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Research Article

Review of the use of clay-based composites for water filtration application in rural areas

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Abstract: A safe water source is one that is available, accessible, and provides water of acceptable quality, free from microbial and chemical contaminations. However, millions living in rural areas have no access to safe water. About 60 percent of Nigerians live in rural areas and have a larger share of inadequate supply of safe drinking water. Consumption of contaminated water leads to highly contagious disease infections and can lead to loss of lives or reduction in life expectancy. Clay-based Composite Water Filter (CCWF) treats water and makes it safe for consumption. They are made from a mixture of clay and carbonaceous material. The principle underlying this water treatment method is that the carbonaceous material is burned off during firing, leaving pores that are large enough to allow water to pass through but small enough to trap bacteria and other water contaminants, such as dissolved solids, and in some cases virus. This review summarizes published works on the parameters (filter materials, firing temperature, shape of the filter, etc.) that influence the performance of CCWF and the corresponding results of these parameters. This is to enable producers of CCWF make informed decisions.

Keywords: Ceramic filters, clay composite, water treatment, water contaminants.

1. Introduction

Clay-based composite water filters (CCWFs) are a point-of-use (PoU) household water treatment alternative used in over 20 countries (Kallman et al., 2011; Zhanget al., 2012) in Africa, India, Asia, and some parts of America (Shuaib-Babata et al., 2016). The newsletter from Potters for Peace (PfP) reports that the production of low-tech, low-cost, and colloidal silver CCWF has expanded to more than 30 countries, with over 50 independent factories operating in these countries (Potters for Peace, 2019). CCWF are non-toxic storage devices that can be used for water purification (Rayner et al., 2013; Lyon-Marion et al., 2018; Erhuanga et al., 2021). CCWFs aims to enhance the quality of water for drinking and other household purposes to help decrease the incidence of diarrheal infections and other water-transmitted diseases like cholera, and typhoid. One of the major challenges facing developing countries is the lack of adequate and safe drinking water sources, particularly among rural communities. This challenge can be tackled using ceramic water filter. Well water, harvested rainwater and surface runoff can be converted to drinkable water by filtering using CCWFs (Nnaji et al., 2016). Over 4 million people predictably use CCWF (van der Laan et al., 2014). This means it is a potentially sustainable means to providing safe and cheap water supply for all. A typical CCWF has the set up represented in Figure 1.

A study carried out by the Nigeria National Bureau of Statistics indicated that more than 63% of Nigerians live in rural areas and about 59% lack access to safe drinking water (NBS and UNICEF, 2017). This result was based on reports of over 200, 000 Nigerians from the 36 states but can only be partially generalized

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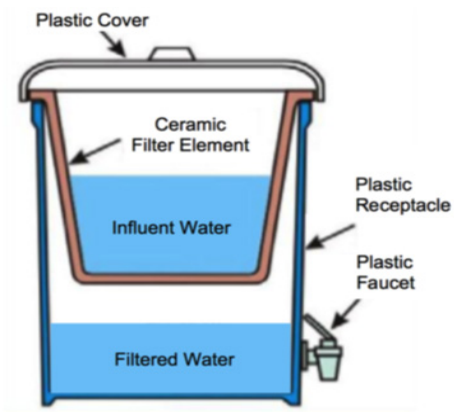

Fig. 1: Typical pot-shaped CCWF setup

Source: Gupta et al. (2018).

because participation is not from an equal percentage of each State's population. Among the 4% of rural dwellers who can assess safe drinking water, most must transport water from the source to their various households, during which the water can become contaminated (Francis et al., 2015). This reveals the need to consider and evaluate clean and safe drinking water source especially at household level for all Nigerians. Most agricultural activities are carried out in the rural areas. These activities involve the use of fertilizers, pesticides and other additives that can find their way to the water sources and pose risk to human health (Borgi et al., 2020). The supply of potable water is a greater problem in Nigeria's rural areas because of the high poverty rate and dearth of auxiliary infrastructure, such as power. Nigeria's public water supply is inconsistent, wildly flawed, and, occasionally, distant (Aribigbola, 2010). Shallow wells are one of the most common sources of water. These wells often have high bacterial content and appalling quality making them unsuitable for drinking. Additional ground-water sources, such as deep wells and bore-holes, are increasingly common ; however, they are often prone to elevated level of naturally occurring minerals and chemical contaminations from underlying rocks (Erhuanga et al., 2014) and therefore require treatment.

Identifying a reliable and effective technology that can help remove faecal contaminations from water is a major obstacle to safe drinking water source provision (WHO/UNICEF, 2015). While installing upgraded drinking water sources, such as in-home pipe water or communal tap water, offers the qualities of a desirable long-term safe drinking water solution maintaining and configuring these sources can be challenging and non-parsimonious, particularly in rural locations (Farrow et al. (2018)). This is because of the lack of infrastructures like stable electricity in most of these areas. Usually, the process of transporting the water from the source, in the case of community tap water, introduces contaminations (Wright et al., 2004).

Clay-based composite water filters are manufactured with materials that can be locally sourced such as clay sand and burnout materials and it is a favorable way of reducing diseases caused by infected water. The constituents for making ceramic water filters can also include water, grog, laterite (soil that contains iron oxide), and bone char aside from the basic materials (clay and carbonaceous material). Clay is defined by Uddin et al. (2017) as a crystalline aluminosilicate material with particle size of less than 2 μm when dissolved. Clay in a plastic state can be easily molded without breaking (Nnaji et al., 2016). CCWF is an affordable, accessible, and applicable technology for empowering households, school classrooms, and workplaces to manage their drinking water quality. It is suitable for treating the most common risk of drinking water, contamination with biological pathogens, and removing general macro contaminants (Soppe et al., 2015).

Hence, owing to the inadequate quality of available sources of drinking water and the apparent lack of suitable centralized water treatment systems for delivery of safe water to households in Nigeria, it has become expedient to investigate low-cost and efficient household water treatment techniques with CCWF showing promising potentials. Therefore, this review aims to examine the different materials and methods of production of CCWF under different regimens and the resulting characteristics.

A total of 1048 Journal articles and books were found under Scopus search for "ceramic" and "water" and "filter" while there were 48 articles for "ceramic water filters" and "ceramic filters". Other search engines like Google scholar and Google were also used. The articles were first reviewed by topic and abstract, and categorized according to the following criteria: materials (blends of clay, carbonaceous material and other components) process (manufacturing techniques), product (shapes, cost and lifespan), and application (efficiency, effectiveness and tests). A detailed review of the selected articles was then carried out to compile this paper, using the descriptive method of literature review. The inclusion criteria encompassed published works that described one or more of the aforementioned categories: material, process, product, and application. The exclusion criteria comprised literature older than 20 years at the time of writing this review, meaning only studies published between 2003 to 2023 were considered.

Table 1: Possible factors/parameters that influence the performance/efficiency of CCWF

Indicators	Variables	Ref
Filter materials	Size and type of the clay, type of burnout material, form and amount of silver used (If applicable), type of water used, use of additional materials like laterite or bone char.	Annan *et al.* (2016); Farrow *et al.* (2018); Rayner *et al.* (2017)
Production parameters	The particle size of materials, the ratio of clay to other materials, firing temperature, rate of firing, type of furnace, application of silver, the pressure of compacting, amount of water added during mixing	Rayner *et al.* (2017); Solomon *et al.* (2023);
Physical parameters	Thickness, Height, diameter, and shape of the filter, pore size, surface area, filter cleaning frequency and procedure, age of filter.	Shepard, *et al.* (2020); Solomon *et al.* (2023); Zhao *et al.* (2020)
Test Parameters	Bacteria and virus type and concentration, method of analysis. Test duration (Short or Long term), laboratory or field study, influent water quality (turbidity, pH, temperature, concentration bacteria, viruses)	Akosile, *et al.* (2020); Farrow *et al.* (2018); Venis and Basu, (2020)

2. Clay-based composite filters

Numerous factors influence the final performance and efficiency of CCWF, as summarized in Table 1. This Table compiles key factors to consider before producing a ceramic filter. which are . These factors varies widely but they all fall under the four indicators as extracted from some of the literatures reviewed by this paper and cited in the Table.

2.1. *Filter materials*

There are several varying compositions of CCWF, ranging from one researcher to another but the main component is clay. As described by Brown and Sobsey (2010), a typical CCWF mix contains 30 kg clay, 9.7 kg rice husks, 1 kg laterite and 14.5 L of water per batch of six filters in line with Resource Development International Cambodia (RDIC) production guidelines. The study of Zereffa and Desalegn (2019) found ultimate properties of high porosity, flow rate and contaminant removing from filters of composition 50% clay-35%Sawdust-15% grog fired at 900°C. This shows that the composition of a CCWF has wide range of compositions and materials depending on the expected properties.

The study of Shuaib-Babata et al. (2016) produced a disc shaped ceramic filter using different mixtures of clay and sawdust, clay and rice husk, clay and charcoal, and clay and silica sand and ended up with different values of total dissolved solids, total coliform, turbidity and porosity but concluded that additives should be between 20 and 30 percent to produce a filter suitable for removing bacteria in water. Solomon et al. (2023) mixed clay with sawdust and Eragrostis tef husk in different compositions and concluded that an 80:20 mixture ratio achieved the highest flowrate, using fluoride as bacterial removal agent.

The materials include clay, a widely available mineral resource in Nigeria; carbonaceous materials, typically waste products; and other additives, which are mostly waste products or easily accessible processed materials . Different compositions reported literature produced CCWF with varying flow rates and bacteria removal efficiencies, depending on the mix of clay and carbonaceous materials as extrapolated in Table 2.

2.1.1. *Plasticity of clay*

Acceptable plasticity for clay material to be used for producing CCWF should be between 10 and 30 % (Shepard et al., 2020). When the plasticity is less than 10 %, the filter will be brittle and less moldable and when it is more than 30 %, the filter takes a long time to dry and shrinks beyond acceptable allowance. According to Annan et al. (2016) if a clay material has plasticity below the acceptable range pure clay can be added to adjust it. Bentonite could also be added to increase its plasticity. If the clay material has above the needed plasticity for CCWF, silica sand can be added to reduce it (Ceramics Manufacturing Working Group, CMWG, 2011). The plasticity of clay can be easily adjusted to improve the durability and manufacture-ability of the filters to be used in the field. According to Lemons et al. (2016) and Murphy et al. (2010), 15–32% of CWFs in the field are broken or damaged within a period of

6 weeks to 6 months which could be attributed to the durability of the clay material used in manufacturing the filter. The mineralogy of the clay material used in producing CCWF affects the performance (Shepard et al., 2020), strength and plasticity (Ajibade et al., 2019; Solomon et al., 2023). The plasticity, linear shrinkage, bulk density, permeability and refractoriness of clays from Ado-Ekiti, Ilorin, and Kaduna was tested in the study of Shuaib-Babata et al. (2016) with a conclusion that the Ado-Ekiti clay has the best fit properties for producing CCWF based on plasticity, linear shrinkage, bulk density, and porosity of 4.8.6%, 6.0 %, 1.66 %, and 25.79 × 103 % respectively.

Firing clay material during the process of making CCWF affects the mineralogy of the clay (Shepard et al., 2020). Kaolinite, when fired to 1000 °C is converted to mullite crystals and amorphous silica (Xu et al., 2008). The inter-spaces of montmorillonite tend to collapse when heated (Andrini et al., 2017). This causes it to become brittle as the plasticity is totally lost. Quartz, albite, and muscovite can survive the firing process because of their higher melting points (Bennour et al., 2015; Chede et al., 2019). When clay material is fired in an oxidative environment, there is the possibility of Iron oxides being formed (Guerrero-Latorre et al., 2015). Firing temperature and source of clay material also affects biofilm formation (Shepard et al., 2020). The analysis of results by Shepard et al. (2020) showed that the difference in biofilm growth of clay materials can be linked to their origin and method of processing.

2.1.2. Silver application

Silver nanoparticles are effective in enhancing bacterial removal rates and their impregnation increased the sorption capacity of lead in comparison to unmodified filters (Sullivan et al., 2017; Lyon-Marion et al., 2018). Silver nanoparticles (nAg) or silver nitrate (AgNO3) are added to the fired CCWF through brushing/painting or dipping, or before firing by direct addition to the filter mixture (CMWG, 2011). Sullivan et al. (2017) noted the effect of silver particle size on bacteria removal; mono-dispersed solution of small nanoparticles added to disk yielded higher log removal values (LRV) than disks impregnated with larger or polydispersed nanoparticles. Oyendel-Craver and Smith (2008) showed that embedding a CCWF in zero-valent silver nanoparticles (10–100-nm diameter) improved the filter's effectiveness in disinfecting harmful substances.

Van der Laan et al. (2014) overruled the premise that the removal of virus is enhanced with no application of silver because biofilms are formed on the surface of the filter as assumed by Van Halem et al. (2007) and Van Halem et al. (2009). The addition of silver to CCWF disallows the formation of biofilms on the surface of the filter. Biofilms can reduce the microbial removal efficiency of the filter (Rayner et al., 2013; Bogler and Meierhofer, 2015; Shepard et al., 2020). Howe et al. (2006) observed that silver prevents the formation of mold on the surface of the filter with time. This was also supported by Lyon-Marion et al. (2018) who stated that the application of silver to CCWF reduces biofilm formation.

So many authors concluded that the addition of silver to CCWF increases its bacteria removal efficiency (Bielefeldt et al., 2009; Kallman et al., 2011; Sullivan et al., 2017; Bulta & Michael, 2019) while some others described the addition of silver as insignificant to the efficacy of bacteria removal in ceramic filters (Brown and Sobsey, 2010; van der Laan et al., 2014). According to Kallman et al. (2011) even with an increase in porosity with increasing burn-out material, the ability of the filter to effectively remove bacteria is not reduced when the filter is treated with silver nanoparticles. The various filter materials (with and without silver addition) and the corresponding bacteria removal efficiencies as experimented and reported by different authors are presented in Table 2.

A study carried out by van der Laan et al. (2014) concluded that the efficiency of E. coli removal from effluent water of a CCWF is more dependent on the filter's contact time with silver than on the burnout material content. The application of silver to CCWF makes them more sustainable and reduces the glitches of recontamination of stored water (Erhuanga et al., 2014; Lyon-Marion et al., 2018).

One of the challenges in CCWF production is knowing enough silver to add to increase efficacy, prevent biofilm formation and protect stored water from microbial recontamination without adding so much silver that exceeds the maximum recommended silver concentration in effluent drinking water. The maximum acceptable silver contaminant level in drinking water is 0.1 mg/L (USEPA, 2003; WHO, 2011). Besides the impending health impacts of ingesting silver, its elution leads to the depletion of silver from the filter matrix, thus wearing-out of advantageous effects with time (Lyon-Marion et al., 2018).

The use of nAg instead of AgNO3 is recommended by literatures because it lasts longer in the filter (Rayner et al., 2017). Although, nAg is more expensive and needs to be imported (Lyon-Marion et al., 2018). The recommended for applying silver is painting, as dipping is difficult to control and the amount of silver

Table 2: Some literature showing the relationship between filter parameters and corresponding effectiveness of composite ceramic filters

Author (year)	Shape of Filter	Weight (kg) and Dimension (cm)	Composition	Porosity (%)	Firing Temperature (°C)	Flow rate (l/hr)	% E. coli Removal	Silver /no silver
van der Laan *et al.* (2014)	Frustrum	≈ 10	Clay, Rice husk and Laterite				92	Silver
Bulta and Micheal, (2019)	Pot		Clay, Sawdust and Grog	63.91 - 51.63	700 - 800	0.35 - 0.15	77.9 - 96.51	NA
Ajibade *et al.* (2019)	Pot		Clay and Sawdust			1.91	100	NA
Farrow *et al.* (2018)	Cylindrical	8 kg (24h × 34 ø)	Clay and rice husk	22.4	830	1.0 - 3.0	94.7 & 99.5	Silver
Kallman *et al.* (2011)	Disk & Pot	0.08kg (6.5 ø × 1.5 t) and 8kg	Clay and Sawdust	19.9 - 45.5	900 & 800	1.0 - 2.5	87 -92 & 99.99 - 99.7	Silver
Zerefa and Belako, (2017)	Pot	11.8 h, 8 ø, 1 t	Clay, Sawdust and Grog	65.4 - 49.1	900, 950 & 1000	0.4 - 0.2	83.7 - 97.5	Silver
Soppe *et al.* (2015)	pot	9 kg	Clay, Laterite, and rice husk		800 - 950	3 - 10.1	2.3 - 1.9	Silver & no silver
Abebe *et al.* (2016)	Pot	8 kg (24h × 32 ø × 1.0 t)	clay, grog, and sawdust		830	1.4 - 2.3	79.9 - 83.3	NA
Yusuf and Murtala, (2020)	Cylindrical	2 kg (10h × 4.5 ø × 1.5 t)	Clay and sawdust		750 - 800	0.36 - 0.46	83.78 - 97.50	NA
Erhuanga *et al.* (2021)	Pot		Clay, laterite, bonechar, and charcoal	42.26	850 - 900		77 - 78	Silver
Shepard *et al.* (2020)	Disk	(4.7 ø × 1.5 t)	Clay and Sawdust		900			silver
Yoon *et al.* (2013)	Pot	8 kg (24h × 32 ø × 1.0 t)	clay, grog, and sawdust		830	1.4 - 2.3		NA
Lyon-Marion *et al.* (2018)	Disk	0.045 (5.0 ø × 1.5 t)	Clay and Sawdust	41.9	900	2.0 - 3.0		Silver
Gupta *et al.* (2018)	Frustrum	(23h × 25.5ø× 3.5 t)	Clay and Sawdust		900	0.6 - 0.9	99.7 - 99.8	
Ehdaie *et al.* (2017)	Tablet and Pot		Clay and Sawdust			1.5 - 3.0	86 - 99	Silver
Annan *et al.*, (2014)	Frustrum		Clay and saw dust		850	1.4 - 3.0		Silver
Ajayi & Lamidi, (2015)	Circular/ Disk	(6.35 ø × 1.27 h)	Clay, snail shell, cullet, charcoal, sawdust		850 - 900	0.03 - 0.09		NA
van Halem *et al.* (2017)	Frustrum	≈ 10	Clay, Rice husk and Laterite		830	6.0 - 19.0		Silver
Zhao *et al*, (2020)	Disk	(10 ø × 1t)	Clay and rice husk		1000	0.12	99.99	NA
Sullivan *et al.*(2017)	Disk	(5.5 ø × 1.5t)	Clay and sawdust	43.2	1050	0.03	99	Silver

absorbed cannot be easily determined (CMWG, 2011; Rayner et al., 2013). However, Lyon-Marion et al., (2018) reported that the firing-in process is preferable to painting or dipping methods for silver application.

2.2. Firing temperature

The process of firing a CCWF will make the carbonaceous material used to burn out and leave pores in the filter. The size and quantity of the carbonaceous material in a filter affects the flow rate, porosity, strength, and microbial removal efficiency of the filter. Zereffa and Bekalo (2017) noticed a reduction in grain size with increasing firing temperature and deduced that it might be the reason for the difference in the flow rate and micro-organism removal efficiency between filters fired at 900 °C, 950 °C and 1000 °C. Soppe et al. (2015) confirmed that an increase in firing temperature leads to an increase in flow rate. The effect of firing temperature on filter properties is highlighted in Table 2.

There is a strong correlation between the strength (fracture toughness) (Modulus of rupture) of the filter and the quantity of the carbonaceous material (rice husk) used (Soppe et al., 2015). An inverse correlation exists for the strength and firing temperature. As the firing temperature increases, the filter's strength increases but as the carbonaceous material increases, it decreases. Also, the change in the maximum firing temperature causes a change in the pore size but does not necessarily affect the porosity of the filter. An increase in the particle size of the burnout material decreases the filter's strength. (Soppe et al., 2015)

2.3. Shapes

From literature, ceramic filters can be shaped like a flowerpot/frustum, disk, and candle (Figure 2) (Lamichhane and Kansakar, 2013). These shapes do affect the bacteria removal property and flow rate of the filter (See Table 2). The most common shape is pot shaped/frustrum (van der Laan, 2014; Zereffa & Desalegn, 2019) and disk shape filters (Nnaji et al., 2016; Sullivan et al., 2017). There is also the tablet shaped silver-embedded type of ceramic filter (Ehdaie et al., 2017). According to the study of Erhuanga et al. (2014) the surface area of the pot filter being large makes it have higher filtration rate compared to other shapes.

3. Effectiveness of clay-based composite filter

A study by Hunter in 2009 revealed that clay-based ceramic water filter is more effective in treating water long-term than other treatment methods such as bio-

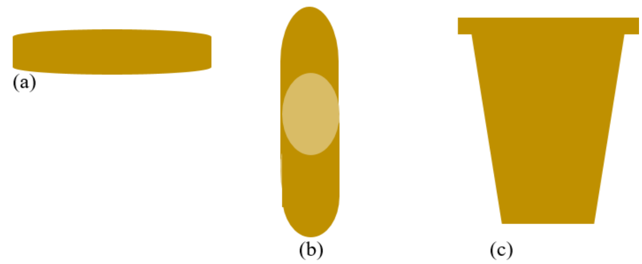

Fig. 2: Shapes of ceramic filter (a) disk (b) candle (c) Pot/Frustrum

sand, chlorination, and solar disinfection. As compared to other water treatment sources that diminish in efficiency over time, Howe et al. (2006) observed that in the continued use of CCWF, the pores of the filter lessen in size due to clogging and become more effective in retaining contaminants from the water. CCWF can remove many microorganisms from drinking water due to its ability to combine filtration, disinfection, and biofilm development (Farrow et al., 2018). Effective in filtering biological substances and can remove other organic and inorganic contaminants from drinking water (Sullivan et al., 2016; Gupta et al., 2018).

The variation in properties and efficiency of CCWF can be attributed to the differences in production parameters (Table 1 and 2). There is need for agreement on acceptable range production parameter for the optimization of CCWF property and increase in water treatment efficiency.

3.1. Flow rate and Porosity of typical ceramic filters

The priority of the CCWF is the ability of the filter to remove particles in micro and macro size range through physical processes like clogging, inertia, and adsorption (Zereffa & Bakalo, 2017; Bulta & Micheal, 2019). The porosity of the prepared filters increased with an increase in the percentage of burnout material incorporated in the compositions of the filters (Kallman et al., 2011; Soppe et al., 2015; Zereffa & Bekalo, 2017). High value of porosity means that the filter has bigger pore spaces which will allow the easy flow of water. Hence, the rate of water discharge by CCWF increases with porosity. The relationship between porosity and flowrate is that as porosity increases, flowrate also increases and vice versa. This was shown in the results of Bulta and Michael (2019) where the minimum flow rate observed was 150 mL/h, having porosity 53.06% and maximum flow rate was 350 mL/h for with porosity 63.91%. Increase in firing temperature causes a decrease in porosity (Bulta and Michael, 2019). Erhuanga et al. (2014) corroborated by Brown et al. (2008) reported that the change (increase) in laterite composition in the CCWF mix leads to an increase in the porosity of the filter. Also, increase in charcoal content increased the porosity of the filter (Erhuanga et al., 2014).

The flow rate of the filters also decreased with increasing of the % of clay for some filters and increased for others (Zereffa and Desalegn, 2019). A study by Ajibade et al. (2019) using clays from 5 different regions (Ara, Igbara odo, Ikere, Ire Isan) in Ekiti state to produce household CCWF had flow rates ranging from 0.003 L/hr for a clay to sawdust ratio of 90:10 to 8.9 L/hr for a 30:70 ratio. The flow rate through the filters was found to vary with increase in proportion of sawdust (Nnaji et al., 2016). Soppe et al., indicated that the more proportion of rice husk added to the mix of CCWF, the increase in porosity and flow rate; and the larger the rice husk particle size the larger the pore size. The flow rate of CCWF is enhanced with porosity, which can also mean the fraction of burn out material (sawdust) used in making the filter (Nnaji et al., 2016; Bulta and Michael, 2019). Nnaji et al. (2016) also indicated that the main justification for adding burnout materials into ceramic water filters is to increase the filtration rate, while achieving an elevated level of treatment. However,an der Laan et al. (2014) reported that the burnout material inclusion in CWF has no effect in the deactivation of bacteria (E. coli). In contrast, several studies have shown that increasing the particle size of the burn out materials, such as rice husk, can significantly enhance the flow rates of CCWFs without compromising bacterial removal efficiency (Bloem, 2009; Plappally et al., 2010; Soppe et al., 2015). The bigger the particle size the bigger the pores and subsequently higher flow rate.

Another factor that determines flow rate is the surface area of the filter. Filters with larger surface area have a higher flow rate than those with smaller surface area (Halem, 2009; Bulta & Michael, 2019). Flow rate increases with increase in the surface area of the filter in contact with the water (Erhuanga et al., 2014). The plasticity of the clay material can affect the flow rate and durability of the filter (Rayner et al., 2017; Shepard et al., 2020).

Soppe et al. (2015) notice a 17% reduction in flow rate of CCWF that were painted with silver as compared to filters with no silver. The study concluded that the reduction in flow rate with silver addition can be attributed to clogging of the pores in the filter membrane by silver. Using Pearson correlation coefficient, Soppe et al. (2015) deduced that with a varying proportion of rice husk to clay there is no correlation between the LRV and the flow rate of the CCWF. This implies that the flow rate can be adjusted without affecting the LRV and vice versa. Increasing the maximum firing temperature of CCWT from 800 °C to 950 °C causes a whooping increase in the average flow rate from 3.8 L/hr to 8 L/hr (Soppe et al., 2015).

Flow rate is mostly given in litres per hour, which means that it can be calculated using the equation 1 (Soppe et al., 2015; Bulta and Micheal, 2019);

$$\text{Flow Rate (FR)} = \frac{quantity\ of\ effluent\ water\ (Q)}{time\ taken(T)} \qquad (1)$$

3.2. Microbiological Removal Efficiency of CCWF

A significant obstacle to bacteria is the surface of the ceramic disks, it has the highest portion of E. coli stored (Sullivan et al., 2017). The Escherichia coli (E. coli) removal efficiency of CCWF is favorable as recorded by various authors. E. coli (Escherichia coli) is a pointer bacterium for the presence of bacterial pathogens and for fecal contagion in water (Paulinus& Salina, 2014). The result from Ajibade et al. (2014) for coliform and E. coli removal ranges from 12 and 4 for 30:70 clay to sawdust ratio to 100 for 90:10 clay to sawdust ratio, respectively. This was also supported by Bulta and Micheal (2019) who reported that the microbial removal efficiency of CCWF increases with increase in the percentage composition of clay and firing temperature. Less porous CCWF have a higher microorganism removal efficiently. Some literature concluded that ceramic filters with low porosity remove more microorganisms from water (Zereffa & Belako, 2017). Van der Laan et al. (2014) recorded that the E. coli removal efficiency of a CCWF is more dependent on the contact time with silver (i.e, storage time) than on the characteristics of the filter (like, composition of clay or burn out material).

Lyon-Marion et al. (2018) reported an increase in the microbial removal efficiency of CCWF with the application of silver nanoparticle or silver nitrate to the filter. Some studies recorded that the application of silver to the CCWF have no significant effect on its log removal efficiency (Oyanedel-Craver and Smith, 2008; Brown and Sobsey, 2010; van der Laan et al., 2014) unless the storage time of the water in the receptacle is increased to above 5 hours. While Bielefelt et al. (2009) stated that the application of silver to the CCWF immediately increases its E. coli removal efficiency, without considering the storage time.

Soppe et al. (2015) while investigating the critical parameters that can enhance the performance of CCWF pointed out that the pore size of the pot is a major determinant in its microbial removal efficiency. The study further stated that an increase in pore size, resulting from larger rice husk particle size leads to reduced bacteria removal efficiency. However, increased porosity- caused by a higher proportion of rice husk in the filter mix- had no effect on the log removal but did affect the strength of the filter. This implies that the flow rate of a CCWF can be increased to any length without really affecting the efficiency of the filter once the strength is still intact. This study also reported that increase in the maximum firing temperature has little or no effect on the E. coli removal efficiency of a CCWF. This is caused by an increase in the pore size of the filter with increasing firing temperature.

Most bacterial removal efficiency calculations are obtained from Log Reduction value (LRV) (Soppe et al., 2015). The calculation for LRV is given as;

$$\mathrm{LRV} = \log_{10}\left(\frac{\text{number of bacteria in influent water}}{\text{number of bacteria in effluent water}}\right) \qquad (2)$$

The growth of Biofilm on CCWF can lead to a reduction in its microbial removal efficiency; it is therefore discouraged (van Halem, 2006; Mellor et al., 2014; Bogler and Meierhofer, 2015).

3.3. Virus removal efficiency of CCWF

The efficiency of ceramic water filters in removing/ reducing viruses is still not clear. According to van der Laan et al (2014) no parameter is yet to be found to enhance the virus removal efficiency of CWF as it has been indicated that the CWF is not effective in removing virus enough to meet the WHO standard (WHO, 2011). Many authors have worked on the efficiency of CCWF in virus removal, some of which are Van Halem et al. (2007); Bielefeldt et al. 2010; Brown and Sobsey (2010); Salsali et al. (2011); Abebe et al. (2016). The result from the study of Salsali et al. (2011) revealed a virus log removal value of between 0.21 to 0.45 from ceramic filters manufactured from RDI, ICE and CRC which is much lower than the log removal value gotten from the studies of Van Halem et al. (2006) with virus log removal value ranging from 0.5 to 3.0 and Brown et al. (2009) with values of 1.0 to 2.0. These studies concluded that the higher the flow rate of the pot, the lower the removal efficiency.

In the study of Van Halem et al. (2006), it was noticed that clogging and biofilm build up improves virus removal efficiency. This was because they experienced the lowest removal value in week 5 before the filter was scrubbed and the highest removal value in week 13 when clogging of the filter had already taken place. The study of Salsali et al. (2011) showed that virus removal efficiency is enhanced is increased turbidity. It was postulated that the virus binds with the particles in water which aid their removal.

The presence of iron oxides (hematite) can promote the removal of viruses from drinking water (Brown & Sobsey, 2009).

Abebe et al. (2016) conducted a study with the aim of improving the virus removal efficiency of CCWF by pretreating the water with chitosan (a natural coagulant that can be gotten from shell of seafood like shrimps, lobsters, prawns, and crabs) using coagulation-flocculation. The result of this study reported a reduction in the virus and bacteria contaminants in water even up to the WHO health protecting water standard with Chitosan pretreatment. Therefore, the use of chitosan in pretreating water was recommended. This study also revealed that CCWF alone cannot provide drinking water that meets the WHO protective standard.

Studies from Van Halem et al. (2007) and Van Halem et al. (2009) hypothesized that the CCWF could remove viruses more efficiently if no silver is applied to the filter. This hypothesis was based on the premise that without silver a biofilm can develop on the surface of the filter over time creating a surface or filter cake layer that can remove MS2 bacteriophages. Van der Laan et al. (2014) overruled the premise that the removal of virus is enhanced with no application of silver because biofilms are formed on the surface of the filter as assumed by Van Halem et al. (2007) and Van Halem et al. (2009).

In a book on clay production, Hagan et al. (2013) explained that the addition of laterite to the CCWF mix promotes the binding and inactivation of viruses in influent water. A study by Bloem et al. in 2009 found no difference in virus removal with the addition of laterite, which agrees with Brown and Sobsey (2009).

4. Conclusion

CCWF is a simple and effective method of filtering water that can be easily used in rural areas. It is one of the most effective long-term sources of treating water at the household level in less developed areas as it can last for 3 to 5 years. The use of clay for filter material should be properly monitored to ensure its properties are within the acceptable plasticity level and grain size. It can trap up to 99 % of bacteria and insoluble contaminants in water. It can produce more than 0.6 ml/ hr. of safe and drinkable water and sometimes even up to 2.3 l/hr depending on the pore size of the produced filter. All these varying parameters with varying performance outcomes will enable manufacturers make decision having the intended outcome in mind and knowing the parameters to enable such outcomes. Also, trade-offs can be made based on specific performance requirements.

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