African Journal of Environment and Natural Science Research
ISSN: 2689-9434
Volume 4, Issue 1, 2021 (pp. 53-61)
www.abjournals.org

DEVELOPMENT AND EVALUATION OF THE PERFORMANCE OF CERAMIC WATER FILTER PREPARED FROM DRIED DUCKWEED PLANT

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ABSTRACT: *Most of the available water sources such as streams, rivers and wells have been impaired by anthropogenic activities thereby rendering them unsafe for consumption. This has made access to clean potable water a mirage to communities situated in the semi urban areas, hence, increasing their daily risk of contracting water borne diseases. This work initiates the treatment of these water sources with dried duckweed plant. The duckweed plant was prepared and incorporated into a ceramic water filter (CWF) and was compared with other ceramic water filters prepared alongside. The filters were allowed to filter water obtained from a river source so as to evaluate their removal efficiency on the physicochemical parameters before and after treatment. The experimental results showed a significant reduction in the values of Turbidity from 97.85 NTU to 0.093-0.002NTU, Chloride from 163.74 mg/l to 10.50-7.52mg/l, Nitrate from 129.01mg/l to 13.67-9.88mg/l, Phosphates from 29.86mg/l to 1.20-0.67mg/l, Total Dissolved Solids(TDS) from 400.50mg/l to 105.00 to 95.50mg/l, Total Organic Carbon(TOC) from 62.78mg/l to 16.50-11.80mg/l, Biochemical Oxygen Demand(BOD) from 97.00mg/l to 37.00-22.00mg/l, Chemical Oxygen Demand (COD) from 283.00mg/l to 66.00-47.00mg/l, Total Hardness from148.96mg/l to 103.44-79.22mg/l and pH from 9.64 to7.49. The result of filtration showed that the ceramic water filter incorporated with duckweed gave the best removal efficiency of contaminants within the maximum limit recommended by Nigeria Industrial Standards (NIS) and World Health Organisation (W.H.O*).*

KEYWORDS: Ceramic Water Filters, Clay, Duckweed, Water Treatment.

INTRODUCTION

Access to good adequate water quality is very essential to health and any sustainable development [1]. However, projections indicate that the population living in water – stressed and water- scarce countries will grow from about 1.2 billion or 18% of the world population in 2007 to 4.0 billion or 44% of the world population by year 2050 as reported by International Water Management Institute [2].

Effective water treatment through “conventional methods” which rely on heavy aeration are expensive to install and operate. Hence, there is a need to explore some “non-conventional" methods which are not only economically viable, easy to operate but also environmentally friendly. For this purpose, plant-based phyto-remediation technology is the most promising option, as any aquatic plant that is capable of extracting nutrients or pollutants which has a fast growth rate coupled with high nutritive value is an excellent candidate for bio-remediation of waste waters [3].

Ceramic filters have been used to remove different water pollutants from dyes to biological, organic and inorganic pollutants [4]. Ceramics water filter possesses distinguishing chemical (*adsorption capacity*) and mechanical properties (*high strength, high hardness values, excellent chemical durability and low cost*). These properties have made them favorable candidates for development of different purification materials especially for improving quality of contaminated water through applications at the point of use in places with high user compliance [5].

Duckweed belong to the family *Lemnacea* and taxonomically belong to monocotyledons and have four genera: *Lemna, Sprodela, wollfia* and *wolfiella*. They are free-floating aquatic plant that grows in both still and running freshwater, such as lakes, rivers and streams. Depending on the circumstances, duckweed can be an extremely invasive species or a welcome aquatic plant, they usually have small vestigial roots and grow in the form of thick green carpets of rounded free-floating thalloids, flattened structures which resemble leaves and in most cases can rapidly spread to cover a waterway resisting all attempts to eliminate it. Due to their ability to propagate rapidly by consuming dissolved nutrients from water, duckweeds act as an excellent “nutrient sink” for harvesting nutrients over a short period of time and thus serve as a “nutrient pump” in waste water treatment absorbing nutrients like nitrate, phosphate, calcium, sodium, potassium, magnesium, carbon and chloride from wastewater. These nutrients are permanently removed from the system when the plants are harvested. Besides nutrient extraction, duckweeds reduce total suspended solids (TSS), biochemical oxygen demand (BOD)and chemical oxygen demand (COD) in waste water significantly [3]

The performance of ceramic water filters has been significantly improved by the use of burnout materials which increase the flow rate by creating a network of pores. Burn out materials such as sawdust helps generate pores, increases the flow rate and the efficiency of the ceramic water. Charcoal which has also been used as an additional material adsorbed odour and colour from the filter hence further increasing the flow rate with no significant removal of inorganic and organic pollutants and contaminants which are very detrimental to health [6]

This work explores the possibility of improving water quality by initiating waste water treatment with dried duckweed plant. Hence, in this research, four different filters were produced containing clay and kaolin; clay, kaolin and sawdust; clay, kaolin and charcoal; and, clay, kaolin and duckweed. These filters were marked P1, P2, P3, P4, respectively and they were evaluated based on their removal efficiency of organic and inorganic pollutants from contaminated water.

MATERIALS AND METHODS

Materials Used: The evaluation of the removal efficiency of pollutants by ceramic filter initiated with dried duckweed plant was the focus of this research. Red ball clay, kaolin, sawdust, charcoal and duckweed plant were the raw materials used for the production of the ceramic filters.

The red clay mineral was obtained from Girei in Adamawa State North Eastern part of Nigeria and was preferred because it exhibits high plasticity to hold the filter particles together and a greater dry mechanical strength when fired [7].

The kaolin was obtained from Alkaleri in Bauchi State and was used to increase the plasticity of the clay. The hard wood sawdust was preferred to soft wood because it does not cause bloating and results in a more uniform pore formation with fewer defects in the filter [8].

Charcoal was obtained from a hard wood which is very stable and was used as an odour and colour adsorbent [9].

Duckweed plant of the specie *lemnae minor* as seen in Fig. 1a was identified by a Botanist in the Plant Science Department of Modibbo Adama University of Technology (MAUTECH), Yola, Nigeria and was obtained from Lake Gerio situated in Jambutu area of Adamawa State, Nigeria.

Preparation of the Ceramic Water Filter: Clay, kaolin, sawdust, charcoal and duckweed were grinded and sieved after drying in the sun for about three weeks as seen in Fig 1b. The average particle size of the raw materials that passed through the sieve was 0.36 mm. Sieved clay and kaolin was mixed with water alongside the combustible materials in a required proportion to form a slip. The slip was poured into a 3.5 cm sized bowl shaped mold that removes some of the liquid from the slip near the mold wall by capillary action. The mold used for the slip casting was formed by mixing gypsum and water in a 4:3 ratios and was allowed to harden around a bowl shaped filter [10].

The clay mixture formulations known as *green wares* were removed and was marked as clay and kaolin (P1), clay, kaolin and sawdust (P2), clay, kaolin and charcoal (P3), clay, kaolin and duckweed (P4). They were dried in air at an average temperature of 25 ℃ and average humidity of 59 % in a dry place for 15 days [11].

According to Nnaji *et al.*, [12] the *green wares* were fired in a kiln for about 8-9 hours. The filters after firing were removed from the kiln and allowed to cool to room temperature. These firing is referred to as *sintering* which usually results in further reduction in porosity, increase in density and increases the strength of the material also, the volume shrinkage which occurs is just equal to the porosity decrease and varies from a few 30-40% by volume, depending on the forming process and the ultimate density of the fired ware. After cooling, the filters were soaked in water to ensure that the pores are through for the filtration.

Porosity and Flow Rate Test: The saturation of each ceramic filter was determined by measuring the initial mass of each of ceramic filter. The filters were afterwards dipped into a fix volume of water and increase in mass was monitored at intervals of five minutes until constant mass was observed [5].

Equations (1) and (2) were used to determine the effective pore volume and the porosity of the ceramic filters, respectively

$$V\rho = \frac{Wwet - Wdry}{\rho w} \tag{1}$$

Where V_P is the effective pore volume Pw is the density of water (1.01 g/cm^3). $Wwet$ and $Wdry$ are the wet weight and dry weight of the ceramic filters respectively.

$$\emptyset = \frac{Vp}{Vb} \times 100 \tag{2}$$

Where $\emptyset$ is the % porosity of the ceramic filter and Vb is the bulk volume.

The flow rate test was determined by filling up the ceramic filters with a particular volume of water at the same time and the decrease in the volume of filtered water was recorded. Eq. 3 was used in calculating the flow rate.

$$Q = \frac{V}{t} \tag{3}$$

Where V is the volume and t is time.

Fig2a Polluted Water

Fig 2c Filtration set-up

Fig2b Filtration Process

Collection of Water Sample: Water samples were collected from River Benue off stream which flows through Bwaranji community in Adamawa State, Nigeria and poured into the different filter pots placed on a transparent plastic buckets as seen in Fig 2a, 2b and 2c after which they were transported to the laboratory.

The turbidity, pH, chloride, nitrates, phosphates, total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), total hardness and total organic compound (TOC) were determined within 24 h of collection.

The turbidity was determined by *hand held turbidity meter,* the pH was determined using the *pen pH meter* alongside the TDS which was determined using the *pen TDS meter* while determination of chloride, nitrates, phosphate, COD, BOD, TOC and total hardness were carried out using *HACH DR 2040 spectrophotometer.*

The ceramic filters removed contaminants in the water based on the composition of materials used for their preparation. The percentage removal was calculated using the Eq. 4 below [13]:

$$\% \text{ removal} = \frac{Ci - Cf}{Ci} \times 100 \qquad (4)$$

Where Ci is the concentration of the untreated water and Cf is the concentration of treated water.

RESULTS AND DISCUSSION

Result of the Fired Ceramic Filters: The ceramic filter wares marked “P1” “P2” “P3” “P4” were successfully removed from the kilns with no cracks. The sizes of the filter were reduced because of the presence of burn out materials added to the formulation of the filters.

Porosity and Flow Rate Change over Time: The porosity of the filters P1, P2, P3, P4 were 2.7%, 8.5%, 5.5%, 5.8% respectively, with a uniform bulk volume of 5107.69 cm^3 as shown in table 1. This shows that the filter without a burn out material has the least pore volume (P1), while the addition of sawdust (P2) has been proven by other researchers to be a major component that generates pores in the filters [8].

It was obsereved that the higher the porosity the faster the flow rate, hence the lower the removal efficiency of contaminants. The porosity of the duckweed treated filter (P4) was slightly higher than the charcoal treated filter (P3), but it gave a better removal efficiency of contaminants and slower flow rate, this is because of the plant ash of the duckweed, this ash is formed when oxidation of plant materials in fires has progressed beyond charing, to the point where the carbon, hydrogen and oxygen components are largely vaporized, the previously small quantities of the plant then becomes the major component left behind as ash[14], however, the charcoal filter (P3) gave a better colour removal [9].

The flow rate(ml/min) through the filters was found to vary with the difference in the components of the ceramic filters seen in table 1. The most porous filter (P2), exhibited the fastest discharge followed by P3 and P4. The slowest discharge rate (P1) was associated to the absence of a burnout material i.e total clay formulation. Therefore the rate of the water discharge increases with porosity. This increese in flow rate can be reduced due to contaminants clog on the surface of the filter. To prevent this reduction in performance, users need to scrub their filter with a brush once it becomes noticeably slower [12].

Table 1. Flow rate of filtered samples

Samples	P1	P2	P3	P4
Millilitres	10	250	200	100
Minutes	60	60	60	60
Flowrate (ml/mins)	0.2	4.2	3.3	1.7
Porosity (%)	2.7	8.5	5.5	5.8
Bulk Volume (cm^3)	5107.69	5107.69	5107.69	5107.69

Water Quality Results: Water quality refers to the chemical, physical and radiological characteristics of water with respect to its suitability for a particular purpose (*drinking, irrigation or domestic use*) and this water quality indicators are classified into three categories: these are physical, chemical and biological indicators. Physical indicators are water temperature, conductivity, turbidity, total dissolved solids, colour, odour and taste of water. Chemical indicators include pH, total hardness, dissolved oxygen and chemical oxygen demand [13].

Table 2: Obtained water quality results for both untreated and treated sample

Parameters	N.I.S/WHO(*)	Untreated	P1	P2	Treated P3	P4
Turbidity (NTU)	5.0	97.85	0.005	0.093	0.078	0.002
T.O.C (mg/l)	5.0	62.78	14.75	16.06	16.50	11.80
Chloride (mg/l)	100	163.74	10.50	13.73	16.87	7.52
Nitrates (mg/l)	10.0	129.01	13.67	19.73	21.62	9.88
Phosphate (mg/l)	15.0*	29.86	0.805	1.009	1.20 0	0.673
C.O.D (mg/l)	75.0*	283.00	59.00	63.00	66.00	47.00
B.O.D (mg/l)	60.0*	97.00	29.00	34.00	37.00	22.00
Total hardness (mg/l)	100	148.96	98.78	95.81	103.44	79.22
T.D.S (mg/l)	500	400.50	105.00	166.00	129.50	95.50
pH	6.5-8.5	9.64	7.86	8.00	8.15	7.49

From the values presented in Table 2, the turbidity level of the untreated water was observed to be very high as a result of the high total dissolved solids (TDS) and this could be attributed to inputs from surface flooding of excess water from Lagdo dam, runoffs from agricultural lands due to irrigation, earth moving/loosening activities very close to the banks of the river [1].

The total organic carbon (TOC) was seen to be very high due to living material (directly from plant photosynthesis or indirectly from terrestrial organic matter) and also as a constituent of many waste materials and effluents showing a high degree of pollution [15].

Table 3: Removal Efficiency of the Different Filters

Parameters	P1%	P2%	P3%	P4%
Turbidity	99.99	99.90	99.92	100
T.O.C	76.51	74.42	73.77	81.20
Chloride	93.59	91.61	89.70	95.41
Nitrates	89.40	84.71	83.24	92.34
Phosphate	97.30	96.62	95.98	97.75
C.O.D	79.15	77.74	76.68	83.39
B.O.D	70.10	64.95	61.86	77.32
Total hardness	33.69	35.68	30.56	46.82
T.D.S	73.78	58.55	67.67	76.15

It was observed that the removal efficiency of the filters with respect to anions chloride (Cl^-) and nitrates(NO_3^{2-}), and phosphates(PO_4^{3-}), could be due to the ion exchange on the ceramic surface, formation of precipitate as oxides and hydroxides [11].

The turbidity removal efficiency of the filters was very high (>99%) as seen in Table 3, due to the increase of the percentage of the clay in the formulation which was maintained in all the filters except P1. This also has direct relationship with the high removal of microbes in the form of Total Coliform Count (TC), which indicates fecal contamination. This can also be attributed to the low pore size of the ceramic filters as this enables it to remove particles and pathogens by a size exclusion principle [16].

The pH value was decreased significantly by all the filters and this decrease is possibly because of the high removal of the Total Dissolved Solids(TDS) by adsorption of the components of the filters [17].

The significant high removal efficiency of BOD and COD by the duckweed treated filter (P4), shows the efficiency of duckweed in reduction of BOD and COD in waste water [18].

The significant difference in P4 as compared with P1, P2, and P3 in the removal of COD and TOC can be attributed to duckweed tolerance and adsorption of high organic load and high concentration of micronutrients [19].

Although P4 gave a slight increase in the removal efficiency of the total hardness of the untreated water, the high increase of the hardness may possibly be due to the presence of magnesium and sulphate forming $MgSO_4$ and this can be attributed to the high weathering activities of rocks around the river banks, this indicating the presence of Gypsum.

CONCLUSIONS

The turbidity, pH, chloride, phosphate, BOD, COD and TDS of the treated water are within permissible level [21, 22] for P1, P2, P3 and P4 filters. The nitrate removal was above the permissible limit except for P4 (92%), confirming the ability of duckweed to reduce nitrates significantly in waste water [3,6]. The TOC removal was also above the permissible level for all the filters, this indicates that the water may be good for irrigation and other domestic activities but not drinking because of the high influx of organic contaminants in the water. The pH was regulated from 9.64 (pH of contaminated water) to pH in the range 7.49 to 8.15. In general, the ceramic water filters prepared with dried duckweed plant can be used alongside other water purification methods in other to make the water suitable for drinking.

Acknowledgement

The authors are grateful to the Department of Chemistry and Industrial Design and Ceramics, Modibbo Adama University of Technology, Yola for their assistance and support.

REFERENCES

[1] A.H., Hong, P.L., Law, O.S., Selaman, Physicochemical Quality Assessment of Pollutants in River Benue Water in Jimeta/Yola Metropolitan, Adamawa State, Northeastern Nigeria Am. J. Environ. Prot (2014) 3(2) 90-95.
[2] Comprehensive Assessment of Water Management in Agriculture, Water for Food and Life; A Comprehensive Assessment of Water Management in Agriculture. London, Earth scan and Colombo: International Water Management Institute, 2007
[3] C, Gupta and D, Prakash, Duckweed: An Effective Tool for Phyto-Remediation Toxicology and Environmental Chemistry, 2014
[4] M.T. Amin, A.A. Alazba, U. Manzoor, Adv. Mater. Sci. Eng. 2014 (2014) 1-24
[5] J.O. Madu, F.V. Adams, B.O. Agboola, B.D. Ikotun, I.V. Joseph, Purification of Petroleum Products Contaminated Water Using Modified Rice Husk Ask Filters, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr. 2020.03.466
[6] S. Korner and J.E. Vermaat, The Relative Importance of *lemna gibba* Bacteria and Algae for Nitrogen and Phosphorus Removal in Duckweed Water Research 32(1998):3651-3661
[7] B.A. Ajayi and Y.D. Lamidi, Formulation of Ceramic Water Filter Composition for the Treatment of Heavy Metal and Correction of Physiochemical Parameters in Household water, Art and Design Review 3 (2015) 94-100
[8] L.C, Katherine and E.F, Lauren, Implementation of an Appropriate House-Hold Water Purification System in Tourou, Cameroon (2000) http://www.sys.virginia.edu
[9] P. Himanshu, Charcoal as an Adsorbent for Textile Waste Water Treatment, Separation Science and Technology 2018 53(17) 2977-2812
[10] Ceramic Processing: Slip Casting, Ceramic and Glass Industry foundation. The American Ceramic Society.www.ceramics.org
[11] A. Z Enyew and T.B Bekalo, Clay Ceramic for Water Treatment Materials Science and Applied Chemistry Journal 34(2017) 69-74
[12] C.C. Nnaji, B.C. Afangideh, C. Ezeh, Performance of Clay-Sawdust Composite Filter for Point of Use Water Treatment Nigerian Journal of Technology(NIJOTECH),2016 35(4) 949-956
[13] F.V.Adams, F. Hategekimana, O.P. Sylvester, Crude Oil Contaminated Water Treatment: Development of Water Filter from Locally Sourced Materials, Procedia Manufacturing 7 (2016) 465-471
[14] M.G. Canti, J.E. Brochier. Plant Ash, *Archeological Soil and Micromorphology,* first ed. John Wiley & Sons Ltd. 2017

[15] T.E. Aniyikaiye, T.Oluseyi, J.O. Odiyo, J.N, Edokpayi, Physico-Chemical Analysis of Waste water Discharge from Selected Paint Industries in Lagos, Nigeria, Int. J. Environ Res. Public Health. 2019 Apr; 16(7):1235

[16] A.R. Bielefeldt, K. Kowalski, C. Schilling A. Schreier, S. R. Summers, Removal of virus to protozoan sized particles in point-of use water filters, Water Research, 2010, 44(5), 1482-1488

[17], A.A. Werkeneh, B.Z. Medhanit, K.A. Abay and Y.J. Dante, Physico Chemical Analysis of drinking Water at Jigjiga City, Ethiopia, Am. J. Environ. Prot.4 (2015), 29-35

[18] W.A.El-kheir, G. Imail, A. El-Nour, T. Tawfik, D. Hammad, Assessment of the Efficiency of Duckweed (*Lemna gibba*) in Waste Water Treatment, Internal Journal of Agriculture and Biology 5(2007) 681-689

[19] W.S. Maisa, H. Zakari, Functions of Duckweed as a Natural Water Purifying Agent and as a Feed Source for Laying Hens 2017DOI:10.12783/dtcse/mcse 2016/10943

[20] Nigerian Industrial Standard (NIS) Nigeria Standard for Drinking Water Quality, 977. 2017 Standard for Bottled/ Packaged Drinking Water.

[21] World Health Organization (WHO) Guideline for Drinking Water Quality 2004., third Ed.

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