Journal of Materials Science and Chemical Engineering, 2023, 11, 43-60
https://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

Elaboration of Ceramic Pot Filter from Kaolinite (Cameroon Clay) for the Elimination of Suspended Particles from Domestic Drinking Water

Celestine Asobo Yanu[1], Ngiongboung Nguiamba[2], Joseph Marie Sieliechi[2], Martin Benoit Ngassoum[2]

[1]Faculty of Science, Department of Chemistry, University of Buea, Buea, Cameroon
[2]National School of Agro-Industrial Sciences, Department of Applied Chemistry, University of Ngaoundere, Ngaoundere, Cameroon
Email: yanucelest@yahoo.com, ronnynguiamba@gmail.com, jsieliechi@yahoo.fr, ngassoum@yahoo.fr

How to cite this paper: Yanu, C.A., Nguiamba, N., Sieliechi, J.M. and Ngassoum, M.B. (2023) Elaboration of Ceramic Pot Filter from Kaolinite (Cameroon Clay) for the Elimination of Suspended Particles from Domestic Drinking Water. *Journal of Materials Science and Chemical Engineering*, **11**, 43-60.
https://doi.org/10.4236/msce.2023.118004

Received: June 13, 2023
Accepted: August 27, 2023
Published: August 30, 2023

Abstract

The objective of this work was to elaborate ceramic water filters from Kaolinite (Cameroon) clay for the elimination of suspended particles from domestic drinking water. In Sub-Sahara Africa and in Cameroon in particular health issues have been linked to the consummation of domestic tap water of high turbidity values both in the rural and urban areas. In order to remedy these problems, ceramic water pot filters have been elaborated in a pilot scale unit with aim of putting in place a unit production. The chemical composition, the thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analyses of the raw materials (clay and rice husks) was determined. The crystal phases and scanning electron microscope of Wack clay was also determined. The ceramic pot filter membranes were fabricated from the formulations 70/20/10 of clay/porogen/chamotte respectively with the particle size of the raw material less than or equal to 500 µm. The formulated ceramic pot filters were then sintered at 900˚C in a furnace. These ceramic pot filters were characterized by determining their porosity, withdrawal percentages, water permeability, mechanical and chemical resistance. The study of the efficiency consisted in evaluating the retention rate and permeate flux with respect to time (days) with synthetic water suspensions of turbidity 100 NTU and particle size of 2 µm. The ceramic pot filters were made aiming at studying the efficiency after physical defouling of filters. Physical defouling consisted in brushing the inner surface of the ceramic pot filters with water and drying them at ambient temperature after being used for 11 days and reusing them under the same initial conditions. The produced ceramic pot filter had a volume of 4 L, an average porosity of 36.15%, shrinkage in mass or withdrawal percentage of 18.23%, a water permeability of 59.6 × 10^3 $L \cdot h^{-2} \cdot m^{-2}$, mechanical resistance of 6.8 MPa and corrosion resistance of 1.6% in acidic medium and 0.8% in alkaline medium. The evaluation of the retention efficiency reveals that the retention rate of 99.9% was obtained from the 9th day of filtration reducing the turbidity value from 100 NTU to less than 0.1 NTU. From the filtration test carried out during the 11 consecutive days, the flow rate varied between 1.46 $L \cdot h^{-1}$ to 2.63 $L \cdot h^{-1}$. Similar results of retention and flow rate were obtained after physical defouling of the ceramic pot filter membranes and re-using for 11 consecutive days, showing the efficiency of the ceramic pot filter membranes in eliminating suspended particles from drinking water. Cost evaluation for the production unit reveals a total cost of production for 50 ceramic pot filters of 1593.6 USD consisting of fixed assets and variable assets. An estimated selling price of 3.3 USD was obtained which is affordable for both the urban and rural population in Cameroon and in sub-Saharan Africa.

Keywords

Ceramic Pot Filter, Retention Rate, Flux, Defouling, Formulation, Production Cost

1. Introduction

Water is undoubtedly the most precious natural resource, comprising over 70% of the earth's surface. Nonetheless, the demand for clean water is worldwide, whether it is for human consumption, agricultural application, or industrial use [1]. Rapid and continuous economic development and growth around the world have also led to a considerable increase in water demand [2]. In some parts of the world, particularly in sub-Saharan Africa, drinking water is not accessible to all. UNICEF defines clean water as water that is safe to drink, but also to use for cooking and washing [3]. Cameroon, like other countries in sub-Saharan Africa, has been struggling to meet the water needs of its population despite its natural predisposition. In the city of Ngaoundere in particular, in urban areas, about 55% of the population have access to tap water service by CAMWATER [4] but most of this water has a reddish appearance due to the presence of suspended laterite particles giving it a high turbidity of about 82 NTU, far exceeding the 5 NTU recommended by the standard [5] [6]. In rural areas, on the other hand, almost the entire population does not have a drinking water distribution facility. The lather gets their drinking water from traditional open wells or from streams such as rivers. These waters are regularly turbid because they are loaded with suspended matter. Regular consumption of these waters leads to health problems such as gastrointestinal diseases, vomiting [1]. To remedy this problem, several treatment techniques have been developed; these include physicochemical techniques such as coagulation/flocculation/sedimentation but are limited by the use of chemical coagulants, the use of filter cloths (granular filtration) but the efficiency depends on the materials used removing little suspended solids [7], and the adsorption technique which is limited by the exclusive removal of dissolved solids. Recent work has shown the use of ceramic membrane technologies in the treatment of domestic drinking water [8] [9] [10]. A membrane is defined as a barrier that limits the transport of certain species between two media that it separates. The membranes used are of two types: organic and inorganic membranes that elute suspended and dissolved substances from drinking water [5] [8]. Inorganic membranes have the advantage of being thermally, chemically and mechanically stable and have a long life span. These inorganic membranes are generally made from clay and we distinguish different forms of membrane filters such as disc, cylindrical, tubular support and pot filters. The latter has the advantage that it has a high filtration capacity, high mobility, can easily be defouled physically and be easily accessible to the rural population at low cost. The raw materials used are clay (which is the mineral material), porogen (responsible for the formation of pores) and chamotte (reduces the plasticity and facilitates the departure of water). These raw materials are mixed in different proportions to obtain a ceramic paste which is extruded into a particular shape and then sintered at high temperature to obtain the ceramic membrane. These membranes are porous support layers capable of eliminating suspended particles and even microorganisms from water [5] [10].

Considering such research trends, the objective of this work was to elaborate a ceramic pot filter from Kaolinite (Cameroon clay) for the elimination of suspended particles from domestic drinking water.

2. Materials and Methods

2.1. Sampling of Raw Materials

The raw materials used for the elaboration of the ceramic pot filters are Wack clay (kaolinite clay), rice husks, and chamotte. Clay mineral was collected at a depth of about 1.5 m from an extraction site located in Wack village, in the Adamawa region, at 50 km South West of Ngaoundere in Cameroon at an altitude of 708 m, latitude 07˚40.685 N and longitude 013˚33.026 E. The rice husk was bought from the central market of the town of Yagoua also in the extreme North region of Cameroon. The rice husks were chosen amongst other porogen because of their abundance in the streets of Yagoua produced by a local rice manufacturing company. After collecting the raw clay and rice husk, lumps, stones and other heavy particles were removed from the samples by sieving. The chamotte was obtained by grinding pre-sintered clay at 1100˚C. It plays an important role in the molding and unmolding of the ceramic paste in order to avoid cracks. It facilitates the shaping of the paste by reducing its plasticity and when incorporated in the ceramic paste it helps to reduce the loss in mass of the raw materials after sintering and also increases the mechanical resistance of the membrane. Prior to use, the clay, rice husk and chamotte were crushed and sieved through a 500 μm sieve to obtain the finest fraction of particles.

2.2. Characterization of Raw Material (Clay and Rice Husks)

The chemical composition of the natural raw clay was analyzed using a wavelength-dispersive X-ray fluorescence apparatus (Shimadzu, XRF-1800) to evaluate the proportions of impurities in the raw material as well as the Loss of Ignition (LOI). Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analyses for both samples were performed using a 2960 TA Instrument under argon from room temperature up to 1200˚C at a heating rate of 5˚C/min. The analysis was performed on the raw clay and the rice husk to evaluate the thermal stability and the minimum sintering temperature required for membrane fabrication.

Scanning Electron Microscope (SEM) JSM-5800 LV, JEOL was used to determine the microstructure of the clay mineral. The crystalline phase of the clay mineral was also determined by X-ray diffractometry.

2.3. Elaboration of the Ceramic Pot Membrane Filter

The ceramic pot membrane filter is made from kaolinite clay, rice husks and chamotte. Figure 1 shows the steps in the elaboration of the ceramic pot membrane filter. The ceramic pot membrane filter was elaborated using the formulation 70:20:10 with respect to clay, rice husks and chamotte of particle size of 500 µm. The raw materials consisting of 2.59 Kg of clay, 0.74 Kg of rice husks and 0.37 Kg of chamotte are first dry mixed in an electric mixer in order to homogenize the particles in the mixture. Then 1.5 L of water is added and wet mixed to obtain a ceramic paste. The ceramic paste is put and closed in plastic paper and then placed in a fridge for 24 h to aging of the paste. This enables better humidification of the paste in order to obtain a plastic paste. After ageing of the ceramic paste, it is molded and then pressed using a piston extruder shown in Figure 2 below into its pot shape. The shaped ceramic pot membrane is then

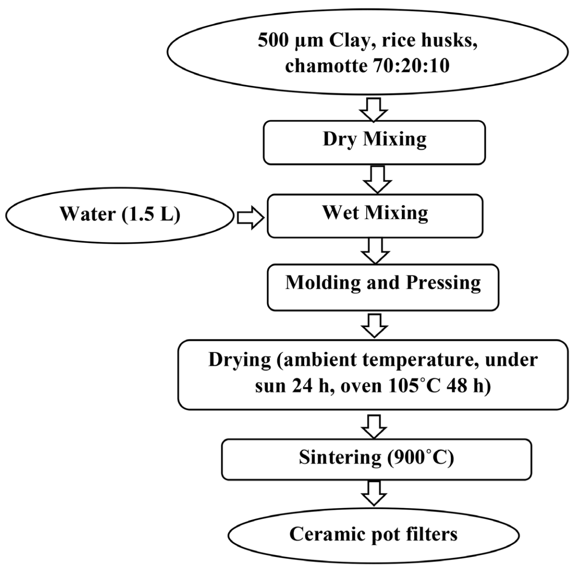

Figure 1. Production process of porous ceramic pot membrane filter.

Figure 2. Piston extruder for shaping of ceramic paste.

subjected to natural drying at room temperature for 24 h. After this, the membrane is dried at 100˚C for 24 h in a hot air oven. Subsequently, the membrane is taken to the sintering process in a Naberthern oven with a heating rate of 2.5˚C/min until 500˚C for 2 h and then 5˚C/min until 900˚C and sintered at that temperature for 2 h to obtain the ceramic pot membrane filter. These restrained thermal treatment steps were followed to avoid the formation of micro cracks and bends in the membrane. Finally, the elaborated membrane was washed with water and dried at 100˚C for further characterization.

2.4. Characterization of the Ceramic Pot Membrane Filter

1) Porosity

The porosity of the membrane was measured by utilizing water as a soaking agent (Archimedes method) [5]. The porosity of the membrane is measured using the below expression.

$$\text{Porosity}(\%) = \frac{W_1 - W_0}{W_1} \times 100 \quad (1)$$

whereby the dry filter is weighed (W_0) and put into water for about 4 h in order to free the pores allowing the distilled water to be in the pores and then reweighed (W_1) and the porosity is given by the difference between the mass of the filter before and after immersion in water divided by W_1.

2) Chemical resistance or strength

The corrosion or chemical resistance of the membrane was evaluated by means of loss of mass after treatment in aggressive acidic and alkaline environments. The acid and alkali solutions were prepared as such: HNO_3 solution with pH 3 and NaOH solution with pH 9. The membrane was soaked into the solutions for 6 days. The corrosion resistance of the recovered membrane was evaluated by weight decrement of the membrane [11].

3) The mechanical strength

The mechanical strength was determined by the bending test (compression test) at three-point using disc filters elaborated from the same formulation, raw materials and sintering conditions as the ceramic pot filter membrane with equivalent thickness.

4) The water permeability test

The water permeability (*Jw*) is a parameter that characterizes the ease with which the fluid passes through the membrane. It is an intrinsic property of the membrane that depends on its structure and allows comparing minerals between them in the absence of solute (pure solvent). It is expressed in liter per hour, per square meter of the membrane ($L\cdot h^{-1}\cdot m^{-2}$). The flow rate is proportional to the surface area, the pressure, the permeability but inversely to the viscosity (μ) of the solution and to the thickness. It depends mainly on the size of the pores and the thickness of the membrane for porous membranes. It is determined by the following formula:

$$Jw = \frac{Q}{A} \tag{2}$$

where,

Jw = Permeability flux in $L\cdot h^{-1}\cdot m^{-2}$;

Q = The flow rate which is the ratio of volume to time in $L\cdot h^{-1}$;

A = The surface in contact with the water to be treated in m^2.

2.5. Filtration Test

1) Preparation of clay suspension

The filtration test was done using synthetic clay water suspension prepared in the laboratory. Clay suspension of 2 μm were prepared based on stoke law which says that for spherical particle of radius r, density ρ_s displacing itself in a liquid of viscosity η and density ρ_l, the particle falls on the influence of its apparent weight and attends rapidly a constant speed v. At this stationary state, frictional forces F which opposes the movement of the particle is equal to the apparent size of particle, P:

$$F = 6\pi\eta v \tag{3}$$

$$P = 4/3\pi r^3 g\left(\rho_s - \rho_l\right) \tag{4}$$

The particle is subjected to a fall speed of:

$$v = \frac{2}{3}\frac{\left(\rho_s - \rho_l\right) g r^2}{n} \tag{5}$$

Several studies [12], have shown that particles of diameter greater than 2 μm need to be soaked in water for 8 h based on the stoke law of sedimentation.

The 2 μm wack clay suspension is prepared by putting about 1 Kg of powder clay into a 25 L plastic bucket having a tap and then adding distilled water up to a 10 cm mark above the tap. The mixture is well homogenized and left to settle for 8 h. After this time the suspension above the 10 cm mark is collected by opening the tap. The suspension collected is a clay suspension of particle size 2 μm. The particle size distribution of the suspension is determined using master sizer 2000 and then brought to a turbidity of 100 NTU by dilution with distilled water using a Nephelometric Turbidimeter (HACH RATIO 2100A).

2) Filtration apparatus and procedure

The ceramic pot filter is mounted on a plastic bucket with a cover as shown in Figure 3 below. It is used in the elimination of suspended particles in synthetic clay water suspension and in water in a frontal filtration mode.

A volume of 3.5 L of clay suspension of turbidity 100 NTU was introduced into the ceramic pot filter shown in Figure 3 below. The permeate was collected, its volume measured and the turbidity read. The process was repeated twice per day for 11 days without cleaning the ceramic pot filter in order to evaluate its retention capacity and permeate flux with time. The mean turbidity and permeate value was calculated each day. A graph of retention against time was plotted.

The water flux of the permeate was measured as a function of time by utilizing the equation below:

$$Jw = \frac{V}{At} \tag{6}$$

where V is the permeated water in volume (m^3); A is the effective membrane area (m^2) and t is the measured time (s). The volumetric flow rate (Q) was measured in this case in order to compare with the value in the literature and is expressed in equation 7 below. The general flow rate for this type of filter in a frontal filtration mode is usually in the range of 1 - 3 $L \cdot h^{-1}$.

$$Q = \frac{V}{t} \tag{7}$$

After filtration, the observed retention of the suspended particle was determined using the expression below:

$$R(\%) = \frac{Cf - Cp}{Cf} \times 100 \tag{8}$$

where Cf is the suspension concentration in the feed stream, Cp is the suspension concentration in the permeate stream and R is the observed retention (%).

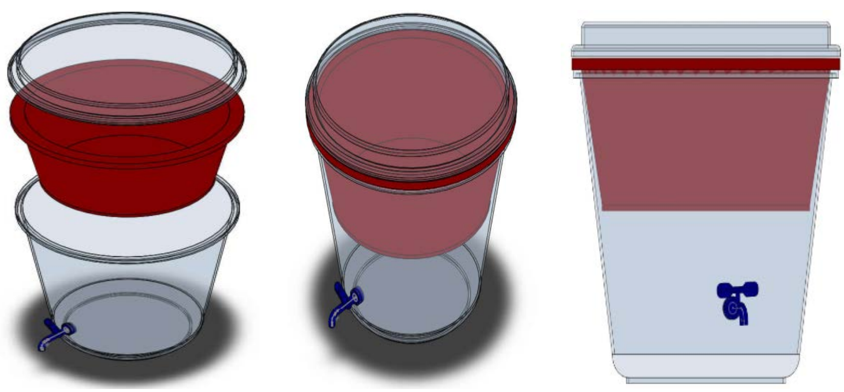

Figure 3. Solid work representation of the microfiltration system.

2.6. Physical Defouling of the Ceramic Pot Filter

The ceramic pot filters were made aiming at studying the efficiency after physical defouling of filters. Physical defouling consisted in brushing the ceramic pot filter's internal surface with distilled water and drying at ambient temperature after being used for 11 days and reusing them under the same conditions.

3. Result and Discussion

3.1. Characteristics of Raw Materials

3.1.1. Chemical Composition of Wack Clay and Rice Husk

Chemical composition of the Wack clay and the rice husks was determined by XRF and is shown in **Table 1** below. The Wack clay is predominantly composed of silica and alumina with a small amount of Fe_2O_3, CaO, K_2O, MgO and Na_2O. The percentage of Al_2O_3 corresponds to non-refractory clay since it does not exceed 45% [8]. The presence of a high-level K_2O confirms that it can be used as a melting material in our formulation [13]. The Loss of ignition (L. O. I) of clay is in the range of 8% - 18% allowable for ceramics [14]. The described composition of the powder corresponds to kaolinite clay according to the formula used by Kamseu [15].

For the chemical composition of the rice husks, it is observed from **Table 1** below that it is essentially made up of silica with a percentage composition of 17.37% and it has a loss of ignition of 69.5%. The loss of ignition of 69.5% proves that the lather is well capable to create pores within the ceramic medium, but given that its value is lower than 100% implies that the rice husks will participle in the physicochemical properties of the ceramic membrane. Actually, the silica (quartz after sintering) which is the principal mineral element in the rice husk will increase the mechanical resistance and reduce the porosity of the filter [8].

Table 1. Chemical Composition of the wack clay and rice husks by XRF (values are given at ±1 wt%).

	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	SO_3 (%)	TiO_2 (%)	Mn_2O_3 (%)	P_2O_5 (%)	L. O. I[a] (%)
Wack clay	54.22	20.15	9.22	1.69	0.56	3.43	0.76	0.05	/	/	/	11
Rice Husks	17.37	0.67	0.48	5.62	0.15	0.51	0.03	0.02	0.07	0.03	0.23	69.50

[a]L. O. I = Loss Of Ignition.

3.1.2. Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) Analyses of Wack Clay and Rice Husk

The temperature evolution of the raw clay sieved at 100 μm was characterized by DSC-TGA as shown in **Figure 4**. The TGA curve is characterized by two main weight losses: from room temperature to 300˚C for the first one with a loss of 5% and from 300˚C to 1200˚C for the second one, with a total weight loss of 12%. The first loss is attributed to the dehydration of the free physisorbed water present in the clay whereas the second one may be related to the departure of the

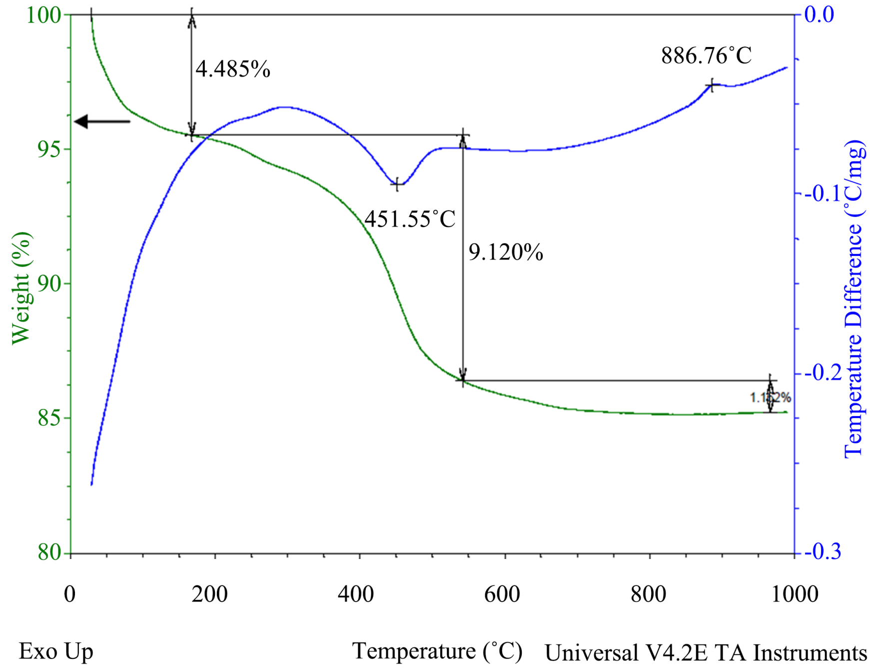

Figure 4. DSC (Blue line)-TGA (green line) curves of the Wack clay powder. [2].

water molecules that are embedded inside the two layers of the lamellar structure of the clay, phenomenon known as dihydroxylation [16]. In addition, crystalline water molecules that are part of the clay structure are also eliminated during this last step. This is in agreement with the loss on ignition measured by XRF up to 1000˚C which was 11% [17] [18].

The thermal behavior of the rice husks was analyzed by DSC–TGA as illustrated in **Figure 5**. This analysis shows the different weight losses encountered by the rice husks upon sintering. It is observed from the DSC curve an endothermic peak between 50˚C and 100˚C, which illustrates the endothermic reaction taking place. In the same temperature interval, on the TGA curve, a loss in weight of 10% is observed as a result of the departure of hygroscopic water. It is still observed on the DSC curve and exothermic peak between 285˚C and 380˚C. This peak illustrates an exothermic reaction that took place corresponding to a loss in weight of 48.5% on the TGA curve attributed to the degradation of cellulose [11] [19]. On the DSC curve, a second exothermic peak appears between 380˚C and 475˚C and this peak is due to the exothermic reaction that took place corresponding to a loss of weight of 20.23% on the TGA curve attributed to the degradation of lignine. Owning to the degradation of cellulose and lignine from the rice husks, it can be concluded that the lather is a lignocellulose material. But an endothermic peak is observed on the DSC curve between 900˚C and 1000˚C which corresponds to no loss in weight on the TGA curve. This behavior is due to the amorphization of the silica of 17.37% present in its chemical composition [20] [21]. Hence, the rice husks by their composition are a silicate lignocellulose material.

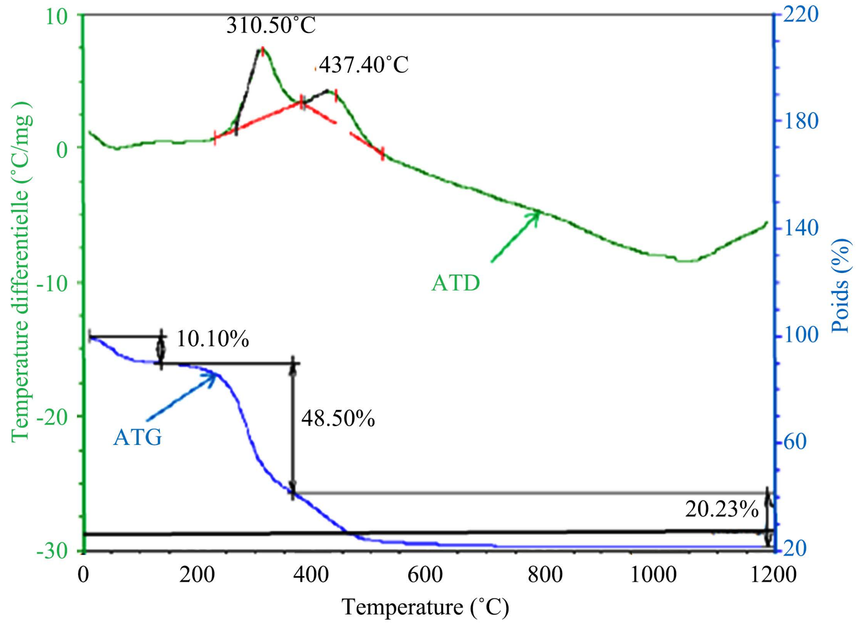

Figure 5. DSC (green line) – TGA (Blue line) curves of the Rice husks.

3.1.3. Scanning Electron Microscopy (SEM) of Wack Clay

Figure 6 below shows Scanning Electron Microscopy (SEM) images of Wack clay powders. This image shows that the mineral powder has a lamellar texture, even though the material has been grind beforehand. These lamellae are thought to be laminae that characterize the structure of the clay material. For example, the large pallets clearly visible in **Figure 6** can be seen in Wack clay. These pallets have undergone alteration, giving rise to blocks. This behavior is attributed to kaolinite clays.

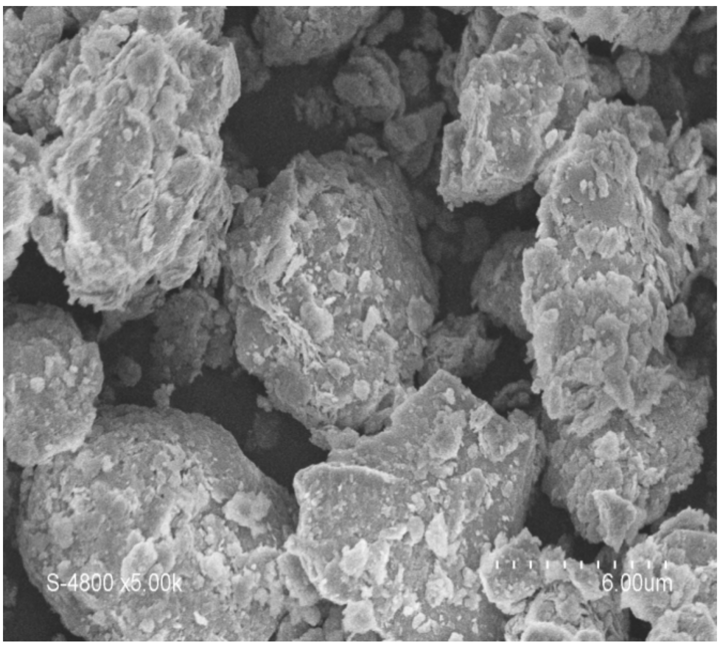

Figure 6. Scanning electron microscopy of Wack clay.

3.1.4. Crystal Phases of Wack Clay

Figure 7 below shows the diffractograms of Wack clay. This diffractogram illustrates the presence of two main phyllosilicate minerals: illite and a predominance of kaolinite. Indeed, the diffractogram detects the presence of relatively weak peaks at diffraction angles: $2\theta = 12.3^\circ$; $2\theta = 20.8^\circ$ and $2\theta = 36.5^\circ$ which correspond respectively to inter-reticular distances of 7.1 Å; 4.5 Å; and 2.4 Å characteristic of Kaolinite. Peaks detected at $2\theta = 19.9$ and 35.2° (d = 5.1 and 2.1 Å respectively) correspond to Illite. The peak at $2\theta = 26.6^\circ$ (d = 3.3 Å) corresponds to quartz. Similar diffractograms were obtained during XRD characterization of a commercial kaolinite ($Al_2Si_2O_5(OH)_5$ [22].

3.2. Characteristics of the Ceramic Pot Membrane Filters

Figure 8 below shows the ceramic pot filter before and after sintering. On appearance, the heat treatment brought about a change of the color. This change of colour is due to the presence of iron(III) in the reaction medium. During sintering,

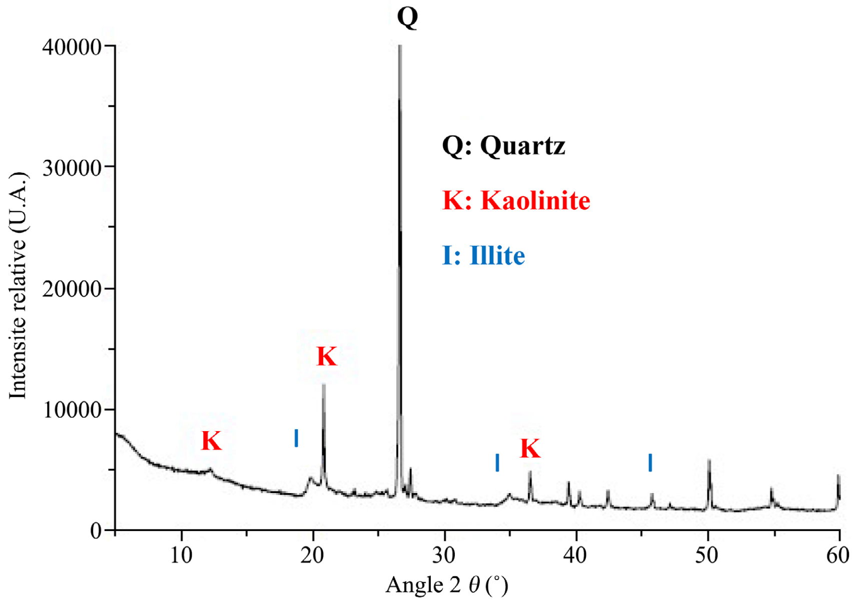

Figure 7. The diffractograms of Wack clay.

Figure 8. Aspect of the ceramic pot filter (a) before sintering and (b) after sintering.

there is an oxidation reaction of the iron(II) to iron(III) whose presence in the medium is identified by the reddish colouring, which intensifies according to the content of iron(III). It's concluded that the amount of Fe_2O_3 in the clay material and in the atmosphere of the furnace is responsible for the colouring of ceramics [5].

The produced ceramic pot filter has a filtration capacity by volume of 4 L with a cylindrical shape. The shrinkage in mass of the membrane after drying at 105˚C and sintering at 900˚C was calculated to be 18.23% and this is due to the departure of interstitial water, linked water and the water of constitution contained in the filters. This value also corresponds to the loss in mass of the porogen in the mixture (20%) but it is lower because the presence of chamotte which is stable at temperatures lower than 1000˚C.

The open-accessible porosity of the fired membrane was found around 36.15%, which is in accordance with values reported in the literature for efficient microfiltration membranes. Porosity is greater than 35% which is accepted for ceramic microfiltration [9] [10].

The average mechanical stability of the membrane was calculated to be 6.8 MPa. This result is in harmony with the results of porosity that showed that the porosity was almost the same for the different samples. In fact, the mechanical strength of a ceramic pot filter drops when porosity increases [5] [9].

The corrosion resistance test was performed with respect to weight decrement of the membrane after keeping it in harsh environments (acid and alkali). The weight decrement of the membrane was calculated to be 1.6% in acidic conditions and 0.8% in alkali conditions. In acid and alkali conditions, the membrane displays an excellent result in resisting corrosion. The loss of weight is <5% indicating the support is stable chemically. The obtained results are more commensurable in comparison with the cordierite membrane fabricated by Dong *et al.* [23].

The water permeability (L_h) of the membrane was found to be 59.6×10^3 $L \cdot h^{-1} \cdot m^2$. The ceramic pot membrane filter is a macroporous membrane in the domain adapted for microfiltration in terms of permeability.

3.3. Filtration Tests

Figure 9 shows the graph of retention against time (in days) of the clay suspension of 100 NTU of particle size 2 μm using the ceramic pot membrane filter. It is observed from this figure that the rate of retention of the suspended particles increases with an increase in time (days). This can be explained by the fact that the suspended particles are blocked within the pores and on the surface of the membrane leading to pore blocking and the formation of a cake layer (an auto-filtering properties) which helps in retaining the suspended particles thus increasing the rate of retention. Similar kind of results is also reported in the literature by [9] [24].

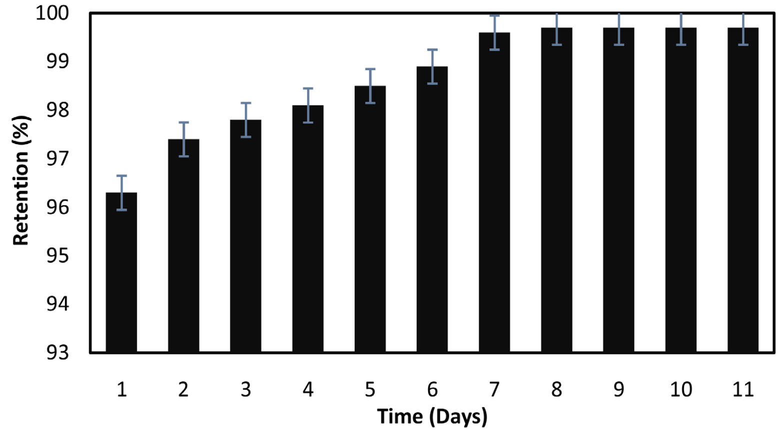

Figure 9. Rate of retention of the clay suspension with time.

A maximum retention rate of 99.9% was obtained from the 9th day of filtration corresponding to a reduction in turbidity value from 100 NTU to 0.1 NTU strictly respecting the norms of 5 NTU set by the WHO (2012).

Figure 10 below is the graph of permeate flux against time. It can be seen from the figure that the permeate flux declines with time. The decrease of the permeate flux with time is due to pore blockage and concentration polarization at the surface of the membrane. This is explained by the fact that in the membrane separation process, the particles rejected by the membrane accumulate in the boundary layer adjacent to the membrane surface. The mechanism can be described by a film theory due to pressure-driven convection, solute and solvent molecules are transported to membrane surface, then the solvent crosses the membrane while large particles are fully or partly retained, resulting in a higher solute concentration on membrane surface than in bulk. At the same time, the rejected solutes diffuse back into the bulk due to the concentration gradient. When the solute convection towards the membrane surface is balanced by the solute diffusion back to the bulk solution, a steady-state boundary layer is formed leading to the formation of a cake layer and cake filtration [5] [9].

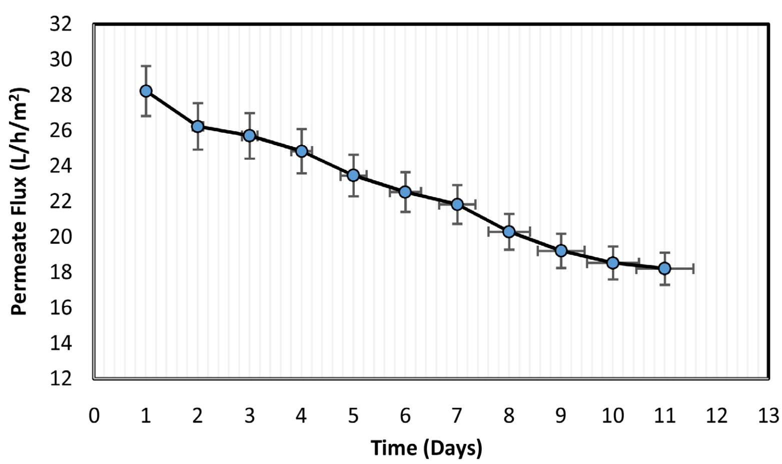

Figure 10. Permeate flux against time.

From the filtration test carried out during the 11 days, the flow rate varied between 1.46 $L \cdot h^{-1}$ to 2.63 $L \cdot h^{-1}$ which is in accordance with the value of flow rate 3 L/h as seen in the literature [10].

3.4. Performance after Defouling

1) Retention Capacity.

The same observation was made as per the initial filtration test carried out on the ceramic pot filter membrane. That is the rate of retention of the suspended particles increases with an increase in time (days) explained by the fact that the suspended particles are blocked within the pores and on the surface of the membrane leading to pore blocking and the formation of a cake layer (an auto-filtering property) [5] [9] [10]. Maximum retention of 99.7% was obtained from the7 day days corresponding to a reduction in turbidity value from 100 NTU to 0.3 NTU strictly respecting the norms of 5 NTU set by the WHO (2012). The slight reduction in retention may be due to the defouling technique which led to a deformation (increase) in the pores sizes of the ceramic pot filter membrane.

2) Permeate flux.

The same observation was also made for the permeate flux as per the initial filtration test carried out on the ceramic pot filter membrane. The permeate flux decreases with time and the decrease with time is due to pore blockage and concentration polarization at the surface of the membrane. From the filtration test carried out on the defouled pot membrane during the 11 days, the flow rate varied between 1.50 $L \cdot h^{-1}$ to 2.65 $L \cdot h^{-1}$ which are in accordance with the value of flow rate of 3 $L \cdot h^{-1}$ as seen in literature. It is slightly higher than the initial flow rate before defouling due to the breaking of the interconnected pores within the membrane during defouling leading to larger pore size.

4. Cost Evaluation for Setting up the Production Unit

To set up the pilot plant, materials and equipment were purchased from the local and national markets. Some of these are fixed assets that will be used continuously in the production unit and others are variable assets which are constantly need to be purchased for production.

Table 2 below shows the materials and equipment purchased their quantities and the purchase price for the production of 50 ceramic pot filter membranes for the pilot unit. The production of a filter of volume 4 L required 2.59 Kg of clay, 0.74 Kg of rice husks, 0.7 Kg of chamotte and 1.5 L of water. The cost of producing 50 filters from the raw materials to the final filtration device takes 2 weeks.

4.1. Unit Operations and Duration for 50 Ceramic Pot Filters

Table 3 shows the different unit operations involved in the production of the ceramic pot filter membrane and the duration of unit operations in order of proceedings:

Table 2. Estimated cost of setting up the unit production for 50 pot filters.

Materials and equipment	Unit Price (USD)	Quantity	Total Price (USD)
	Fixed Assets		
Furnace	1231.5	1	1231.5
Piston extruder	82.1	2	164.2
Crusher/grinder	9.85	2	19.7
Sieve	16.42	2	32.84
Total			1448.27
	Variable Assets		
Clay	0.032 USD/Kg	150 Kg	4.93
Rice husks	0.16 USD/Kg	50 Kg	8.21
Charmotte	/	20 Kg	/
Water	0.074 USD/m^3	100 L	7.39
13 L plastic bucket + tap	2.46 USD	50	123.15
Electricity	50 KW/h	/	5.75
Total			145.32
Grand Total			1593.6

Table 3. Unit operations and duration.

Operation	Duration (days)
Grinding + sieving + mixing + preparation of the paste	2 - 3
Molding and shaping	2 - 3
Drying	1 - 2
Sintering	2 - 3
Quality test and mounting	1 - 2

4.2. Product Selling Price

The cost price (CP) is the ratio of the production cost (CP) excluding fixed assets (which are furnace, sieve, piston extruder and grinder/crusher) to the total quantity produced (Q). The cost of a filter is equal to:

$$SP = \frac{CP}{G} = \frac{88500}{50} = 2.9\ \text{USD} \quad (9)$$

From the above calculation, the selling price for a ceramic pot filter is estimated to 3.28 USD taking into consideration manpower and other expenses.

4.3. Resizing the Production Unit over the Year

In this case, we need to know the production capacity over a year in order to be able to evaluate the price of a filter on the market and the production costs of a filter on the market and determine the profitability of the project. A three-person team would be able to produce 30 filters per week. Assuming that in a year we will have approximately 2 weeks without production, the estimate, made over 50 weeks in the year, corresponds to a yearly production of 1500 filters.

The quantities of material required to produce 1500 filters with a formulation of 70/20/10 can be estimated from Table 2 above. The cost of production will take into consideration manpower and other miscellaneous expenditures.

5. Conclusions

The objective of this work was to elaborate a ceramic pot filter from Kaolinite (Cameroon clay) for the elimination of suspended particles from domestic drinking water. It resulted from this work that ceramic pot membrane filters elaborated from local raw materials in Cameroon can be efficiently used in eliminating suspended particles from domestic drinking water both in the urban and the rural area of Cameroon. From the filtration test effected on the pot filter for a period of 11 continuous days, it resulted that the filters were capable of retaining up to about 99.9% of suspended particles in water of initial turbidity of 100 NTU of particles size 2 μm. Hence, reducing the turbidity value from 100 NTU to about 0.2 NTU. A flow rate between 1.46 L/h to 2.63 L/h is obtained during the treatment period of 11 consecutive days and is within value of flow rate of 3 L/h. Similar results of retention and flow rate were obtained after defouling and re-use for 11 consecutive days showing the efficiency of the ceramic pot filter membrane in the elimination of suspended particles from drinking water. Cost evaluation for setting up the production unit reveals a total cost of production for 50 ceramic pot filters of 1593.6 USD consisting of fixed assets and variable assets. An estimated selling price of 3.28 USD was obtained which is affordable for both the urban and rural population.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Centers for Disease Control and Prevention (2011) Best Practice Recommendations for Local Manufacturing of Ceramic Pot Filters for Household Water Treatment. The Ceramics Manufacturing Working Group, Atlanta.

[2] World Health Organization (2012) Manganese in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality.

[3] World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF) (2008) Progrès en matière d'eau potable et assainissement: Volet spécial sur l'assainissement; Programme commun de suivi de l'approvisionnement en eau et de l'assainissement de l'Organisation mondiale de la Santé et du Fonds des Nations Unies pour l'enfance UNICEF, New York et OMS, Genève.

[4] Johnson, S.M. (2007) Health and Water Quality Monitoring of Pure Home Water's Ceramic Filter Dissemination in the Northern Region of Ghana. Master's Thesis, Massachusetts Institute of Technology, Cambridge.

[5] Yanu, C.A., Sieliechi, J.M. and Ngassoum, M.B. (2020) Optimization of Ceramic Paste Viscosity Use for the Elaboration of Tubular Membrane Support by Extrusion and Its Application. *Journal of Materials Science and Chemical Engineering*, **8**, 1-22. https://doi.org/10.4236/msce.2020.83001

[6] Djou, B. (2018) Elaboration et caractérisation des filtres céramiques tubulaires: Application à la filtration tangentielle des eaux de consummation. Ph.D. Thesis, Université de Ngaoundéré, Ngaoundéré.

[7] Brown, J. and Sobsey, M. (2011) Evaluating Household Water Treatment Options: Health Based Targets and Microbiological Performance Specifications. World Health Organization, Genève.

[8] Belibi Belibi, P., Nguemtchouin, M.M.G., Rivallin, M., Ndi Nsami, J., Sieliechi, J., Cerneaux, S., Ngassoum, M.B. and Cretin, M. (2015) Microfiltration Ceramic Membranes from Local Cameroonian Clay Applicable to Water Treatment. *Ceramics International*, **41**, 2752-2759. https://doi.org/10.1016/j.ceramint.2014.10.090

[9] Nguiamba, N., Yanu, C.A., Belibi Belibi, P.D., Sieliechi, J.M. and Ngassoum, M.B. (2021) Identification of an Appropriate Formulation for Domestic Water Ceramic Filters from Soukamna Clay (Cameroon). *Journal of Metallic Material Research*, **4**, 12-18. https://doi.org/10.30564/jmmr.v4i1.3462

[10] Fabrice, N.W. (2020) Elaboration des membranes minérales multicouches de microfiltration contenant des nanoparticules d'argent pour le traitement de l'eau de consummation. Master's Thesis, Université de Ngaoundéré, Ngaoundéré.

[11] Karimizade, A., Takallu, S. and Mirzaei, E. (2018) Evaluating the Effect of pH on Mechanical Strength and Cell Compatibility of Nanostructured Collagen Hydrogel by the Plastic Compression Method. *Nanomedicine Journal*, **5**, 180-185.

[12] Adjia, Z.H. (2012) Epuration des métaux lourds des eaux usées par les argiles alluviales de l'"Extrême Nord Cameroun. Master's Thesis, Université de Ngaoundéré, Ngaoundéré.

[13] El Yakoubi, N., Aberkan, M. and Ouadia, M. (2006) Potentialité d'utilisation d'argiles marocaines de Jbel Kharrou dans l'industrie céramique. *Comptes Rendus Geoscience*, **338**, 693-702. https://doi.org/10.1016/j.crte.2006.03.017

[14] Abubakar, I., Birmin Yauri, U.A., Faruq, U.Z., Noma, S.S. and Sharif, N. (2014) Characterization of Dabagi Clay Deposit for Its Ceramics Potential. *African Journal of Environmental Science and Technology*, **8**, 455-459. https://doi.org/10.5897/AJEST2014.1741

[15] Kamseu, E., Leonelli, C., Boccaccini, D.N., Veronesi, P., Miselli, P., Pellacani, G. and Chinje Melo, U. (2007) Characterisation of Porcelain Compositions Using Two China Clays from Cameroon. *Ceramics International*, **33**, 851-857. https://doi.org/10.1016/j.ceramint.2006.01.025

[16] Ali, M.S., Ariff, A.H.M., Jaafar, C.N.A., Tahir, S.M., Mazlan, N., Maori, K.A. and Naser, H. (2017) Factors Affecting the Porosity and Mechanical Properties of Porous Ceramic Composite Materials. *Encyclopedia of Materials: Composites*, **2**, 66-115. https://doi.org/10.1016/B978-0-12-803581-8.10131-6

[17] Majhi, A., Monash, P. and Pugazhenthi, G. (2009) Fabrication and Characterization of γ-Al_2O_3-Clay Composite Ultrafiltration Membrane for the Separation of Electrolytes from Its Aqueous Solution. *Journal of Membrane Science*, **340**,181-191.

https://doi.org/10.1016/j.memsci.2009.05.030

[18] Esharghawi, A., Penot, C. and Nardou, F. (2009) Contribution to Porous Mullite Synthesis from Clays by Adding Al and Mg Powders. *Journal of the European Ceramic Society*, **29**, 31-38. https://doi.org/10.1016/j.jeurceramsoc.2008.05.036

[19] Hettiarachchi, P., Motha, J.T.S. and Pitawala, H.M.T.G.A. (2010) Identification of an Appropriate Body Composition for Red Clay Products. *Cerâmica*, **56**, 285-290. https://doi.org/10.1590/S0366-69132010000300012

[20] Fisher, T., Hajaligol, M., Waymack, B. and Kellogg, D. (2002) Pyrolysis Behavior and Kinetic of Biomass Derived Materials. *Journal of Analytical and Applied Pyrolysis*, **62**, 331-349. https://doi.org/10.1016/S0165-2370(01)00129-2

[21] Caillère, S., Henin, S. and Rautureau, M. (1982) Minéralogie des argiles: Classification et nomenclature (Tome 1 et Tome 2). Ed. Masson, Paris, pp 9, 107 et 114.

[22] Bouchet, A. and Sammartino, S. (2002) Caractérisation minéralogique de 6 échantillons de minéraux du commerce. Rapport d'analyse ERM 02-173 AB 273.

[23] Dong, Y., Feng, X., Dong, D., Wang, S., Yang, J., Gao, J., Liu, X. and Meng, G. (2007) Elaboration and Chemical Corrosion Resistance of Tubular Macro-Porous Cordierite Ceramic Membrane Supports. *Journal of Membrane Science*, **304**, 65-75. https://doi.org/10.1016/j.memsci.2007.06.058

[24] Costa, A., Depinho, M. and Elimelech, M. (2006) Mechanisms of Colloidal Natural Organic Matter Fouling in Ultrafiltration. *Journal of Membrane Science*, **281**, 716-725. https://doi.org/10.1016/j.memsci.2006.04.044