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Surface Water Filtration Using Porous Clay-Based Ceramic Materials in Côte d'Ivoire

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ABSTRACT

The valorization of surface waters becomes a necessity in the face of the overexploitation of groundwater because of human activities and the rapid population growth. However, these surface waters are often polluted. Several effective but expensive treatment processes are used to make these waters drinkable. Porous ceramics based on local clays could be a cheaper alternative for the filtration of this water at home. The present article aims to evaluate the filtering capabilities of porous ceramic materials for use in the treatment of drinking water. These materials, made from local clays and cornflour and then consolidated at 1000 ° C, were used to filter the waters of the Aghien lagoon. Comparative analyzes of the different Physico-chemical and microbiological parameters of raw and filtered water reveal the reduction of organic pollutants and nutrients as well as the elimination of the main indicators of microorganisms from faecal pollution. These results are attributed to the pore size and the specific surface area of the filters. In the long term, it will be a question of popularizing the use of local ceramic filters in the treatment of drinking water.

INTRODUCTION

Across the globe, groundwater is under increasing pressure. Indeed, these underground freshwater reservoirs are overexploited for the needs of industry, agriculture and the ever-growing population. More than two billion people live in countries under high water stress and about 4 billion people face severe water shortages at least a month a year. [1] It has been estimated that almost a third of the world's population could suffer from a lack of drinking water in 2050 given population growth and increased water consumption. [2] The use of surface water becomes necessary in order to meet up with the demand on drinking water. However, this source of water is generally polluted by human discharges, industrial waste and agricultural activities. [3,4] It is absolutely essential to carry out an appropriate treatment before making use as drinking water. Therefore, various purification methods are used to obtain portable drinking water: extraction by emulsified membrane, coagulation-flocculation, electrolysis, extraction by solvent, reverse osmosis and adsorption with activated carbon. [5-7] Unfortunately, these methods are very expensive for most people living in the developing countries. It is therefore necessary to look for viable water treatment methods, which, in addition to being very efficient, must be simple, easily available and inexpensive.

Clay-based ceramic filters could constitute a cheaper and easily available alternative for the purification of water.[8] Thus Amon L. N *et al.*[8] developed ceramic filters based on local clay and cornflour for home use. The aim of this study was to use filters developed for the filtration of surface water for drinking water.

MATERIALS AND METHODS

Raw materials

For the preparation of ceramic filters, different proportions of clay and cornflour are mixed.[8] The clay materials used D and Y are brought from Dabou and Yaou respectively found in the southern region of Côte d'Ivoire, are mainly composed of kaolinite, quartz and illite.[8]

Two compositions are maintained: 75% clay + 25% cornflour (A_{75}); 50% clay + 50% cornflour (A_{50}) because they have shown good bonding capacity.

A commercial ceramic filter marked FC was used as a reference filter.

The porosity tests carried out on the filters developed have shown that they are mainly macropores.[8] The values of the density, the specific surface and the porosity of the filters developed and of the commercial filter are recorded in table 1.

Table No. 1: Physical parameters of ceramic filters

	D_{75}	D_{50}	Y_{75}	Y_{50}	FC
Density	2.7 ± 0.1	2.7 ± 0.1	2.7 ± 0.1	2.8 ± 0.1	2.8 ± 0.1
Specific Surface (m^2/g)	10.6 ± 0.1	5.1 ± 0.1	17.9 ± 0.1	16.7 ± 0.1	2.1 ± 0.1
Open Porosity (%)	52.8 ± 0.1	66.6 ± 0.1	50.6 ± 0.1	68.2 ± 0.1	66.5 ± 0.1

The water samples used for the filtration are obtained from the lagoon of Aghien located in the southern region of Ivory Coast, eastern part of Abidjan. Water samples, physico-chemical and microbiological parameters are measured monthly in this lagoon by Amon L. N *et al.* [9] The area which is the subject of this study has been identified as rich in Suspended matter (MES), in Biochemical Oxygen Demand for 5 days (BOD_5) and Chemical Oxygen Demand (COD).[9]

METHODS

In order to assess the filtering capacity of the ceramic filters developed (D_{50}, Y_{50}, D_{75} and Y_{75}), filtration tests are performed on the water from the Aghien lagoon. The ceramic filters are placed vertically in a suitable container (Figure 1). The water to be filtered passes from the exterior to the interior of the filter and the water is collected at the bottom in another container fitted with a tap as shown by the device in Figure 1. The device is rinsed with distilled water before and after each filtration test to avoid contamination of the filtrate. The filtrates obtained are put into different flasks and stored at 4°C in a cooler containing ice accumulators before the different physical-chemical analyses. The raw water filtrates thus obtained are analysed in the laboratory to determine the physical-chemical parameters, in particular: turbidity, hydrogen potential (pH), nitrate and nitrite contents, MES, COD and BOD_5 using a spectrophotometer. The bacteria culture method performed after filtration made it possible to identify germs originating from faecal pollution, namely: *Escherichia coli*, faecal streptococci, thermotolerant and total Coliforms.

Figure No. 1: Water filtration device

RESULTS AND DISCUSSION

Physico-chemical and microbiological efficiency of filters

The values of the physicochemical and microbiological parameters of the treated water based on the type of filter used are respectively presented in table 2.

Table No. 2: Physico-chemical and microbiological characteristics of water

Parameters	Raw Water	Filtered water				
		D_{50}	D_{75}	Y_{50}	Y_{75}	FC
Physico-chemical Characteristic						
pH	6.5	6.1	5.8	5.7	5.9	6.4
Turbidity (NTU)	3.5	2.9	2.8	2.1	2.4	2.1
Nitrate (mg/L)	18.2	0.4	0.2	3.3	0.2	0.2
Nitrite (mg/L)	1.8	0.04	0.02	0.3	0.02	0.03
MES (mg/L)	5	3	4	4	4	4
COD (mg/L)	71.5	64.6	54.4	36.5	53.2	63.8
BOD_5 (mg/L)	23.6	21.3	19	7.7	17.6	21.1
Microbiological Characteristic						
TC (CFU/100mL)	884	0	0	0	0	0
THC (CFU/100mL)	283	0	0	0	0	0
E.Coli (CFU/100mL)	14	0	0	0	0	0
Strep (CFU/50mL)	121	0	0	0	0	0

TC: total coliform **THC:** thermotolerant coliforms **E. coli:** *Escherichia coli* **Strep:** faecal streptococci.

The values of the physical-chemical parameters of the raw water decreased significantly after filtration using the developed ceramic filters and also with the reference filter except for the pH values which remained almost identical.

The decrease in the values of the physicochemical parameters of the water after filtration differs from one filter to another. In addition, a total absence of all the germs studied was observed in the filtered water regardless of the type of filter used.

Variation in flow rates

The flow rate values obtained are shown in Table 3.

Table No. 3: Flow rate values (L / h)

Filters	**D_{50}**	**D_{75}**	**Y_{50}**	**Y_{75}**	**FC**
Flow rate (L/h)	1.46	0.87	3.75	3.21	0.21

Observing these values, the Y_{50} filter allows faster filtration.

Variation in the abatement rate

The variations in the rate of abatement of the physicochemical and microbiological parameters are presented in Table 4.

Table No. 4: Variation in the rate of abatement (%) of the water parameters

Filters	D_{50}	D_{75}	Y_{50}	Y_{75}	FC
Physico-chemical parameters					
pH	5.7	11.1	12.3	10	1.4
Turbidity (NTU)	17	20.2	40.6	30.8	39.5
Nitrate (mg/L)	97.7	98.7	81.9	98.7	98.8
Nitrite (mg/L)	97.9	98.7	81.9	98.9	98.2
MES (mg/L)	40	20	20	20	20
COD (mg/L)	9.7	23	49	25.6	10.8
BOD_5 (mg/L)	9.7	19.7	67.2	25.6	10.8
Microbiological Parameters					
TC	100	100	100	100	100
THC	100	100	100	100	100
E.Coli	100	100	100	100	100
Strep	100	100	100	100	100

Abatement rates concerning the physicochemical parameters are less than 100% and vary from one filter to another, while they are 100% regarding microbiological parameters. The ceramic filter with the formulation Y_{50} favours a greater reduction in certain parameters (turbidity, COD and BOD_5) compared to the Commercial Filter (FC). With regard to nitrate and nitrite, their removals are also high, but those of FC are relatively higher (98.8 and 98.2%, respectively) when compared to the Y_{50} filter (81.9 and 81.9% respectively).

The reduction in MES using the D_{50} filter is greater than that of the FC filter. This decrease is not observed in the case of other parameters. It should however be noted that the reduction in nitrate and nitrite with the D_{50} filter (97.7% and 97.9%, respectively) although lower in the case of FC (98.8% and 98.2 %) is higher than that of nitrate and nitrite in the Y_{50} filter.

Apart from nitrate, nitrite and suspended matter, the reduction rates of the physicochemical parameters obtained using the Y_{50} filters are higher than those obtained using the D_{50} filters.

A greater reduction with the ceramic filter of formulations Y_{75} and D_{75} than those of the FC except in the case of turbidity and nitrate have been observed. Furthermore, the rate of abatement of the suspended matter with the FC filter is identical to that of these two Y_{75} filters (20%).

The formulation filters Y_{75} and D_{75} have enabled the parameters studied to be reduced at all levels. However, the Y_{75} filter has proven to be the most effective filter.

Furthermore, with the values of the abatements rate noted, we observed Y_{50} filter allows a greater reduction in the values of the parameters compared to the Y_{75} filter.

DISCUSSION

A correlation between the physical and microstructural properties of D_{50}, Y_{50}, D_{75} and Y_{75} ceramic filters produced and the physicochemical properties of the water obtained after filtration has made it possible to make several observations.

- Regarding the physicochemical and microbiological efficiency of the filters:

The pH values dropped slightly after filtration. The drop in pH values in water could be explained, due to the dissolution of the CO_2 contained in the ceramic filters into the water, according to the following reaction:

$$2H_2O + CO_2 \longrightarrow HCO_3^- + H_3O^+$$

Indeed, during the sintering of D_{50}, Y_{50}, D_{75} and Y_{75} filters, the combustion of cornflour releases carbon dioxide, part of which is trapped inside the porous structure of the ceramic filter.

The variability of the microstructure of D_{50}, Y_{50}, D_{75} and Y_{75} filters could explain the fact that the decrease in the values of the physicochemical parameters of water after filtration is different from one filter to another.[8]

On the other hand, the total absence of all germs studied after filtration could be due to a simple capillary effect (an interactive phenomenon between the liquid and the surface of the filter). In fact, the use of a porous ceramic filter allows the retention of particles present in the water, which are larger than the pores of the filter.[4]

- Concerning variation of the flows

It appears that the Y_{50} filter allows faster filtration. This could be explained by its higher porosity rate (68.2%). [8] Indeed, the more the number of pores present in the filter, the higher the flow rate.

- Regarding variation in the abatement rate

The maximum reduction (40%) of turbidity was observed with the Y_{50} ceramic filter. This value is higher than that found by Zogo D. *et al.*[10] in the water treated using the aluminium sulphate coagulation-flocculation method. However, it is lower than that found by Abid and Zouhri [11] for water treated by coagulation-flocculation with cactus juice in the presence of lime. This observation could be due to the mode of separation of the constituents in the water sample: filtration, decantation, centrifugation. Coagulation, flocculation with aluminium sulphate is based on the rapid decantation of larges sizes flakes formed, but has the disadvantage of leaving in suspension the particles of smaller sizes for several hours [11,12]. On the other hand, the process of coagulation- flocculation by cactus juice is based on centrifugation, which has the advantage of precipitating the flakes favoured by the bio-accumulator in the bottom. The settling of particles in the water under the effect of the gravity field is less efficient and slower than the centrifugation process. The use of a porous ceramic filter allows the retention of particles present in the water, which are larger than the pores of the ceramic filter through capillary effect.

The Y_{50} formulation ceramic filter has the highest reduction in COD (49%) and BOD_5 (67.2%). These abatement values are higher than those obtained by Ouabou E. *et al.*[13] with two-layer filters (wood chips followed by clay layer). The difference in values can be explained by the nature and microstructure of the filter used by this author. Indeed, the two-layer filters are less compact than the ceramic filters used in this study.

The maximum removal of suspended matter (40%) is obtained with the D_{50} filter. This rate is lower than that obtained by Zalaghi A. *et al.* [14], in the treatment of highly polluted waters using clay soil. The filtration process used by this author is a percolation and infiltration treatment on a fixed granular support which has many disadvantages (non-control of the pore size, saturation of the pores).

The Y_{75} ceramic filter also has the best abatement rates for nitrite (98.85%) and nitrate (98.71%). These results are far superior to those of Zalaghi A. *et al.* [14] in the treatment of leachate using wood ash as filtering substrate. This filter substrate with a less compact structure than that of D_{50}, Y_{50}, D_{75} and Y_{75} the ceramic filters could explain their low capacity for removing nitrogen compounds.

Considering the abatement rate, the ceramic filter Y_{50} proves to be the most efficient because it allows a significant reduction in the values of several physicochemical parameters at the same time (turbidity, COD and BOD_5). This performance of the Y_{50} ceramic filter is linked to its high porosity and its large specific surface (16.7 m^2 / g). Unlike other filters, this filter gave less than 90% reduction rates for nitrite and nitrate. This could be explained by the fact that nitrogen compounds, which are very soluble in water, easily infiltrate through the pores of the filter.[15]

CONCLUSION

Filtration of water from the Aghien lagoon reveals that the Y_{50} ceramic filter is more effective than the D_{50} filter, in view of reduction in physicochemical parameters values (pH, turbidity, COD and BOD_5). The particularly high filtration capacities and flow rates of the Y_{50} clay-based ceramic filter are partly linked to its highly developed porous structure and its large specific surface. Indeed, the flow rate is directly proportional to the size of the pores in the material while the filtration area depends on the useful filtration area (specific surface) of the material used. The absence of germs in the water after filtration shows that D_{50}, Y_{50}, D_{75} and Y_{75} filters play their role of physical barrier against particles whose size is greater than the diameter of the pores.

The use of these porous ceramic materials in the filtration of raw water from the Aghien lagoon has shown that they all act as a physical barrier to particles larger than the diameter of the pores. However, the Y_{50} ceramic filter has proven to be the most efficient filter.

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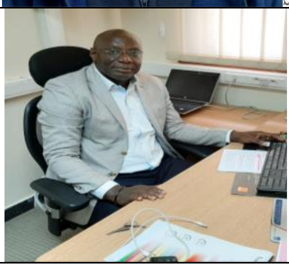	**Yao Jonas Andji-Yapi**[1] *Author Affiliation:* [1]Laboratoire de Constitution et de Réaction de la Matière, Université Félix Houphouët-Boigny, Abidjan, *Author Address/Institute Address:* 22 BP 582 Abidjan 22, Côte d'Ivoire.
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