

Development of Eggshell Powder Potential in Claypot for Water Filtration Process for Rural Dwellers in Nigeria

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Abstract

Access to safe and clean drinking-water in the rural areas of Nigeria is practically impossible, because they are limited to such sources as streams, rivers, hand dug wells and rare cases boreholes which are poorly managed, leading to several health complications. Contaminated water contributes largely to the number of reported health related issues in rural communities of developing countries. Consumption of water contaminated by disease-causing pathogens can cause health problems such as diarrhea, cholera, typhoid, dysentery, and skin diseases. This project attempts to provide a low-cost and environmentally friendly efficient method of water filtration process using clay minerals reinforced with a filter material - eggshell. This was achieved through the characterization of the clay and eggshell materials, the preparation of the clay – eggshell blend mix at 1:1, 1:2 and 2:1 and the construction of prototype clay – eggshell blend pot. The use of clay and eggshell as the adsorption materials offer great advantages, because it is readily available, cheap and practicable.

1. Introduction

Water accessibility is a fundamental requirement for the sustenance of all organisms [1]. Access to safe water remains one of the most pressing concerns confronting Sub-Saharan Africa, which is home to around 48% of the world's population without access to potable water [2]. Nigeria, with its population of over 200 million people, grapples with a critical deficiency of clean water, particularly in rural areas, where inhabitants are disproportionately affected by an acute scarcity of fresh, potable water compared to their urban counterparts [3]. The country is plagued by poor water infrastructure and maintenance, insufficient resources to provide clean water to its citizens, particularly those living in rural areas. Rural communities in Nigeria constitute 48% of the country's overall population [2]. However, these communities usually rely on water resources from rivers, lakes, and streams, which are frequently contaminated and unfit for domestic use [4 – 5].

According to the World Health Organization (WHO), approximately 60 million people in Nigeria lack access to safe drinking water, with most of them residing in rural areas. In rural areas, 39% of households lack access to at least basic water supply, while only half have access to improved sanitation and almost a third (29%) practice open defecation – a fraction that has marginally changed since 1990 [6].

The rural dwellers in various parts of Nigeria depend mainly on surface water such as pond, stream, river, shallow well and these sources of water in the rural areas are normally contaminated with pathogens, guinea -

worm, chemicals and agricultural waste products. Consumption of contaminated water could lead to water-borne diseases such as diarrhea, typhoid, cholera and other deadly diseases [7]. Waterborne infections such as bacteria, viruses and protozoa pose a great threat due to their immediate and severe health effects [8 – 9]. It is important to ensure that low-income communities, which are more vulnerable to waterborne illnesses, have access to affordable and easily accessible clean water.

Ankidawa and Tope [10], reported that treatment of water in the rural areas is very difficult and expensive due to lack of facilities for water treatment in the rural areas; most rural areas don't have electricity to power water treatment plant and lack of petrol or diesel in rural areas to run the machine. Various traditional water purification methods have been employed over the years, but they require significant energy and financial resources, making them unsuitable for rural communities in developing countries [11]. There is a need for developing simple and portable household water treatment equipment such as ceramic water filters, slow sand filter and other simple water treatment for the rural dwellers to prevent water-borne disease among rural dwellers [12].

In recent years, there has been a surge in global research focused on low-cost filtration and decontamination systems. The objective was to investigate various alternative materials for treatment, including adsorbents such as agricultural waste, clays, and industrial waste. Ceramic water filtration involves the passage of water through a permeable ceramic substance. Using local resources, this cost-effective approach offers potential for decreasing the rising incidence of waterborne illnesses. Ceramic filters can be shaped as a flowerpot, disc, or candle [13]. Clay is another potential alternative to activated carbon. Clay minerals are important inorganic components in soil because they are widely available and have excellent sorption properties due to their large surface area and exchange capacities. The charge present in the structure of clay minerals allows clay to effectively attract metal ions.

Also, hybrid ceramic pot water filters (HCPWFs) provide practical options for effectively removing microorganisms and other contaminants from contaminated water in low - income settings. Hybrid water filters combine microscopic pore sizes in ceramics and organic materials to filter dirt, sediment, and pathogens out of water, making this technology appropriate for usage in rural settlements. The microbial removal efficiency, water discharge rate, and decontamination capability of HCPWF are all contingent upon the firing temperature, particle size, ramming (forming) pressure, and the reaction that takes place during firing [9].

There has been a growing interest in the use of clay minerals to remove both inorganic and organic molecules [11, 14]. In this regard, eggshells have been reported to contain a significant amount of calcium carbonate, making it an excellent adsorbent substance for soil and polluted water remediation [15]. Furthermore, due to the porous nature of eggshells, the residue is a promising adsorbent for the removal of various contaminants found in aqueous solutions [16]. An additional benefit of this adsorbent is its potential for use in its natural state without the need for chemical processing to enhance its surface activity, owing to its substantial porosity and natural structure. However, inappropriate disposal of eggshells may result in environmental and public health hazards, as they facilitate the proliferation of microorganisms, including those that are detrimental to health, and attract predators and disease-carrying organisms [17].

Clay-based ceramic water filters are developed by combining clay and water. Additional organic components, such as eggshells, sawdust (woodchips), rice husk, and other substances, are incorporated into the mixture to optimize the effectiveness of the filter and improve the efficiency at which water is discharged. Upon undergoing high temperature firing, the clay mixture containing organic materials acquires enhanced mechanical strength, chemical stability or inertness, and porosity [8, 13].

Many recent research investigations have explored the possibilities of using diverse clay – based water filters to enhance the quality of drinking water, but the use of clay – eggshell water filter for water filtration process for rural dwellers in Nigeria is a unique approach that worth investigating. Eggshell is a solid waste produced in several tons per day. It is economical to transform the eggshell waste to create new values from these waste materials. The eggshell waste can be used as an absorbent of heavy metals from wastewater as it is a serious environmental problem in the ecosystem [18]. Habeeb et al., [19] evaluated the characterization and application of chicken eggshell as green and economical adsorbents for the treatment of hydrogen sulfide from wastewaters, it is concluded that the chickens' eggshells are very useful green and economic adsorbents due to their availability and absence of any toxic and hazardous constituent's elements from all adsorbents.

The porous nature of eggshells makes it an attractive material to be employed as an adsorbent. The eggshell typically consists of ceramic materials which are arranged in a three-layered structure, namely the cuticle on the outer surface, a spongy (calcareous) layer and an inner lamellar (or mammillary) layer. The eggshell by-product represents approximately 11% of the total weight (approximately average 60 g) of egg [20]. Eggs are used in enormous amounts by food manufacturers and restaurants and the shells are discarded as waste. Most of this waste is commonly disposed of in landfills without any pretreatment. Occasionally, a few percentages of these byproducts are reused and applied as a fertilizer or feed additive because of their high nutrition contents such as calcium, magnesium and phosphorus [21]. On behalf of the bio resource recovery and reuse, many investigations have been conducted to explore useful applications for eggshells. The results of this research have shown that

eggshells appear to be able to effectively absorb certain heavy metals and organic compounds [22]. Natural eggshell had some removal capacity of Cd and Cr, with an efficient removal of Pb [18].

Thus, the purpose of this study was to characterize the clay mineral and eggshell as a filter and fabricate a hybrid pot comprising clay and eggshells on a laboratory scale using various compositions of clay and eggshells. The research is limited to the utilization of eggshells from the Intensive (Cage) Chicken Poultry System where the birds are placed in an enclosure throughout. This leads to more output, and the producers keep track of their customers and potential sources of eggshells.

2. Methods

Natural clay was obtained from Jimeta Riverbank Lat 9.30544 N and Log 12.4799 Gerei, Yola – Adamawa State. A representative sample was collected for natural moisture content (NMC) determination, the rest were air – dried in the laboratory at a temperature not more than 50°C in line with BS 1377-1, and subsequently placed in an oven at 105 ° for 24 hours. Samples were then prepared for physical properties tests and characterization. Chicken eggshell waste was obtained from poultry house and fast-food stalls near the poultry, this is to ensure that shells from the same source were utilized and ensure that those from other types of birds (ducks and guinea fowl) were not utilized, for uniformity, colour, and strength of the shells. The shells collected were first sorted to remove dirt and membrane, washed and airdried in the laboratory., Yola, has an annual average temperature range of 17°C – 43°C, with the coldest and hottest months being January and April respectively, and relative humidity of 16.82% - 77.87% in February and August. The research work was conducted in December where the annual average monthly laboratory temperature and relative humidity were measured as 29.54°C and 21.34% respectively. Air-dried samples were subsequently washed using distilled water to avoid contamination that may likely affect the characterization results, as well as the possible outcome., Samples were ground into powder form using Los Angeles abrasion machine and then sieved through 300µm and 600µm ASTM sieve to bring it to the size range required.



Fig. 1 (a) Drying of crushed eggshells waste; (b) Quantity of eggshell waste collected, ready for crushing; (c) Grinding process for eggshell using Los Angeles abrasion machine



Fig. 2 (a) Ground and processed eggshell powder; (b) Clay sample; (c - d) Mechanical sieving using shaker for clay and eggshell powder

Grain size analysis test was conducted on both clay and eggshells in accordance with ASTM C 136 and the materials were subsequently characterized using energy dispersive X – ray fluorescence (EDXRF) and X – ray diffractometry (XRD) to determine their chemical composition, where the scanning regions of the diffraction were $5-80^\circ$ on the 2θ angle. Microstructural analysis by scanning electron microscopy (SEM), as well as other aspects relating to its granulometry and density. The amount and type of waste to be used individually or collectively, in addition to possible conditioning based on fundamentally technical criteria, considering the properties that are intended to be achieved in the clay-eggshell reinforcement.

Preparation of the blend was through a mixture composition of clay - eggshell blend using a replacement ratio of 1:1, 1:2 and 2:1 with special attention paid to moisture content which plays a significant role in the hardening stages, and therefore its content is crucial because it influences the development of mechanical strength. Atterberg Limits Test to ASTM D4318 was subsequently conducted.

Fabrication of the clay pots was done by mixing clay with crushed eggshell waste using different mix ratios (1:1, 1:2 and 2:1) with particle sizes passing through $300\mu\text{m}$ and $600\mu\text{m}$ respectively. The sieved clay materials were taken in the required proportion and mixed, thus wetted by adding water, then wedge and rolled to get a smooth homogeneous mixture. Clay material was molded into a “throw – up” clay, and the crushed eggshell powder sprinkled on the “slab strip” and the clay rolled on it. The clay lump is then molded and remolded again until the required quantity to be used in the mixing ratio is exhausted. This is to ensure uniformity of the mix and dispersed the particles adequately. Subsequently the appropriate shape required for the prototype is obtained as in Figure 3. The framework of implementation of the methodology is given in Figure 4.

3. Results

The particle size distribution for clay, eggshell ($600\mu\text{m}$ and $300\mu\text{m}$) passing the standard ASTM sieve are presented in Figure 5 below where the clay is well distributed. Table 1 presents the physical characterization results, and eggshell powder is non – plastic from Atterberg limits. On the other hand, the clay from the Benue Riverbank is highly plastic (PI = 17%). This is important, because the fine particles in the clay help in alleviating the coarseness of the non – plastic eggshell.

The lack of plasticity of the eggshell was observed during the determination of Casagrande method for the determination of liquid and plastic limit test. It was observed that the grooved portion closes after 2 blows, and when rolling to determine the plastic limit the sample crumble instantly.

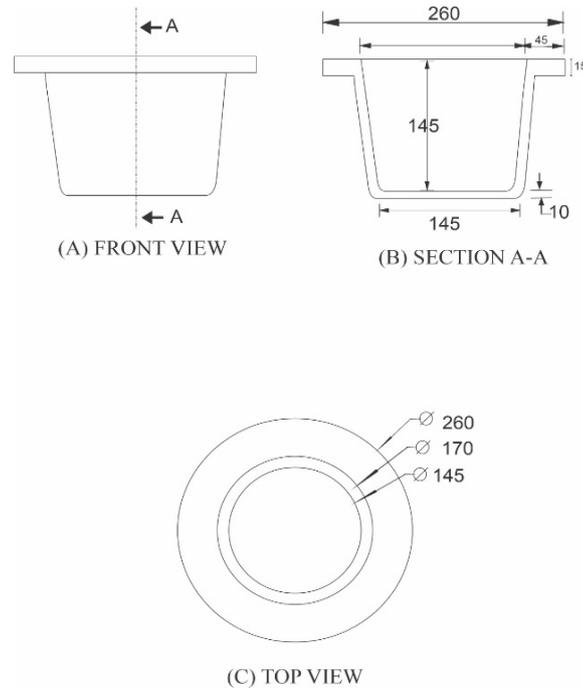


Fig. 3 Schematic diagram of ceramic filter pot

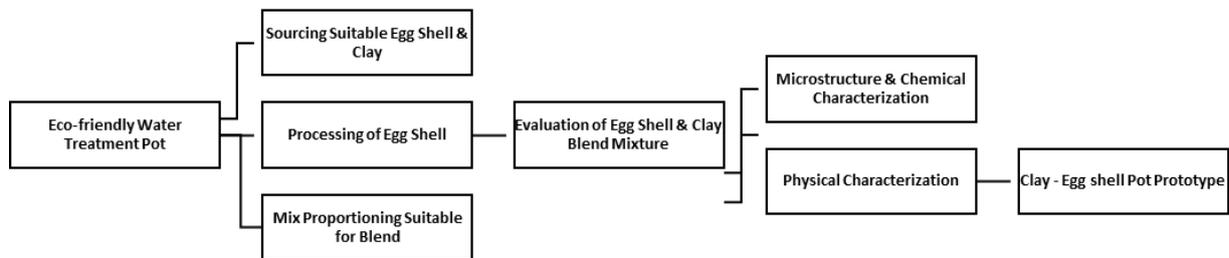


Fig. 4 Framework of implementation

The chemical composition of each sample is presented in Table 2 as determined using EDXRF spectrometer and results obtained shown below. EDXRF confirms the high concentration of SiO_2 and Al_2O_3 in clay and trace amounts in eggshell. The molar ratio for clay and eggshell is 2.02 and 2.83 respectively. This is an indication of a kaolinite clay sample with free silica in the form of quartz present [23]. It can be said that there is an excess amount of quartz with some alumina present. Figure 6 corroborates this assertion with XRD results which shows a 75% quartz content. The major peaks in the XRD results correspond to quartz (Si_6O_6), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_9$), calcite ($\text{Ca}_6\text{C}_6\text{O}_{18}$) and rutile (Ti_2O_4) phases. Results also show abundance of Al_2O_3 , an indication of a kaolinite clay, confirmed from the XRD analysis in Figure 6. K_2O of 2.55% in the chemical analysis shows the presence of illite clay mineral. CaO was found to be the highest oxide in eggshell powder with others in trace amounts. XRD analysis in Figure 6 shows it is entirely composed of calcite.

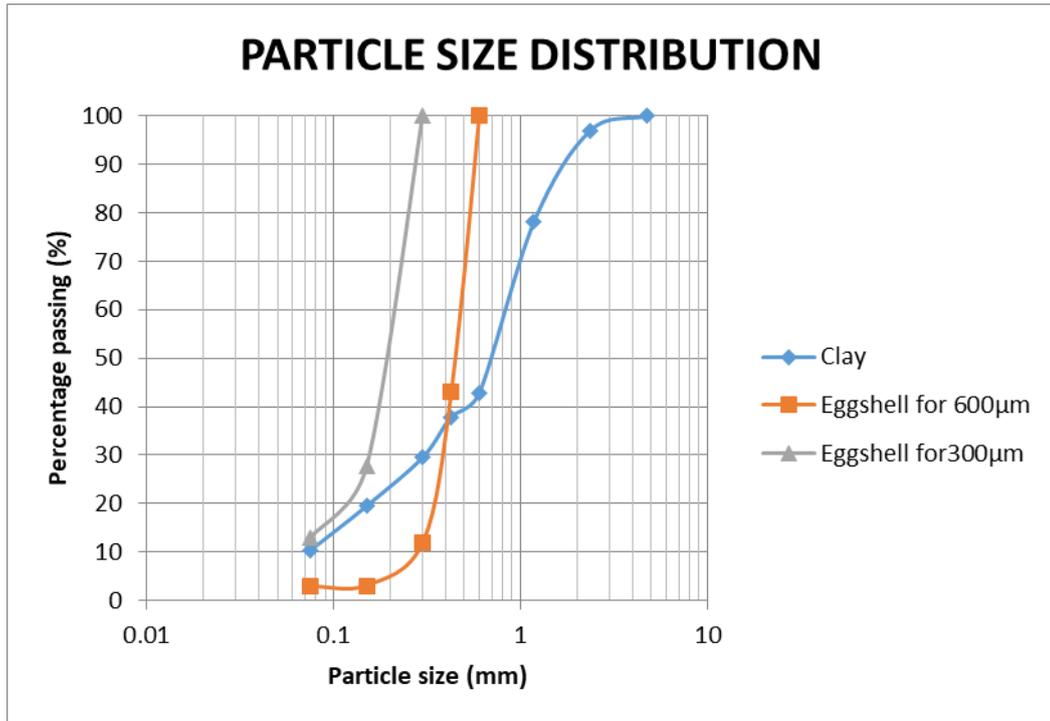


Fig. 5 Particle size distribution for crushed eggshell and clay

Table 1 Physical characteristics

S/No	Material Description	Materials retained on 425 µm sieve (g)	LL	PL	PI (%)
1.	Clay	23.9	49.0	31.4	17.6
2.	Eggshell (600µm)	285.1	-	NP	NP
3.	Eggshell (300µm)	-	-	NP	NP

LL – Liquid Limit; PL – Plastic Limit; PI – Plasticity Index; NP – Non - Plastic

Table 2 Oxide composition of clay mineral and eggshell

Compound	Clay Mineral (%)	Eggshell (%)
Fe ₂ O ₃	3.25	0.15
Al ₂ O ₃	23.30	0.67
SiO ₂	47.20	1.90
P ₂ O ₅	0.19	0.66
SO ₃	0.08	0.80
CL	-	0.29
K ₂ O	2.55	0.34
CaO	1.66	48.81
TiO ₂	1.05	0.01
MgO	3.12	-
V ₂ O ₅	0.02	-
Cr ₂ O ₃	0.01	-
MnO	0.05	-
Na ₂ O	0.96	-
BaO	0.07	-
ZrO ₂	0.26	-
LOI	15.30%	46.80%
Molar Ratio (SiO ₂ /Al ₂ O ₃)	2.02	2.83

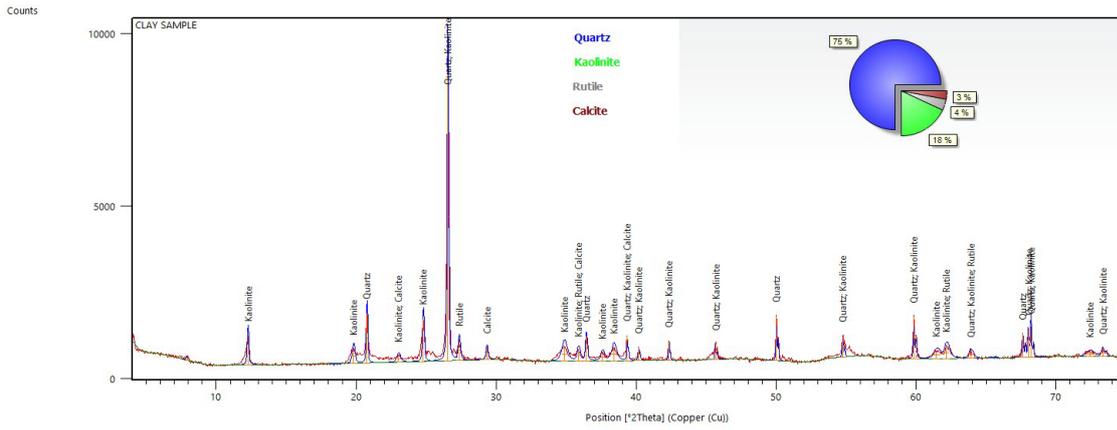


Fig. 6 XRD analysis for the clay mineral

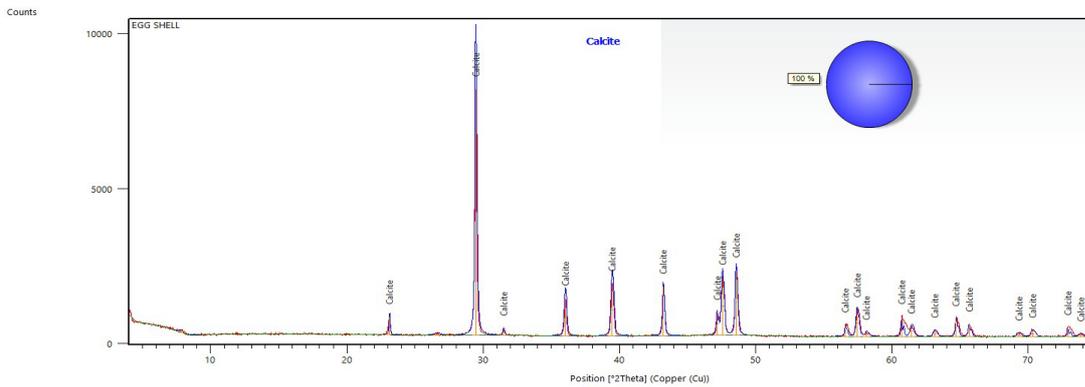


Fig. 7 XRD analysis for eggshell



Fig. 8 (a-d) Shows Atterberg limit test for clay and crushed eggshell. (a) Grooved eggshell sample; (b) Eggshells sample after 2 blows; (c) Clay sample; (d) Determination of weight

Four methods of molding ceramic clay pots (coiling, throwing, hand build and slab strip method), Slab strip method were tried. Coiling and hand build methods were experimented, but the required thickness and shape was not achieved, while in the throwing method, the blend collapses as it is pull up due to the application of additional water during the throwing process (Figure 9). The slab strip method eventually gives the required thickness and shape and is therefore recommended when incorporating eggshell powder. The molded pots in Figure 10 were stored in an air – tight polyethene bag for 4 – 5 days in the laboratory to ensure that the prototype do not undergo rapid drying, losing moisture in the process accelerating drying shrinkage cracking, considering the thickness of the wall in Figure 3. The laboratory conditions described in the methodology section still applies and is a spacious area will provision for proper ventilation. Specimens were constantly monitored for onset of cracks on the prototype clay pot.



Fig. 9 Methods used in molding the clay pots. (a) Coiling method; (b) Hand build method; (c) Throwing method; (d) Slab strip method



Fig. 10 (a) Moulding of pot; (b) Moulded pot during inspection; (c) Laboratory curing of prototype pot

SEM analysis conducted on the pure clay samples in Figure 11 shows particles of irregular shapes and sizes on the surface. These are possible clay mineral particles of varying sizes and can be attributed to the size utilized. XRD analysis indicates the presence of kaolinite clay minerals. A significant feature of Figure 12 for varying composition of clay and eggshell is the manifestation of cracks. This becomes evident in Figure 12 (d – f) due to the higher amount of 600 μ m eggshell powder incorporated in the matrix. In 300 μ m particle size, isolated cracks were observed, however, at 600 μ m, the cracks became pronounced and coalesce and intersecting at a pore. Pots constructed with 600 μ m eggshell showed signs of cracks at early stages of drying during inspection

and did not attain the 3 – 5 days of drying in a polyethylene bag. There was a significant reduction in cross section and the mortality rate for the pots were 100% during drying as shown in Figure 13.

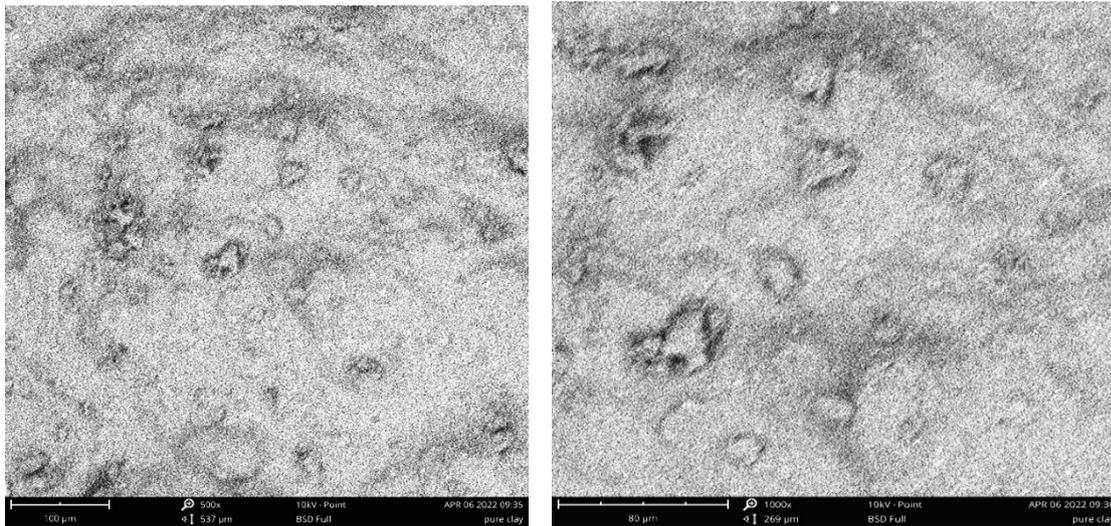
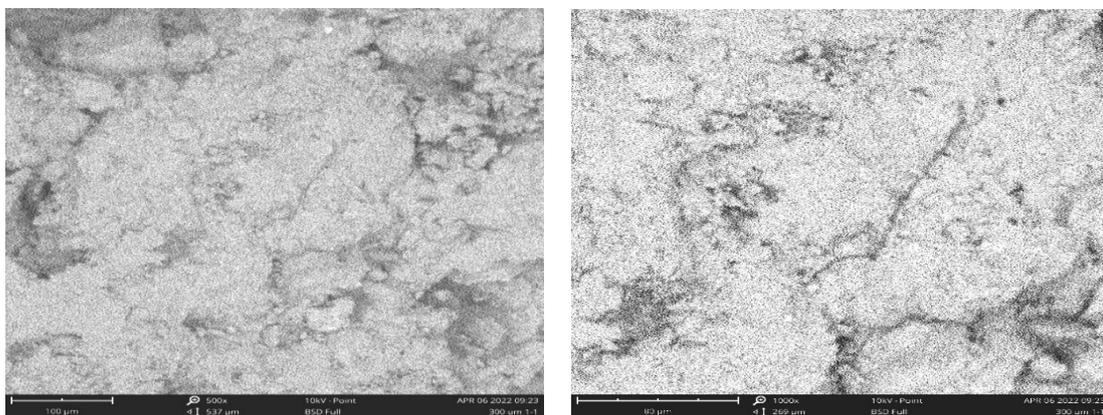
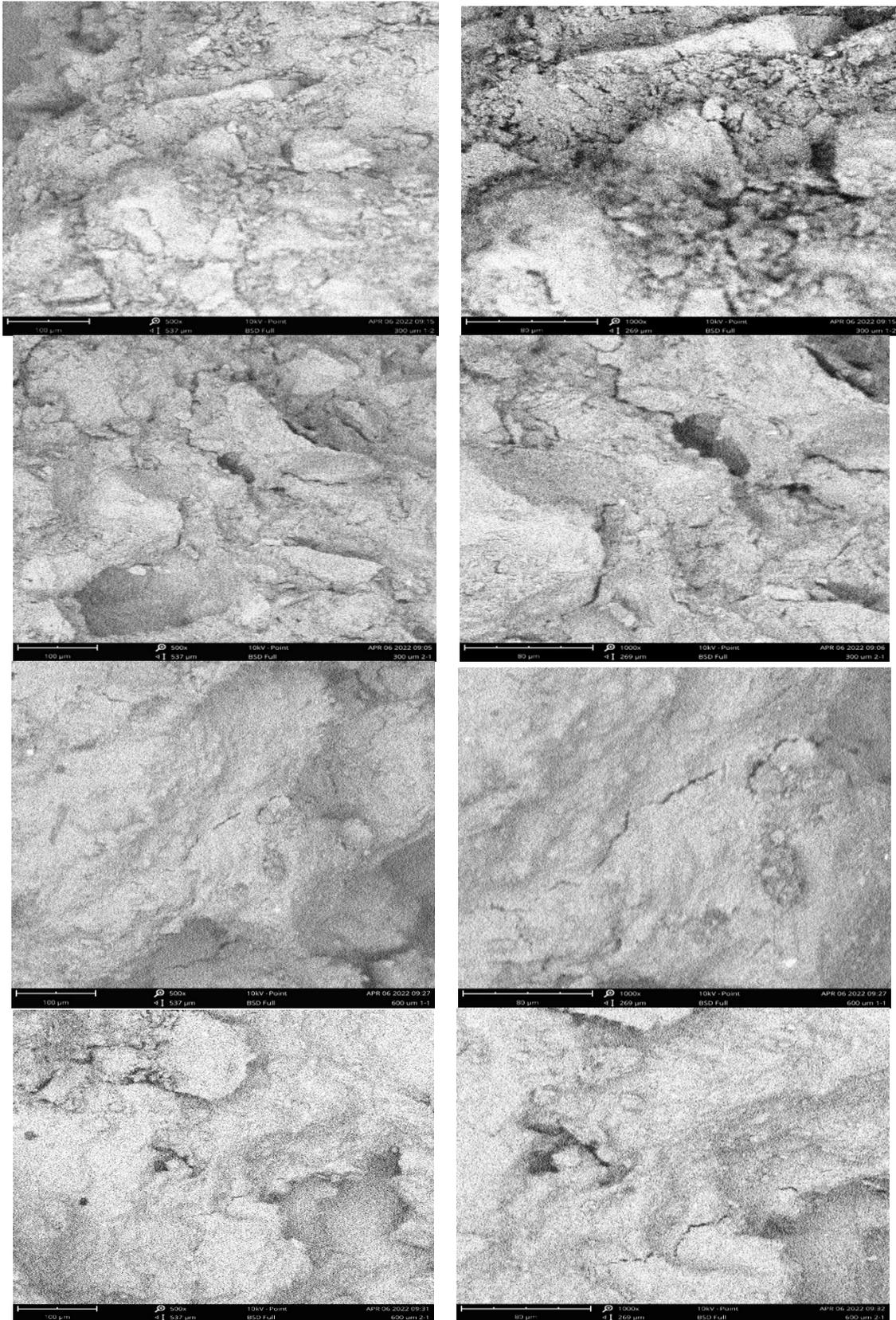


Fig. 11 Scanning electron micrographs at 500x and 1000x of Pure clay

4. Conclusions

This research investigated the development and utilization of eggshell powder to make ceramic pot for low-cost drinking water treatment techniques. To ensure eggshells were from the same source and properties, poultry client list was obtained, and collection of shells was done over a period of few months to get the required quantity. Characterization showed that quartz (SiO_2), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_7$), calcite (CaCO_3) and rutile (TiO_2) were the major clay minerals present with possibility of Illite. The clay was found to be highly plastic, as opposed to the eggshell powder. Clay – eggshell pot molded in 300µm 1:1 and 2:1 successfully cured, while 600µm 1:2 (clay – eggshell) had a mortality of 100%, due to debonding between the clay – eggshell matrix interface. Potential utilization of the clay – eggshell blend would involve lower particle sizes for both eggshell and clay powder. It is hereby recommended that future research should explore lower percentages of eggshell powder as the filter material for improved efficiency.





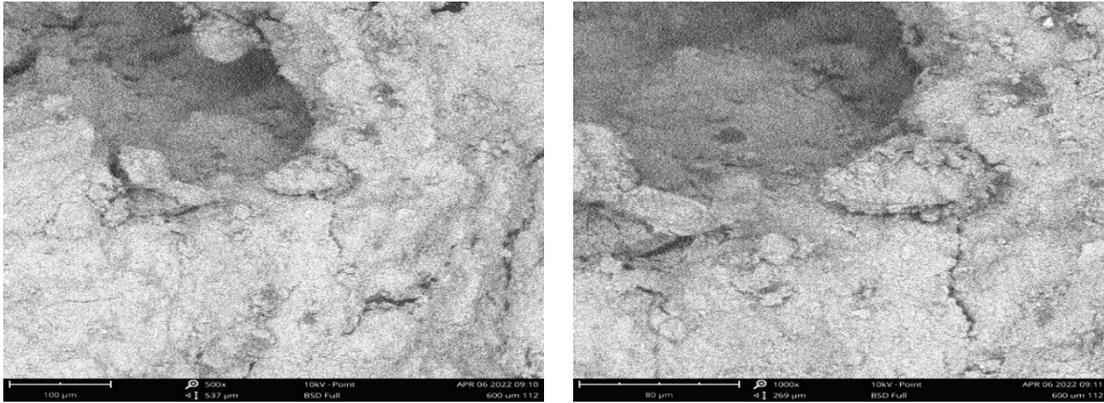


Fig. 12 Scanning electron micrographs at 500x and 1000x (a) 300 μ m 1:1 Clay Egg Shell; (b) 300 μ m 1:2; (c) 300 μ m 2:1; (d) 600 μ m 1:1; (e) 600 μ m 2:1; (f) 600 μ m 1:2



Fig. 13 (a) Prototype pot using 600 μ m 2:1 (eggshell – clay); (b) Awaiting firing

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** A. Idris, M. S. Nadro, A. U. Abubakar; **data collection:** A. Idris, A. T. Buni, H. Mamman, I. S. Diwa; **analysis and interpretation of results:** E. W. Gadzama, H. A. Mahmoud, I. A. Yahya, S. Bala, A. U. Abubakar; **draft manuscript preparation:** I. A. Yahya, M. B. Yawale, Y. Aliyu, M. L. Tumba, A. U. Abubakar. All authors reviewed the results and approved the final version of the manuscript.

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