustainable development as the Millennium Development Goals came to a close and a new cycle of Sustainable Development Goals (SDGs) was introduced to guide national governments and the international community in the quest to achieve a sustainable world. The Official Agenda for Sustainable Development adopted on 25 September 2015 has 17 SDGs and associated 169 targets [6]. Goal 6 of these SGDs is tagged 'Clean Water and Sanitation' and its target is that everyone on earth should have access to safe and affordable drinking water by the year 2030 [7].

A sustainable water management approach requires 'fit for purpose' use and reuse of water [8]. The conventional water treatment plants being adopted in high income countries are neither cost effective nor technically adoptable to low-income countries [9]. These conventional methods are also operated in many developing countries but they are often highly centralized. This results in the requirement of a large number of pipes, pumps and appurtenances to transport treated water to the points of need. For the communities which could not be served by the centralized system, household water treatments have been proposed as viable, interim means to provide clean water until improvements in the water-supply infrastructure can be achieved [10]. Promoting household water treatment and safe storage (HWTS) helps vulnerable populations to take charge of their own water security by providing them with the knowledge and tools to treat their own drinking water [11].

Various point-of-use water treatment methods, which include biosand and ceramic filtration, solar disinfection and natural water purifiers (e.g. Moringa oleifera) have been reported to improve the quality of drinking water as well as to decrease the incidence of endemic diarrhoea caused by waterborne pathogens [12]. It was also pointed out, [13], that HWTS lets people take responsibility for their own water security by treating and safely storing water themselves; and it can be adopted immediately in the homes of poor and vulnerable families to dramatically improve their drinking-water quality.

According to Smieja [14], Lantagne [15] and Clasen and Boisson [16], porous ceramic filters have been used in developing countries to treat water at the household level. The Centres for Disease Control and Prevention [17] have enumerated the benefits of ceramic filters as follows: proven reduction of bacteria and protozoa in water; acceptability to users because of the simplicity of use; proven reduction of diarrheal disease incidence in users; long life if the filter remains unbroken; and, a low one-time cost. The drawbacks have also been identified as lower effectiveness against removal of viruses; lack of residual protection that can lead to recontamination if treated water is stored unsafely; variability in quality control of locally produced filters; filter breakage over time, and need for spare parts; the need to regularly keep the filter and receptacle clean, especially when using turbid waters; and, a low flow rate. The use of Ceramic Pot Filter (CPF) has been promoted by governmental and non-governmental organisations (NGOs). Typical NGOs are the US-based Potters for Peace [18] and Resource Development International Cambodia [19]. The modes of production of CPF are hand mould, potters' wheel and mechanical press [20]. Upon firing, combustion of the organic matter results in a porous material that is permeable to water. After cooling, the filters are painted with, or dipped in, a silver solution. Manufacturers aim for an optimal flow rate of water out of the filter of 1 to 2.5 litres per hour [21].

Nigeria has vast deposits of clay across every region with differing characteristics depending on the geology of the site [22]. Akintonde et al. [23] identified primary clay and secondary clay as the two categories of clay and enumerated the locations where each type could be found in southwestern Nigeria. According to these authors, the primary clay is whitish in colour, coarse in texture and loosely packed and could withstand temperatures between 1400 and 1700°C while the secondary clay has off white, reddish-brown and gray or black colours and could be fired to temperatures between 850 and 1100°C. Secondary clay is more common and it is found virtually everywhere in the world; the Ipetumodu clay is of the secondary type [23]. Ipetumodu is the headquarters of Ife North Local Government Area in Osun State, in the southwestern part of Nigeria; it is 64 square kilometres in area and it is at an elevation of 227 m above sea level [24]. Various studies on the use of Ipetumodu clay for different engineering applications have been reported in literature. For instance, Ibitoye and Afonja [25,26] investigated its use for foundry construction while Aramide [27] considered its suitability for the production of masonry bricks. The modification of the properties of the clay by the addition of other materials has also been investigated; Oke [28] considered the effect of sand, Oke et al. [29] studied the effects of adding sawdust while Aramide et al. [24] investigated the effects of yttria-stabilized zirconia on the mechanical properties of the Ipetumodu clay.

There have been efforts to produce ceramic pot filters in commercial quantities in Nigeria [30,31]. Nigeria was cited as an example of a developing country whose government could not provide some basic services, such as potable pipe-borne water and electric power, to a large proportion of the population in an affordable manner [30]. The report [30] then examined how Nigeria could mobilize private companies to provide some basic services that might be sustainable and cost-effective for government, company, and consumer. That study demonstrated that it should be possible to make a profit providing safe household water in Nigeria without direct government support. In the case study that was employed, the Filtron CPF produced by Potters for Peace was chosen as the technology. Filtron Nigeria was listed among the participating companies in the manufacturing process surveys conducted with 25 filter factories worldwide to document production methods and identify areas where manufacturing and quality control guidelines were needed; and it was indicated that the monthly production in 2008 was 400-500 ceramic pot filters [31]. There are other efforts being made to develop the local production of ceramic filters in Nigeria [32]. The current study is to be viewed as part of the efforts required to encourage the local production of CPF. The entire project is planned to be in three phases as follows: (a) to identify local sources of clay and combustible materials and evaluate them to establish their suitability for the production of CPF; (b) to develop a simple hydraulic press for the production of CPF; and (c) to produce the CPF in sufficient quantity for field test on its application and accessibility for water treatment in rural areas in southwestern Nigeria. This write-up is a report on the first phase of the project. Specifically, it was intended to determine the suitability of Ipetumodu clay and other locally sourced raw materials for the production of CPF and evaluation of the effectiveness of the produced filters in the treatment of raw water samples.

2. MATERIALS AND METHODS

2.1 Materials

The materials used include clay, sawdust, and rice husk. The clay was procured from a pottery producer in Ipetumodu, the sawdust was obtained from a saw mill in Ile-Ife while the rice husk was obtained from a rice-processing mill at Erin-Ijesa; all these towns are in Osun State of Nigeria.

2.2 Production of the Ceramic Pot Filters

The method of producing indigenous ceramic wares (from clay) in the southwestern Nigeria is the hand built technique [32,33]; the procedure consists of three steps: base forming, body building, and rim forming. All the raw materials (clay, rice husk and saw dust) were air-dried and crushed in mortar and passed through a sieve with 1.18 mm pore size to remove coarse and foreign particles. Clay-to-rice husk and clay-to-sawdust mix ratios of 90:10, 80:20, 70:30, 60:40 and 50:50 by volume were employed for the study. For each mix, the materials were measured into a container and thoroughly mixed together manually. Water was then added to the mixture in incremental volumes until a clay ball was formed. In order to form the base, wood ash was sprinkled on the bottom of an already fired pot, a lump of clay was placed on it and the hands were used to spread it until the desired size and thickness were achieved. After 45 minutes, the cast base was removed from the mould and placed upright on a shallow pot, the rim was dampened and prepared for building of the wall of the pot. Several lumps of clay were rolled into coils and added one after the other to the base to form the wall of the pot. In forming the rim, big coils of clay were added to the wall of the pot to produce the rim. The surface of each filter was smoothened by using scrapping tools used by the potters to remove observed rough surfaces. The filters were placed on wooden boards inside the pottery and left to air-dry for seven days.

2.3 Firing of the Filters

Firing was achieved by using the kiln being employed by the potters. The pots were arranged inside the kiln (Fig. 1a) and covered with broken pieces of pots (Fig. 1b). Bamboo poles were used for firing the kiln. The firing temperature was monitored with the aid of a thermocouple during the firing process. The filters were left to cool down and later arranged inside the pottery. They were later transported to the Environmental Engineering Laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife.

2.4 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 300-litre plastic tank for 24 hours. This was to completely saturate the filters and remove internal bubbles. The constant-head method was used for determining the flow rate (Fig. 2). 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 water. A stopwatch was started and the volume of water filtered by each pot was collected every 15 minutes for eight 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.

Turbidity was determined by using a colorimeter that was calibrated to give Nephelometric Turbidity Unit (NTU) readings. For each water sample the absorbance at 470 nm was measured with the colorimeter, the equivalent turbidity was then determined by inserting the value in the calibration equation. 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°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.

Concentration of total solids (mg/L) =

$$\frac{W_2 - W_1}{50} \times 10^6 \quad (1)$$

(a) (b)

Fig. 1. Firing of ceramic filters (a) arrangement in the kiln (b) the firing process

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.

Concentration of suspended solids (mg/L) =

$$\frac{W_2 - W_1}{50} \times 10^6 \quad (2)$$

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)

Fig. 2. Laboratory set-up for flow rate test on the ceramic filters

3. RESULTS AND DISCUSSION

Fig. 3 shows the ceramic pot filters, they have hemispherical base with an average top diameter of 255 mm and mean wall thickness of 15 mm. The mean capacity is five litres. The variation of cumulative volume of filtrate with time for the CPF produced from rice husk is as shown in Fig. 4 while Fig. 5 shows the results for those CPF made from sawdust. The cumulative volume increased with increasing amount of combustible materials; filters with 10% rice husk and sawdust have the least values while those with 50% have the highest. The reason for this could be attributed to the fact that the combustible material burnt off during the firing process left a network of pores; the more the volume of combustible materials 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.

Figs. 6a and 6b show the variation of cumulative volume of filtrate with the type of combustible material. In these figures, filters having rice-husk as the combustible material produced more filtrate than their counterparts made from sawdust; the trend is the same for filters with 30%, 40% and 50% of combustible material. This could be attributed to the types of pores developed from each type of combustible material.

Table 1 shows the values of volume of filtrate produced on hourly basis during the experiment. From these results, the filter design with 20% rice-husk gave flow rate falling in the 1 and 2 L/h range recommended in literature [21]. The turbidity removal efficiency for this filter design is presented in Table 2. The removal efficiency increased as filtration progressed. This can be explained by considering the pores as becoming smaller as impurities get deposited in them as filtration progressed. Therefore, the pores 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 [10]. Though the trend is not consistent, the turbidity was reduced from the initial value of 36 NTU to 4 NTU at the end of the fifth hour of operation. The removal efficiencies of

(a) (b)

Fig. 3. The produced ceramic filters, (a) hemispherical filters (b) filter assemblage

the 20% rice-husk filter are shown in Table 3 for total, suspended and dissolved solids. The filter exhibited high efficiency in the removal of suspended solids and low efficiency for dissolved solids removal. This could be explained by the fact that the major mechanism of filtration in 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 [33]. This trend was the same for all the other filter designs that were produced in this study.

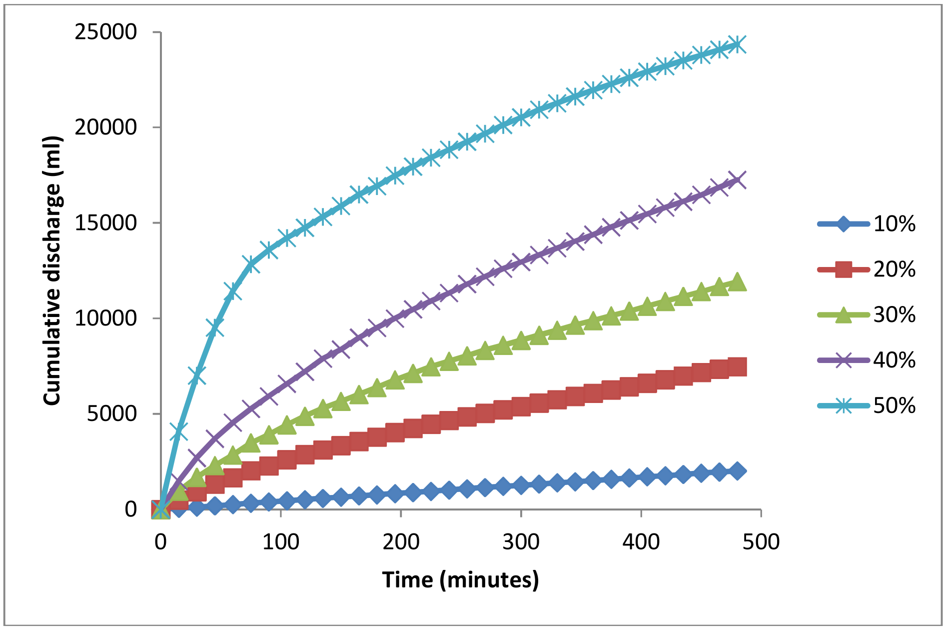

Fig. 4. Variation of cumulative discharge with time for ceramic pot filters with different percentages of rice husk

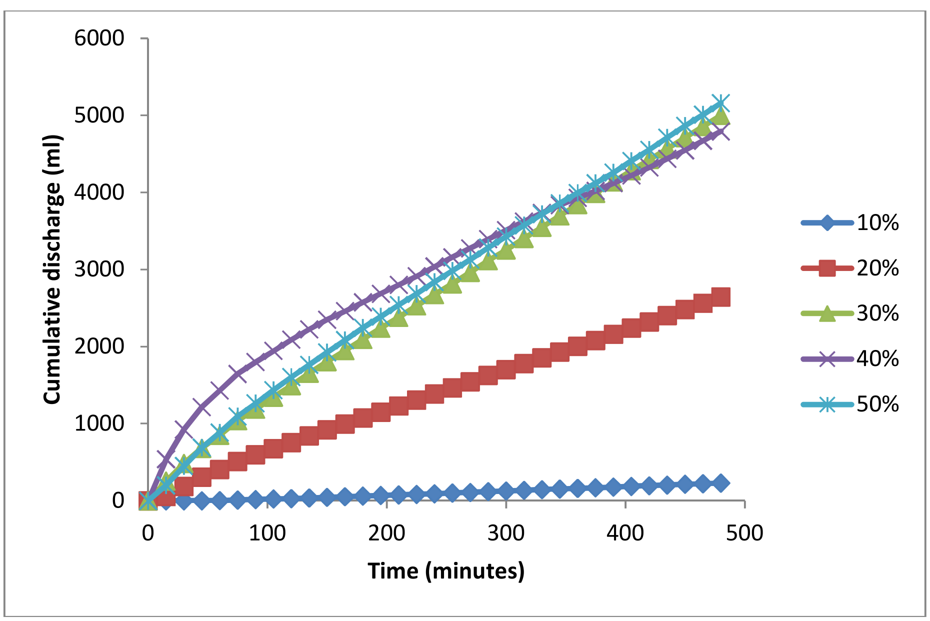

Fig. 5. Variation of cumulative discharge with time for ceramic pot filters with different percentages of sawdust

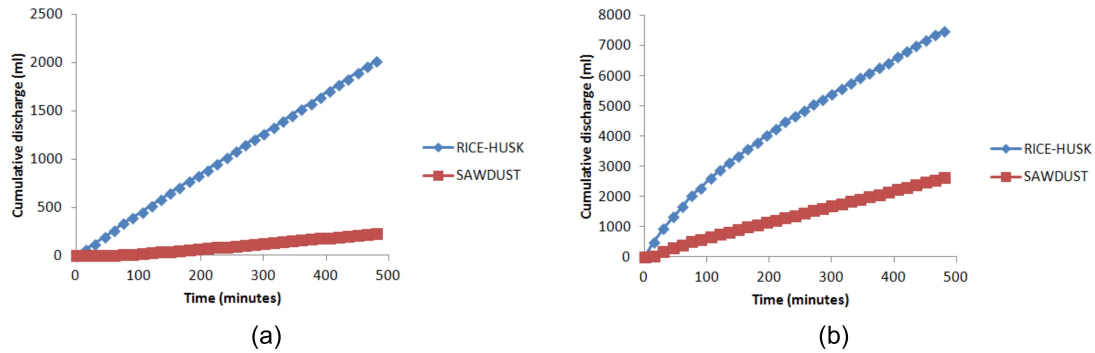

Fig. 6. Variation of cumulative discharge with time for varying proportions of material – (a) 10% (b) 20%

Table 1. Hourly discharge of ceramic pot filter with varying amounts of combustible material

	Hourly discharge (mL)							
% of combustible	**1st hour**	**2nd hour**	**3rd hour**	**4th hour**	**5th hour**	**6th hour**	**7th hour**	**8th hour**
Rice-husk								
10	260	260	250	250	250	252.5	250	250
20	1660	1210	920	870	730	695	715	675
30	2860	2030	1495	1385	1090	1035	1005	1035
40	4545	2665	2300	1825	1620	1440	1410	1455
50	11440	3310	2180	1915	1690	1430	1250	1145
Sawdust								
10	2	27	30.5	32	35	34	34.5	34
20	405	350	320	310	315	305	315	322.5
30	850	645	600	580	580	587.5	585	575
40	1430	660	485	465	470	420	395	467
50	885	720	640	595	590	565	560	605

Table 2. Turbidity removal characteristics for ceramic filter having 20% rice husk

Sample number	**Time (minutes)**	**Colorimeter reading (x)**	**Turbidity (NTU =323.78 – 3.2668x)**	**Efficiency (%)**
1	30	95	13	63
2	60	97	7	81
3	90	97	7	81
4	120	96	10	72
5	150	97	7	81
6	180	96	10	72
7	210	99	0.4	99
8	240	99	0.4	99
9	270	97	7	81
10	300	98	4	90
11	330	97	7	81
12	360	99	0.4	99
13	390	99	0.4	99
14	420	99	0.4	99
15	450	97	7	81
16	480	98	4	90
Raw Water		88	36	

Table 3. Total (TS), suspended (SS) and dissolved solids DS) removal characteristics for ceramic filter having 20% rice husk

Sample number	Time (minutes)	TS (mg/L)	SS (mg/L)	DS (mg/L)	TS Efficiency (%)	SS Efficiency (%)	DS Efficiency (%)
1	30	167	40	127	55	78	32
2	60	200	40	160	45	78	14
3	90	190	40	150	48	78	20
4	120	200	40	160	45	78	14
5	150	167	20	147	55	89	21
6	180	200	40	160	45	78	14
7	210	200	40	160	45	78	14
8	240	200	40	160	45	78	14
9	270	167	20	147	55	89	21
10	300	233	60	173	36	67	7
11	330	167	20	147	54	89	21
12	360	233	60	173	36	67	7
13	390	233	60	173	36	67	7
14	420	200	20	180	45	89	4
15	450	200	40	160	45	78	14
16	480	167	20	147	55	89	21
Raw Water		367	180	187			

4. CONCLUSION

Ceramic filters have been produced by using locally sourced clay and combustible materials. Ipetumodu clay was employed while rice-husk and sawdust were the combustible materials used in the study. Five different designs (based on the percentage combination of clay and the combustible materials) were considered and their performances were evaluated by using flow rate and water quality characteristics of the ceramic pot filters produced. Ceramic filter design which had 80% clay and 20% rice husk was the most efficient because of its acceptable flow rate and water quality; the first-hour flow rate was 1.66 litres per second while the turbidity of the effluent was reduced from 38 NTU to 4 NTU after five hours of filtration. The efficiency of suspended solids removal ranged between 67 and 89%. The next phase of the study, which is in progress, involves the construction of a hydraulic press to facilitate the production of the filters in a sustainable manner.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/20337