Karbala International Journal of Modern Science

Volume 5 | Issue 4 Article 4

Performance Study Of The Membrane Based Layered Double Hydroxides 'ZnAl-Gh' In The Purification Of Groundwater

Jaouad Zerhouni
University of Moulay Ismail, Morocco, boumnihi_jaouad@hotmail.com

Omar Qabaqous
university of Moulay Ismail, Morocco, qomar2010@gmail.com

Fouzia Rhazi Filali
University of Moulay Ismail, Morocco, fouzia.filali@yahoo.fr

Mohammed Naciri Bennani
University of Moulay Ismail, mbennanin@gmail.com

Najib Tijani
university of Moulay Ismail, Morocco, najibtij@gmail.com

Recommended Citation
Zerhouni, Jaouad; Qabaqous, Omar; Rhazi Filali, Fouzia; Naciri Bennani, Mohammed; and Tijani, Najib (2019) "Performance Study Of The Membrane Based Layered Double Hydroxides 'ZnAl-Gh' In The Purification Of Groundwater," *Karbala International Journal of Modern Science*: Vol. 5 : Iss. 4 , Article 4.
Available at: https://doi.org/10.33640/2405-609X.1148

Performance Study Of The Membrane Based Layered Double Hydroxides 'ZnAl-Gh' In The Purification Of Groundwater

Abstract

The objective of this work is focused on the preparation and characterization of plan microfiltration membrane Zn_3Al-Gh and the study of their efficiency in the treatment of ground water. This membrane was carried by using the support of the clay such as Ghassoul 'Gh' prepared by using dry uniaxial compaction method. The layered double hydroxides (LDH) based on $Zn_3Al-CO_3$with molar ratio (Zn^{2+}/Al^{3+}=3) was deposited on support by direct co-precipitation method.

The characterizations of the membrane LDH-Gh 'Zn_3Al-Gh' and deposited layer Zn_3Al-CO_3, was done by scanning electron microscopy analysis (SEM), X-ray diffraction (XRD), porosity and Fourier Transform Infrared Spectroscopy (FTIR),and shows that the deposition of the $Zn_3Al-CO_3$was carried on the Ghassoul support successfully. The chemical resistance and pure water permeability tests suggest the use of the Zn_3Al-Gh membrane for the microfiltration applications.

In this context, the performance of Zn_3Al-Gh membrane has been used in attempt to remove the indicator bacteria of fecal pollution, and eventually pathogenic bacteria in company with them, which are existing in groundwater of the urban commune "Sebaa-Ayoune" (Fez-Meknes region, Morocco). The analysis of the samples of water after and before microfiltration showed the bacteria removal is important for all germs indicating of fecal pollution. On the other hand, the diminution of the turbidity, the conductivity and the concentration of Ca^{2+}, SO_4^{2-}, NO_3^- and NH_4^+ were established.

Keywords

Membrane; Hydrotalcite, Ghassoul, Microfiltration, Groundwater

Cover Page Footnote

Acknowledgment This work is done in the frame work of the project ((PPR2), supported by MENFPESRS and CNRST, Rabat, Morocco

1. Introduction

The conventional drinking water treatment processes face several obstacles that are seriously affected by water pollution and scarcity, making it difficult to produce drinking water efficiently. Low-pressure membrane filtration, which includes ultrafiltration (UF) and microfiltration (MF), is one of the most promising treatment technologies to improve water quality [1], and one of the alternatives for water disinfection [2,3]. Membrane water treatment devices were once used mainly in desalination projects. But improvements in membrane technology make their use increasingly appreciated for the removal of microorganisms, particles and natural organic materials that disturb the water and spoil its taste [4]. Over the past twenty years, significant efforts have been made to develop processes using purifying membranes. Indeed, this separation technique allows partial or total disinfection of water guaranteeing food safety while limiting the use of chemical additives [5]. Other studies have attempted to investigate the applicability of an electrocoagulation method, using iron and aluminum electrodes to remove fluoride from aqueous media. The results showed that electrocoagulation process with iron and aluminum electrodes could successfully remove fluoride from the aqueous environments [6]. While other studies are focused on the methods of manufacturing aligned carbon nanotube membranes (VA-CNT) grown on an anodized aluminum oxide (AAO) substrate, show better tolerability and flexibility for the removal of other pollutants from water [7].

Microfitlration and ultrafiltration are recognized as effective processes for eliminating bacteria and their selectivities are dominated by screening [8]. The retention of microorganisms is one of the main advantages of membrane filtration for drinking water production, this process eliminates microorganisms from the raw water by retention on the selective physical barrier that is the membrane [9,10]. During membrane filtration, two phases are obtained: the retentate enriched on the retained compounds and the permeate containing the solvent and the element capable of passing through the membrane. The performance of the filtration process is determined by productivity and efficiency [11].

Taking into account the massive consumption of raw water in the rural areas of our country, our attention was focused on the search for a practical and inexpensive physico-chemical purification method to make these contaminated waters drinkable.

Our work aims to study the performance of a ceramic membrane based on natural and local “Ghassoul” clay and a Zinc-Aluminium hydrotalcite matrix and its application in the filtration of well water in the city of Sebaayoune; Fez-Meknes region; Morocco.

2. Material and methods

2.1. Characteristics and choice of the water studied

Five stations were initially pre-selected (Fig. 1) from the database; quality and risk factors for peri-urban groundwater pollution in Sebaayoune city [12], and taking into account the desired objectives; more contaminated water and high turbidity, we chose to test and filter the water from the Alawia station for our study.

2.2. Elaboration of membrane‘Zn_3Al-Gh’

The inorganic membrane used in this study, is prepared according to the protocol described in the previous article [13]by using a support of the Ghassoul clay (40 mm in diameter and 2 mm thick), developed by the axial compaction method of a mixture of Ghassoul powder with 3% of activated carbon [14]. One side of the support was polished with 600-abrasive papers to obtain a leash surface, and then washed with deionized water to remove particles created during polishing, then dried at60 °C for 48 h. Finally, the polished face of the support was coated with LDH-Zn_3Al-CO_3prepared by the co-precipitation method. This method consists of preparing an aqueous solution containing a mixture of NaOH and Na_2CO_3 and another solution containing a mixture of salts $AlCl_3$ and $ZnCl_2$ with a molar ratio $Zn^{2+}/Al^{3+} = 3$. The precipitation is caused by adding the two solutions drop by drop in a flask containing 20 ml of distilled water to maintain a pH = 10. Then, the mixture was stirred at 70 °C for 18 h until crystallization of the solid on the surface support placed horizontally into the beaker. Finally, the prepared membrane‘Zn_3Al-Gh’ was washed several times with distilled water and dried at 100 °C for 4 h. The precipitated product was filtered and washed twice in the filter with warm water to remove excess ions (Cl^-, Na^+ ...), followed by drying at 105 °C for 18 h.

https://doi.org/10.33640/2405-609X.1148

2.3. Characterization instruments and methods

The XRD analysis was performed by the powder method using a Philips PW 1800 diffractometer (copper Kα line λ = 1.5406 Å, 40 kV, 20 mA) in Bragg-Brentano geometry. The spectra of the prepared materials were recorded in a range of 2θ equal 5°—70° with an angular step of 0.04°.

The infrared analysis was performed using Fourier Transform Infrared Spectroscopy (FTIR) with a JASCO 4000 spectrometer, equipped with a detector (TGS) and a ceramic source. The absorption spectra were performed with tablets containing 1 mg sample and 100 mg KBr, and recorded in the range 4000—400 cm^{-1}, with a resolution of 4 cm^{-1}.

The porosity of the prepared membrane was evaluated according to the Archimedes principle [15]. First, the dry mass M_d of the membrane was determined after drying in an oven at 110 °C for 6 h. Then it is placed in a beaker filled with distilled water. After 24 h, the membrane is recovered and its wet mass Mw is measured. Porosity (p) was calculated using the following relationship [16]:

$$p=\frac{M_w - M_d}{M_w}*100 \tag{1}$$

The surface morphologies and pore size of the membrane were controlled by scanning electron microscope (SEM) using a Zeiss Sigma instrument at acceleration voltages of 3 KeV. The chemical composition of the LDH-Zn_3Al-CO_3 was performed by energy dispersive X-ray (EDX) analysis.

2.4. Water microfiltration protocol and tests

The microfiltration experiments of water through the membrane'Zn_3Al-Gh' were performed, using a filtration system (Fig. 2) consisting of a stainless steel cell sealed by an O-ring facing the feed flow, a porous stainless steel disc was placed under the clay support to prevent cracking of the membrane under the effect of applied pressure, and two manometers: pressure gauge 1 for measuring the pressure at the inlet of the filter module, and pressure gauge 2 for measuring the retentate pressure at the outlet of the filter module. The pilot is cleaned before each microfiltration operation with bleach at 12 chlorometric degrees (300—400 mg/l chlorine) [17]; which consists of recirculation of chlorinated solution, soaking, rinsing and draining the solution into the drain. This cleaning is carried out in order to disinfect the filtration device. Before starting the tests, we circulated the water treated in the pilot; in order to remove traces of chlorine that can remain in the circuit of the filtration device.

2.5. Permeability study of the support and the membrane

The support and the Zn_3Al-Gh membrane have been characterized by their permeability to groundwater. In

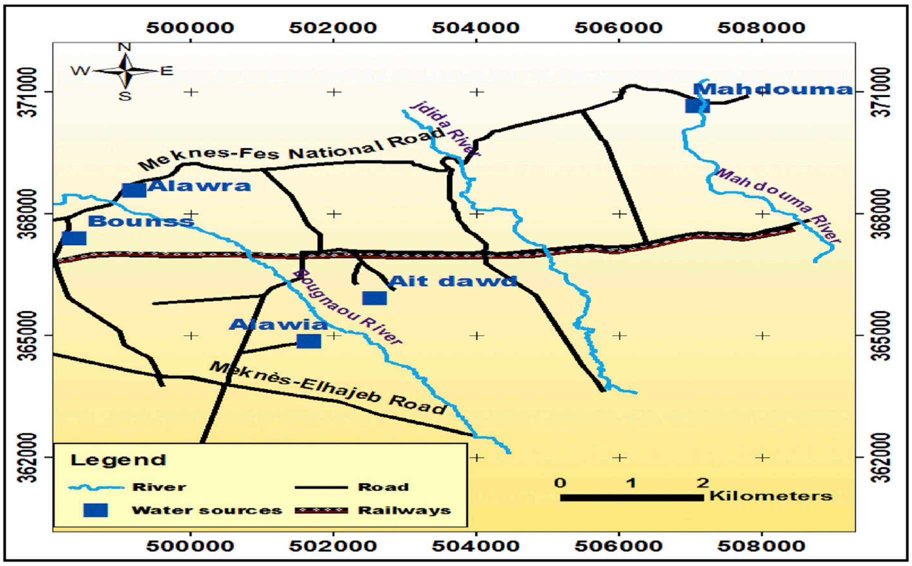

Fig. 1. Spatial presentation of preselected water sources.

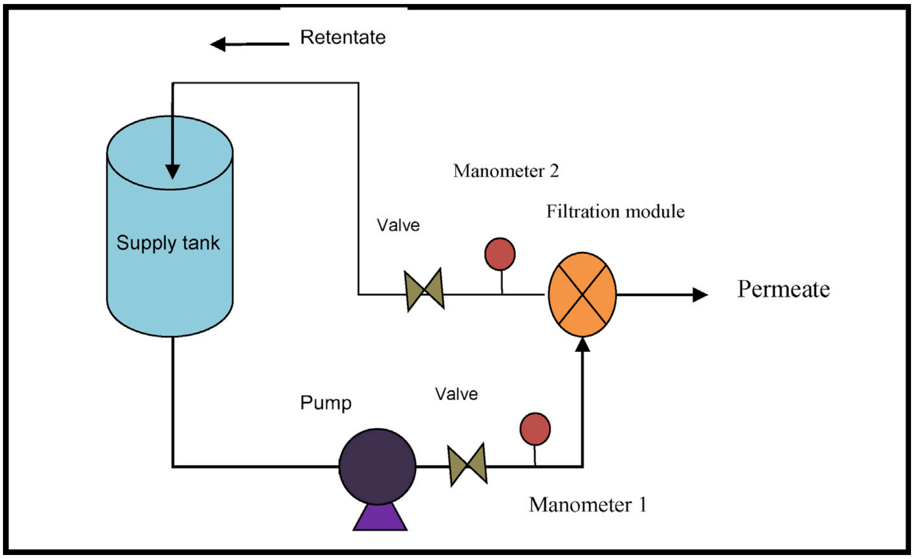

Fig. 2. Schema of the pilot used in frontal microfiltration.

the first, the membrane and substrate were conditioned by immersion in distilled water for 24 h before the filtration tests in order to obtain rapid stabilization of the permeation flow. The flow values (J) were measured in transmembrane field pressure (ΔP) from 1 to 5 bars. Permeability was evaluated on the basis of Darcy's law expressed by this equation [18]:

$$J = Lp * \Delta P \tag{2}$$

Lp is the permeability of the membrane.

The hydraulic resistance (R_m) of the membrane was evaluated by Equation (3) [19]:

$$Lp = \frac{1}{\mu R_m} \tag{3}$$

μ is the dynamic viscosity of water ($\mu = 10^{-3}$ Pa. s à 20 °C).

Table 1
References and methods of bacteriological analysis.

Parameters	Methods and references	Units
Revivifiable microorganisms (22 °C and 37 °C)	NM ISO 6222 (2007) Agar incorporation technique. Culture medium: yeast extract agar. Aerobic incubation at (36 ± 2) °C for (44 ± 4)h and at (22 ± 2)°C for (68 ± 4)h. Colony listing	cfu/ml
Total coliforms and *Escherichia coli*	NM ISO 9308-1(2007); Classification index NM 03.7.003. 0.45 μm membrane filtration method. Incubation (36 ± 2)°C for (21 ± 3) h; Agar lactose to the TTc and the heptadecylsulfate of sodium Test 'indole production': incubation of the typical colonies in a broth to tryptophan at (44 ± 0.5)°C for (21 ± 3) h. "oxidase" Test: incubation of the typical colonies on agar tryptonee to the soy-TSA (36 ± 2)°C during (21 ± 3) h. counting colonies (indole+ and oxidase)	cfu/100 ml
Intestinal enterococci	NM ISO 7899-2(2007); Classification index NM 03.7.006. 0.45 μm membrane filtration method. Incubation (36 ± 2)°C for (44 ± 4) h; Middle Slanetz and Bartley (44 ± 0.5)°C for 2 h Incubation. Middle bile esculineazide. Enumeration of typical colonies.	cfu/100 ml
Spores of anaerobic sulfite-reducing microorganisms	NM ISO 6461-2 (2007). 0.2 μm membrane filtration method. Incubation at (37 ± 1)°C for (20 ± 4) h and (44 ± 4) h, sulfite-iron agar medium or tryptose-sulfite-agar medium. Spore enumeration.	cfu/100 ml

2.6. Bacteriological and physicochemical analysis

Sampling and routing of samples were carried out in accordance with international standards [20,21], and bacteriological analyses were carried out in accordance with the appropriate Moroccan standards (Table 1).

Chemical analyses of the parameters Ca^{2+}, Cl^-, Mg^{2+}, NH_4^+, NO_3^- were performed according to the reference [22], while the physical parameters (conductivity and turbidity) were measured with a conductivity meter (Cond 340i) and a turbidimeter (HANNA HI88703). Measurements were taken before and after filtration, with three repetitions.

The evaluation of membrane selectivity in the microfiltration of pretreated water is examined by the TR retention rate defined by equation [23]:

$$TR = 1 - \frac{CSP}{CSA} \tag{4}$$

CSP and CSA are the concentrations of a solute in permeate and feed water respectively.

3. Results and discussion

3.1. Porosity test

The porosity was calculated using Equation 1:

$$p = \frac{M_w - M_d}{M_w} * 100$$

The porosity of Ghassoul clay supports sintered at a temperature of 900 °C was 39%.

3.2. X ray diffraction

The XRD diffractogram of the $Zn_3Al\text{-}CO_3$ obtained during the elaboration of the membrane (Fig. 3) shows the formation of a well-crystallized phase characteristic of theLDH-$Zn_3Al\text{-}CO_3$ structure.

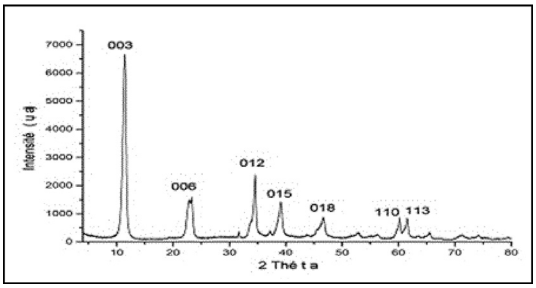

Fig. 3. Diffractogram of LDH-$Zn_3Al\text{-}CO_3$.

The main peaks corresponding to the basal planes (003) and (006) are present at low values of 2θ equal to 11.40° and 23.08° respectively. They are characteristic of the lamellar structure of the synthesized sample [24].

The lattice parameters ***a*** and ***c*** can be calculated from the positions of the reflections (110) and (003) respectively. They are equal to 3.07 Å and 23.25 Å which corresponds respectively to interfoliar spacing and to half the metal-metal distance in the sheet [25].

3.3. Scanning electron microscopy (SEM)

The surface morphology of the membrane'Zn_3Al-Gh' is presented in Fig. 4. SEM image right gives information on the texture of the surface. We can observe in the photograph the good arrangement of the LDH in the form of laminated sheets on the surface of the support. The pores size distribution and average pore diameter of the prepared membrane are estimated from SEM image presented in the image at the left. The observed pores are sized between 0.20 μm and 0.40 μm.This lets us consider the use of this membrane in the field of microfiltration.

Fig. 5 shows the EDX pattern of the membrane'Zn_3Al-Gh'. The peaks of elements Zn, Al, C, O, and Chlorite are clearly found which exhibits a deposition of LDH-$Zn_3Al\text{-}CO_3$ on the Ghassoul clay support.

The molar ratio measured of the peaks intensities values of the elements Zn and Al is in accordance with the atomic ratio $Zn^{2+}/Al^{3+} = 3$ initially put in solution. From these results, it can be concluded that the LDH-$Zn_3Al\text{-}CO_3$ are successfully prepared.

3.4. Infrared spectroscopy analyses

Fig. 6 shows the infrared spectrum of the synthesized LDH-$Zn_3Al\text{-}CO_3$ (Fig. 6a) and membrane 'Zn_3Al-Gh' (Fig. 6b) respectively. The spectrum FTIR of LDH-$Zn_3Al\text{-}CO_3$ is characteristic of layered double hydroxides (LDH) [24]. The spectrum of the membrane 'Zn_3Al-Gh' has in addition to characteristic bands of hydrotalcite phase other bands at 1077, 930, and 890 cm^{-1} corresponding to the vibrations of the Si-O-Si, Si-OH groups and vibration of the quartz group respectively, due to the presence of the Ghassoul. The main bands of vibration observed are summarized in the Table 2.

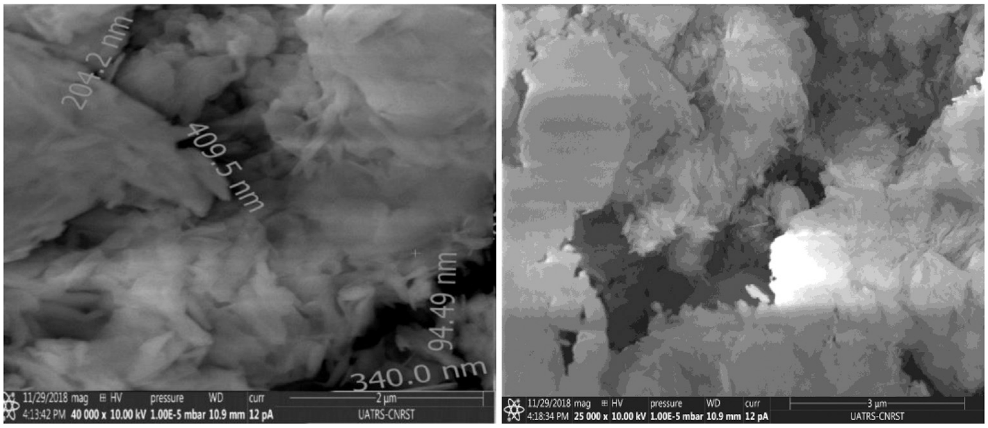

Fig. 4. SEM photographs of Zn_3Al-Gh membrane.

These results are in good agreement with the chemical composition of the membrane and the sintered support. The typical bands of the Zn_3Al-CO_3 phase characteristic of LHD compounds have been observed, suggesting the formation of deposited microfiltration layer Zn_3Al-CO_3 crystals on the ceramic support surface.

3.5. Determination of membrane permeability

Fig. 7 shows the evolution of the permeation flow of the support and the membrane. The permeate flow increases linearly with transmembrane pressure, confirming Darcy's law.

The permeability values for the support and the prepared membrane are respectively Lp = 200 l/h m^2 bar and 60 l/h m^2 bar. This high permeability of the support is due to its porosity. However, the low value found for the membrane is due to the low-flow.

Equation (3) allowed us to calculate in a practical way the hydraulic resistance of the membrane: $R_m = 6.10^{12}$ m^{-1}. This could be explained by the charge behavior of membrane surface with solution.

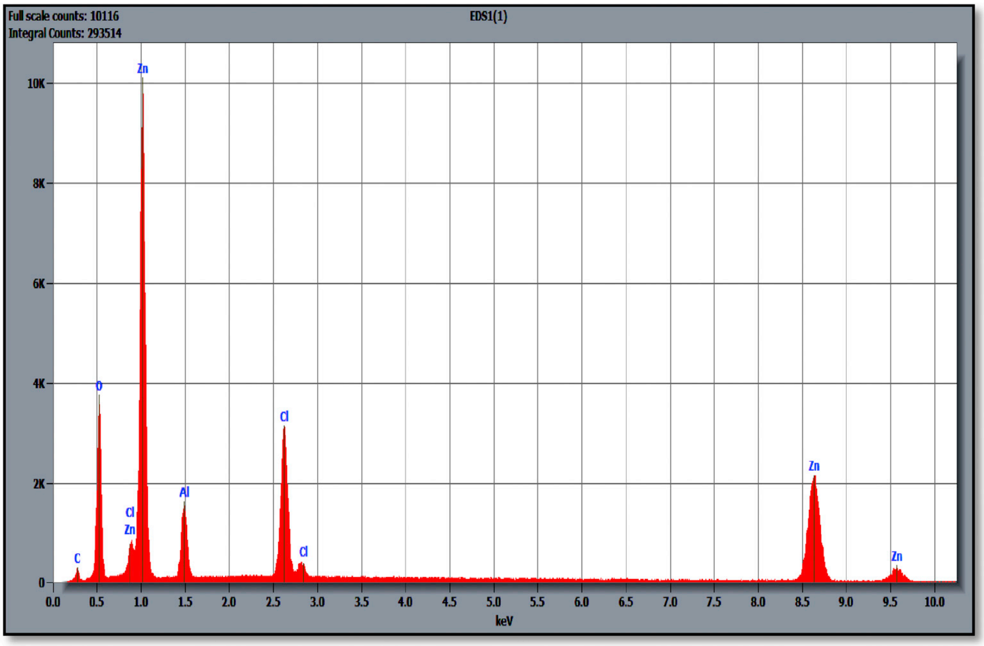

Fig. 5. EDX pattern of the membrane'Zn_3Al-Gh'.

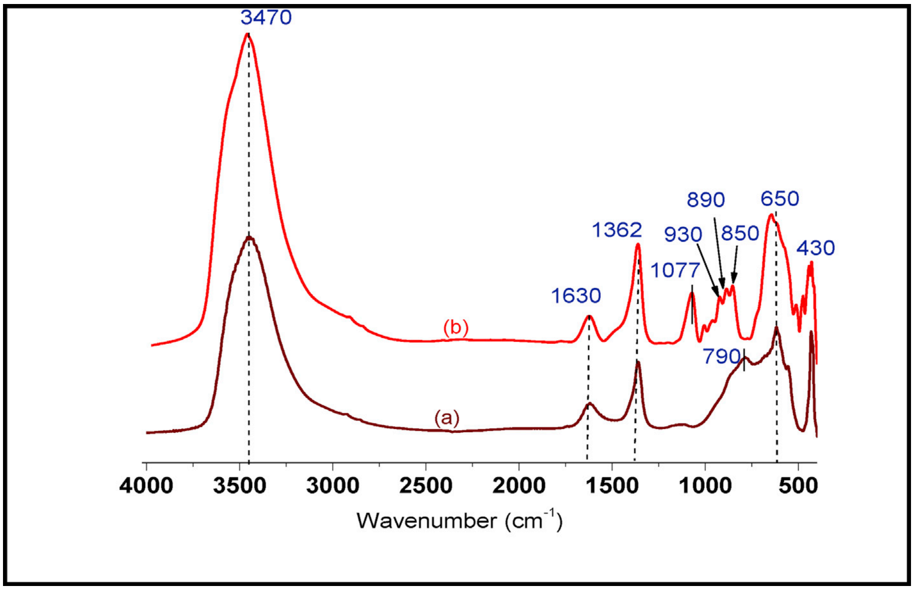

Fig. 6. Infrared spectrum of the (a) LDH-Zn_3Al-CO_3 and (b) membrane'Zn_3Al-Gh'.

3.6. Filtration flow

The selectivity of the membrane synthesized for groundwater filtration has been determined for a pressure of 1 bar and at ambient temperature. The evolution of the flow function with time using distilled water and groundwater is given in Fig. 8.

The two curves have the same aspect, namely a decrease of the flow at the beginning followed by stabilization. In the case of distilled water, a decrease in permeation flow is observed during the first 50 min from 400 l/h.m^2 to 220 l/h.m^2 and then stabilized at 180 l/h.m^2, but for the filtration of groundwater, we observe a decrease of 58% during 1 h from 102 l/h.m^2 to 42 l/h.m^2 then stabilized at 35 l/h.m^2.The decrease in permeate flux is a characteristic of membrane processes which can be interpreted by the interaction between the membrane and the solution that leads to the clogging of membranes pores.

3.7. Bacteriological analyzes of preselected station

Preliminary raw water analysis showed that the water from the Alawia well is highly loaded with microorganisms (fecal pollution indicators). Table 3 summarizes the degree of pollution at each station.

3.8. Physicochemical parameters of Alawia station

Table 4 below summarizes the results of the physicochemical analyzes of the groundwater before and after microfiltration on the membrane'Zn_3Al-Gh'.

Table 2
Bands mains attribution of the LDH-Zn_3Al-CO_3 and the membrane'Zn_3Al-Gh'.

Bands (cm^{-1}) LDH Zn_3Al-CO_3	Bands (cm^{-1}) Zn_3AlGh membrane	Attribution
3470	3470	Valence vibration of hydroxyl groups
1630	1630	binding vibration of adsorbed water molecules
1362	1362	Deformation vibration of the carbonate anion CO_3^{2-}
790		
–	1077	Deformation vibration of the link δ(Si-O-Si) [26]
–	930	Déformation vibration Si-OH [27]
–	890	Deformation vibrations of the quartz group [28]
–	850	Characteristic vibrations of Zn-OH/Al-OH
650	650	Deformation vibration of the link δ(OH-Zn) [29]
430	430	Characteristic vibrations of the linksδ (OH-Al)

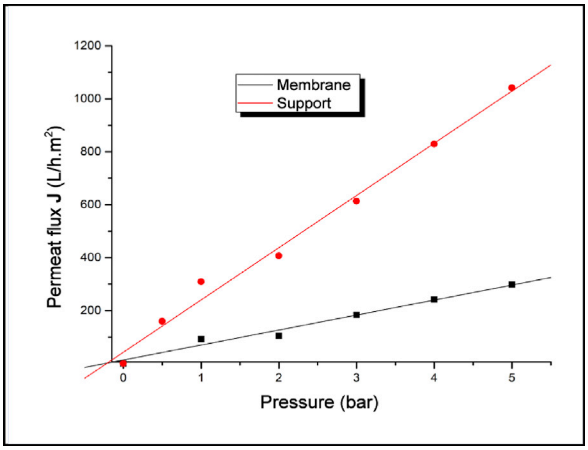

Fig. 7. Permeate flow of water as a function of applied pressure.

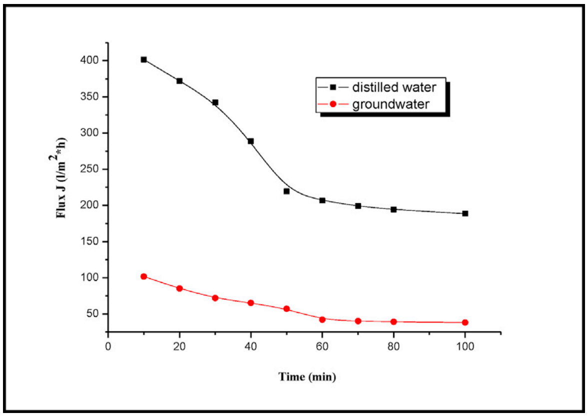

Fig. 8. Permeation flow of raw water in function of time at 1 bar pressure.

The results of the physicochemical analyses (Table 4) show a significant decrease in turbidity (88%) in accordance with Moroccan drinking water standards, which can be interpreted as a decrease in the quantity of suspended solids (SS) contained in groundwater. There is also a decrease in salt concentration (calcium 63%, nitrate 57%, ammonium 67% and magnesium 2%), which is explained by the interaction between the charged surface of the membrane and the ions contained in the groundwater, this decrease in salt results in a decrease in conductivity (10%). Chlorides increased by 0.22%, possibly due to the release of the chemical element Chloride contained in the membrane'Zn_3Al-Gh' (Fig. 5) and/or the pilot's cleaning with bleach before the microfiltration test.

Other microfiltration work on ceramic membranes has shown a similar decrease in turbidity to that of our membrane 'Zn_3Al-Gh' [30,31]. Indeed, groundwater quality at any point below the surface shows the combined effects of the following many processes on the groundwater flow path. Chemical reaction factors such as precipitation, alteration, dissolution, ion exchange and various common biological processes occur below the surface, affecting fluoride concentrations in groundwater, which are positively correlated with Ca^{2+} and Chloride; and negatively correlated with NO_3^- [32].

3.9. Bacteriological parameters of Alawia station

Table 5 below summarizes the results of the bacteriological analyzes of the groundwater before and after microfiltration on the membrane 'Zn_3Al-Gh'.

The bacteriological analyses presented in Table 5 clearly show that this membrane ensures water treatment in accordance with Moroccan standards (NM 03.7.001) [33]. Indeed, the reduction of germs was 100%. In addition, since the SASR are smaller than protozoan oocysts and can be useful indicators of the effectiveness of filtration processes. However, the presence of microorganisms at 22 °C and 37 °C (heterotrophic plate count: HPC) in the permeate, can be explained by the ability to grow rapidly in water and on surfaces in contact with water as biofilms, the main determinants of their growth are temperature, nutrient availability, including assimilable organic carbon and water stagnation [34]. HPC measurement covers a

Table 3
Microbiological analysis of raw groundwater of preselected station.

Stations	Total coliforms (cfu/100 ml)	*Escherichia coli* (cfu/100 ml)	Intestinal enterococci (cfu/100 ml)	Spores of anaerobic sulfite-reducing microorganisms (cfu/100 ml)	Revivifiable microorganisms (cfu/1 ml)	
					22 ± 2 °C	36 ± 2 °C
Alawia	280	280	146	15	1900	2800
Mahdouma	2	2	0	0	100	150
Al awra	36	36	30	0	100	150
Ait dawd	0	0	4	0	150	50
Bounss	16	16	30	0	300	200

Table 4
Physicochemical parameters of raw and filtered waters.

Parameters	Groundwater	Filtered water	Moroccan standard
Conductivity (µs/cm)	1250 ± 33,3	1130 ± 73,3	<2700
Turbidity (NTU)	42 ± 5	4,9 ± 0.4	<5
Ca^{2+} (mg/l)	152 ± 7	56 ± 7,3	<100
Mg^{2+} (mg/l)	137 ± 6	134 ± 7	<100
Cl^{-} (mg/l)	163 ± 9	199 ± 13	<750
NO_3^-(mg/l)	4.7 ± 0.1	2 ± 0.0	<50
NH_4^+ (mg/l)	0.6 ± 0.0	0.2 ± 0.0	<0.5

Table 5
Results of bacteriological parameters.

Parameters	Groundwater	Treated water	Moroccan standard
Revivifiable microorganisms at 22 °C. (cfu/1 ml)	1900 ± 267	2 ± 1	<100
Revivifiable microorganisms at 37 °C (cfu/1 ml)	2800 ± 200	18 ± 4	<20
Coliformbacteria(cfu/100 ml)	280 ± 74	0 ± 0	0
Escherichia coli (cfu/100 ml)	280 ± 74	0 ± 0	0
Intestinal Enterococcci (cfu/100 ml)	146 ± 8	0 ± 0	0
Spores of anaerobic sulfite-reducing microorganisms(SASR) (cfu/100 ml)	15 ± 3	0 ± 0	0

wide spectrum of heterotrophic microorganisms, including bacteria and fungi. Indeed, this contamination of permeate by HPC can be due to deformation and then a leakage of the latter [34,35]. The observed retention of the other microorganisms sought may be the result of an aggregation phenomenon of bacteria [10]. In fact, Madaeni et al. [36] also filtered three separate suspensions: the poliovirus alone, the virus in the presence of *Escherichia coli*, and viruses in the presence of suspended particles on microfiltration membranes of average pore diameter 0.22 µm. Their results show that a significant turbidity in suspension or the addition of bacteria promotes an improvement in virus retention. This is the case of our test water used, which has a turbidity of 42NTU.

So we can say that the clay-zinc-aluminum composite membrane performs well its role for removing micro-organisms larger than 0.22 µm, because the texture and the porosity of this synthetic membrane are in favor of this disinfection of groundwater. The membrane fulfills its role of disinfection.

4. Conclusion

This study of microfiltration by membrane ‘Zn_3Al-Gh’ has allowed purification of the polluted water. The performance of this membrane is confirmed in terms of abatement of bacteria indicative of groundwater pollution and the improvement in the physicochemical quality of these water; especially the diminution of concentration for nitrates, ammonium and calcium. The results obtained shows that the membrane ‘Zn_3Al-Gh’ based on LDH-Zn_3Al-CO_3 and Ghassoul clay as support has been successfully elaborated and the microfiltration by this membrane is very interesting for the treatment water field especially water for human consumption.

Declaration of Competing Interest

There is no conflict of interest among authors.

Acknowledgment

This work is done in the frame work of the project (PPR2), supported by Ministry of National Education, Professional Training for Higher Education and Scientific Research, Morocco (MENFPESRS) and National Center for Scientific and Technical Research/ Rabat, Morocco (CNRST).

References

[1] H. Chang, H. Liang, F. Qu, B. Liu, H. Yu, X. Du, G. Li, S.A. Snyder, Hydraulic backwashing for low-pressure membranes in drinking water treatment: a review, J. Membr. Sci. 540 (2017) 362–380. http://www.sciencedirect.com/science/article/pii/S0376738816319937. (Accessed 16 October 2019).

[2] J. Kwaśny, M. Kryłów, W. Balcerzak, Oily wastewater treatment using a zirconia ceramic membrane - a literature review, Arch. Environ. Prot. 44 (2018) 3–10, https://doi.org/10.24425/122293.
[3] M. Bodzek, K. Konieczny, M. Rajca, Membranes in water and wastewater disinfection – review, Arch. Environ. Prot. 45 (2019) 3–18, https://doi.org/10.24425/aep.2019.126419.
[4] A. Bennett, Drinking water: pathogen removal from water – technologies and techniques, Filtr. Sep. 45 (2008) 14–16, https://doi.org/10.1016/S0015-1882(08)70495-6.
[5] Y. Bessiere, Filtration frontale sur membrane : mise en évidence du volume filtré critique pour l'anticipation et le contrôle du colmatage. Génie des procédés, Thèse de doctorat, Université Paul Sabatier - Toulouse III, 2005, https://tel.archives-ouvertes.fr/tel-00143769. (Accessed 2 March 2019).
[6] E. Bazrafshan, K.A. Ownagh, A.H. Mahvi, Application of electrocoagulation process using iron and aluminum electrodes for fluoride removal from aqueous environment, E-J. Chem. 9 (2012) 2297–2308, https://doi.org/10.1155/2012/102629.
[7] A. Jafari, A. Mahvi, S. Nasseri, A. Rashidi, R. Nabizadeh, R. Rezaee, A. Complex, Ultrafiltration of natural organic matter from water by vertically aligned carbon nanotube membrane, J. Environ. Health Sci. Eng. 13 (2015) 51.
[8] V. Lazarova, P. Savoye, M.L. Janex, E.R. Blatchley III, M. Pommepuy, Advanced wastewater disinfection technologies: state of the art and perspectives, Water Sci. Technol. 40 (1999) 203–213. http://www.aquanetto.ch/data/documents/ressources/advancedwastewaterdisinfectiontechnologies.pdf.
[9] N. Lebleu, C. Roques, P. Aimar, C. Causserand, Role of the cell-wall structure in the retention of bacteria by microfiltration membranes, J. Membr. Sci. 326 (2009) 178–185, https://doi.org/10.1016/j.memsci.2008.09.049.
[10] N. Lebleu, Désinfection des eaux par procédés membranaires : étude des mécanismes de transfert des bactéries, phd, Université de Toulouse, Université Toulouse III - Paul Sabatier, 2007. http://thesesups.ups-tlse.fr/189/. (Accessed 17 October 2019).
[11] A. GAVEAU, Etude des mécanismes de transfert de bactéries déformables en microfiltration frontale, Thèse de doctorat, Université Toulouse 3 Paul Sabatier, 2016, https://tel.archives-ouvertes.fr/tel-01523275.
[12] J. Zerhouni, F. Rhazi Filali, A. Aboulkacem, Qualité et facteurs de risque de pollution des eaux souterraines périurbaines de la ville de Sebaa Ayoune (Meknes, Maroc), Larhyss J. 22 (2015) 91–107. http://larhyss.net/ojs/index.php/larhyss/article/viewFile/280/269. (Accessed 1 June 2018).
[13] O. Qabaqous, M.N. Bennani, N. Tijani, H. Ziyat, S. Arhzaf, Removal of hexavalent chromium by Ghassoul Hydrotalcites Membranes (GHTM), J. Mater. Environ. Sci. 9 (2018) 2511–2519.
[14] O. Qabaqous, N. Tijani, M.N. Bennani, A.E. Krouk, Elaboration et caractérisation des supports plans à base d'argile (Rhassoul) pour membranes minérales, J. Mater. Environ. Sci. 5 (2014) 6.
[15] P. Monash, G. Pugazhenthi, Development of ceramic supports derived from low-cost raw materials for membrane applications and its optimization based on sintering temperature, Int. J. Appl. Ceram. Technol. 8 (2011) 227–238, https://doi.org/10.1111/j.1744-7402.2009.02443.x.
[16] N. Tahri, I. Jedidi, S. Cerneaux, M. Cretin, R. Ben Amar, Development of an asymmetric carbon microfiltration membrane: application to the treatment of industrial textile wastewater, Separ. Purif. Technol. 118 (2013) 179–187, https://doi.org/10.1016/j.seppur.2013.06.042.
[17] P.J. Remize, Etude des rétrolavages assistés par l'air et contrôle du colmatage résiduel. Application à la production d'eau potable en filtration frontale, Thèse de doctorat, INSA Toulouse, 2006, https://core.ac.uk/download/pdf/35285198.pdf. (Accessed 9 March 2019).
[18] K. Kawasaki, A. Matsuda, S. Tanabe, N. Katagiri, E. Iritani, Effect of suction pressure and aeration on the hollow fibre microfiltration of excess activated sludge, Process Saf. Environ. Prot. 85 (2007) 176–180, https://doi.org/10.1205/psep05023.
[19] M. Boussemghoune, M. Chikhi, F. Bouzerara, Experimental Study of the Microfiltration for the Production of the Drinking Water, 2015, p. 5. https://scholar.google.com/scholar?q=related:DKw-sldVQyUJ:scholar.google.com/&scioq=&hl=fr&as_sdt=0,5. (Accessed 2 March 2019).
[20] ISO 5667-1, Water Quality - Sampling - Part 1: Guidance on the Design of Sampling Programmes and Sampling Techniques, 2006. https://www.sis.se/api/document/preview/908187/. (Accessed 29 January 2019).
[21] ISO 5667-3, Water Quality - Sampling - Part 3: Guidance on the Preservation and Handling of Water Samples, 2003. https://www.sis.se/api/document/preview/904281/. (Accessed 29 January 2019).
[22] J. Rodier, B. Legube, N. Merlet, coll, L'Analyse de l'eau, in: L'Analyse de l'eau, ninth ed., DUNOD, Paris, France., 2009, p. 1579. https://www.chapitre.com%20›%20BOOK › l-analyse-de-l-eau-9e-edition, 22974734.
[23] P.D. Belibi Belibi, S. Cerneaux, M. Rivallin, N. Martin, M. Cretin, Elaboration of low-cost ceramic membrane based on local material for microfiltration of particle from drinking water, J. Appl. Chem. 3 (2014) 1991–2003. www.joac.info › ContentPaper › 2014.
[24] Q. Liu, C. Wang, W. Qu, B. Wang, Z. Tian, H. Ma, R. Xu, The application of Zr incorporated Zn-Al dehydrated hydrotalcites as solid base in transesterification, Catal. Today 234 (2014) 161–166, https://doi.org/10.1016/j.cattod.2014.02.026.
[25] K. Djedid, N. Rezak, N. Bettahar, A. Bahmani, Utilisation de matériaux macroporeux dans le traitement des eaux polluées, Revue des Energies Renouvelables ICESD'11 Adrar Algérie, 2011, p. 12. http://www.cder.dz/download/icesd2011_29.pdf (accessed March 28 2018).
[26] J.T. Kloprogge, R.L. Frost, L. Hickey, Infrared emission spectroscopic study of the dehydroxylation of some hectorites, Thermochim. Acta 345 (2000) 145–156, https://doi.org/10.1016/S0040-6031(99)00359-7.
[27] A.K. Basumatary, R.V. Kumar, A.K. Ghoshal, G. Pugazhenthi, Author's Accepted Manuscript, Elsevier, 2014, https://doi.org/10.1016/j.memsci.2014.10.055.
[28] Y. Anbri, N. Tijani, J. Coronas, E. Mateo, M. Menéndez, J. Bentama, Clay plane membranes: development and characterization, Desalination 221 (2008) 419–424, https://doi.org/10.1016/j.desal.2007.01.101.
[29] J. Madejová, W.P. Gates, S. Petit, IR spectra of clay minerals, Dev. Clay Sci. 8 (2017) 107–149, https://doi.org/10.1016/B978-0-08-100355-8.00005-9.
[30] M. Mouiya, A. Bourriche, A. Bouazizi, A. Benhammou, Y. El Hafiane, Y. Abouliatim, L. Nibou, M.M. Oumam, M. Ouammou, A. Smith, H. Hannache, Flat Ceramic Microfiltration Membrane Based on Natural Clay and Moroccan

Phosphate for Desalination and Industrial Wastewater Treatment, 2018, https://doi.org/10.1016/j.desal.2017.11.005.

[31] P. Belibi Belibi, M.M.G. Nguemtchouin, M. Rivallin, J.N. Nsamia, J. Sieliechi, S. Cerneaux, M.B. Ngassoum, M. Cretin, Microfiltration ceramic membranes from local Cameroonian clay applicable to water treatment, Ceram. Int. 41 (2015) 2752−2759, https://doi.org/10.1016/j.ceramint.2014.10.090.

[32] H. Biglari, A. Chavoshani, N. Javan, A. Hossein Mahvi, Geochemical study of groundwater conditions with special emphasis on fluoride concentration, Iran, Desalin. Water Treat. 57 (2016) 22392−22399, https://doi.org/10.1080/19443994.2015.1133324.

[33] NM 03.7.001, Norme marocaine relative à la qualité des eaux d'alimentation humaine, 2005. https://www.imanor.gov.ma 〉 Norme 〉 nm-03-7-001.

[34] WHO, Guidelines for Drinking-Water Quality, fourth ed., World Health Organization, 2017. https://www.who.int 〉 publications 〉 drinking-water-qu.

[35] A. Smith, K. Moxham, A. Middelberg, Wall material properties of yeast cells. Part II. Analysis, Chem. Eng. Sci. 55 (2000) 2043−2053. https://pdfs.semanticscholar.org〉.

[36] S.S. Madaeni, A.G. Fane, G.S. Grohmann, Virus removal from water and wastewater using membranes, J. Membr. Sci. 102 (1995) 65−75, https://doi.org/10.1016/0376-7388(94)00252-T.