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COMPARISON OF THE FILTERABILITY OF MINERAL, ORGANIC, AND MIXED SUSPENSIONS APPLICATION TO WATER CLARIFICATION

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Abstract. Filtration operations were conducted on porous membrane to evaluate the specific contribution of the main fractions encountered in raw water (solids in suspension, soluble, or colloidal compounds) on the system permeability evolution during industrial operations. Experiments were conducted in a frontal filtration mode with single or mixed synthetic suspensions (clay, ferric hydroxide, activated carbon, latex, and humic acids). Results showed a wild specific resistance coefficient (α.W) difference between mineral and organic suspensions. The α.W coefficient increased with suspended solids concentrations. On the other hand, no actual differences were observed between the tested mineral suspensions, which also presented no actual differences in particle size distribution. In the same condition, latex suspensions composed by smaller elements induced higher hydraulic resistance, comparatively to mineral suspension, the resistance coefficient values were ten to one hundred times greater than the mineral suspensions. Nevertheless, a latex suspensions conditioning with $FeCl_3$ allowed a notably reducing of the resistance coefficient. Moreover, experiments on humic acid suspension pointed out the membrane fouling during filtration, which could disappear in the presence of activated carbon in the suspension. Since similar results were obtained in an immersed membrane system, it can be considered that this methodology can be developed to characterise the filterability of natural suspensions, and optimise the suspension conditioning

Keywords: Water clarification, cake filtration, porous membrane, hydraulic resistance, synthetic suspensions

1.0 INTRODUCTION

Ultra-filtration is the new alternative process to conventional surface water clarification because it provides a good water quality with a great accuracy not only on a physico-chemical point of view, but also with regard to its PACacity to remove specific particular infectious contaminants [1-4]. However, the process development is still limited because of the lack of appropriate tools for controlling the fouling phenomena, permitting a better constant running process.

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The fouling problems can be caused by several factors, such as concentration polarisation, adsorption, gel layer formation, and pore plugging. Membrane properties (material, porosity, molecular weight cut off, etc) also influence the fouling phenomena whereas, chemical cleaning is essential to remove compounds causing non-reversible fouling.

On the contrary, high concentrated zone close to membrane surfaces induced fouling which is considered as reversible by hydraulic ways, such as tangential shear stresses increase in accordance with a permeate flux control or back pulsing regeneration.

Then, an effective continuous operating is possible [5-11]. However, the numerous compounds present in raw water will bring the filterability prediction to fail because of their characteristic variations (according to accidental pollution, climate variation etc). Therefore, the permeability evolution due to the compounds deposit on the membrane surface during industrial operations is so difficult to evaluate and expect.

The objective of this work is to evaluate and quantify the role of compound fractions that can be found in raw water. Experiments were successively conducted on a single or mixed suspensions of particular mineral compounds (clay, activated carbon, and ferric hydroxide suspension), colloidal organic compounds (latex suspension), and soluble humic acid solutions. In each suspension concentration tested, turbidity, UV absorbance, and the particle size distribution allowed the suspensions characterisation before and after operations whereas, filterability was characterised with a frontal filtration lab scale unit installed with organic porous membranes (Millipore). In all conditions tested, no turbulence was induced upon the membrane surface, where deposits formed rapidly. The hydraulic resistance of these deposits were evaluated through the resistance coefficient $\alpha.W$ (L^{-2}) which is useful in order to find optimal suspension conditioning and to control a clarification step on membrane system.

2.0 MATERIALS AND METHODS

Aqueous suspensions were prepared in a Jar-Test system where mixing conditions were perfectly defined in Table 1.

Synthetic suspensions were prepared by adding mineral-organic compounds directly in tap water: clay (bentonite), powder activated carbon (PAC), colloidal latex solution, humic acids, and ferric chloride (that induced ferric hydroxide formation in the pH

Table 1 Mixing conditions in Jar Test

Operation step	**Speed mixing (RPM) and velocity gradient (s^{-1})**	**Time (min)**
Coagulation	150 (110 s^{-1})	1
Flocculation	40 (25 s^{-1})	15
Sedimentation	0	30

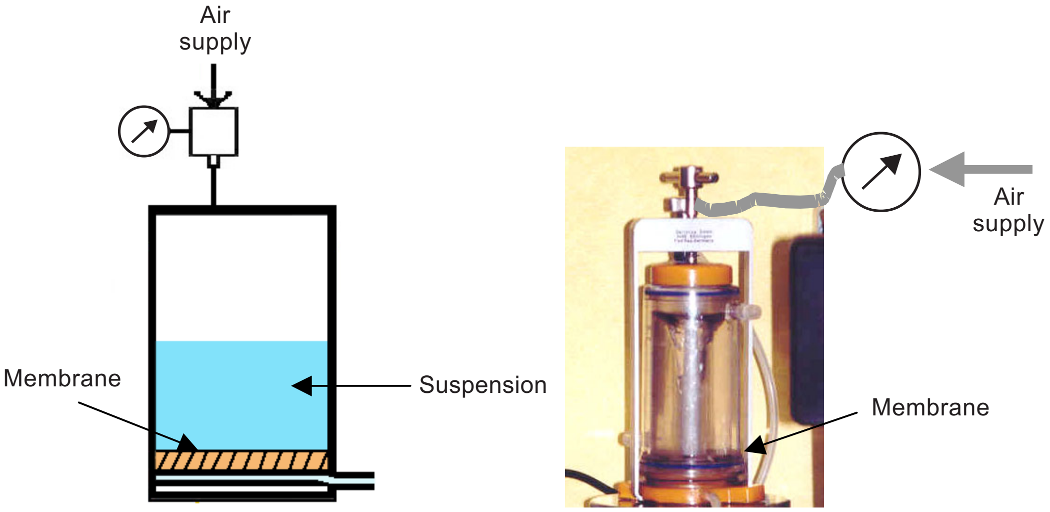
Table 2 Examples of studied suspensions

Suspension	**Concentration ($g.L^{-1}$)**	**Turbidity (NTU)**	**UV absorbance**	**Mean particle size (μm)**
- $FeCl_3$ (abs-254 nm)	0.10	2	0.023	1500±1000
- PAC (abs-254 nm)	0.02	non-analysis	0.005	37±30
- Bentonite	0.10	31	non-analysis	8.9±4.6
- Latex (abs-300 nm)	0.10	430	1.640	0.64±0.3
- Humic acid (abs-254 nm)	0.10	non-analysis	2.670	non-analysis
- Bentonite-Latex, mixing ratio 1:1 (abs-300 nm)	0.10	175	–0.205	50

range of working, 7.5 to 8). Each compound was studied alone before mixing together with one or several other compounds. Examples of studied suspensions are given in Table 2.

Suspensions were characterised through parameters such as mass concentrations, turbidity, conductivity, pH and UV absorbance, and particle size distribution (measured by laser granulometry and microscopic image analysis).

Filtration operations were operated in a Sartorius module (Figure 1) equipped with plane organic membrane (cellulose ester material, 0.05 μm pore size, and $10^{12} m^{-1}$ hydraulic membrane resistance).



1a: Schematic filtration module

1b: Filtration module photo

Figure 1 Representation of the Sartorius filtration module

To evaluate the filterability of suspensions, the first step is preparing and characterising during Jar-Test operations. The Sartorius module was filled with a 200 cm^3 sample of each suspension and the filtration was operated in a frontal mode under a defined pressure constant. The permeate volume evolution with time was quantified and obtained by an electronic balance.

Except for humic acid compounds, all experiments showed the presence of an increasing deposit rapidly on the membrane surface during experiments. This phenomena explains why a cake filtration model was chosen and intended to represent the experimental results by using the following relation:

$$t / V = a\,V + b \qquad (1)$$

with $a = \mu.\alpha.\,W / (2.\Omega^2.\Delta P)$
$b = \mu.R_m / (\Omega.\Delta P)$

In this relation, the parameter (α. W) has a dimension [L^{-2}] opposite to a permeability unit and also, it is representative to the difficulty of a mechanism translating of the permeate flux throughout the cake deposit.

3.0 RESULTS AND DISCUSSION

3.1 Suspensions Characterisation

Mean particle size range of the different suspensions with and without conditioning is given in Table 3. Mineral suspensions are characterised and showed a large size distribution (ferric hydroxide ranging from 200 to 2500 μm, activated carbon from 3 to

Table 3 Mean particle size of example studied suspensions

Suspension	Concentration ($g.L^{-1}$)	Mean particle size (μm)	
		Non conditioning	Conditioning with $FeCl_3$ (ratio of [$FeCl_3$]:[conc susp])
- $FeCl_3$	0.1-0.4	200±100	-
- PAC	0.1-0.5	37±30	-
- Bentonite	0.1	8.9±4.6	40±4.0 (1:10)
	0.5	6.8±3.3	60±20 (1:10)
	1.0	5.8±4.2	40±25 (1:10)
- Latex	0.01	0.6±0.3	100±50 (1:1)
	0.3	0.67±0.3	200±50 (1:1)
- Bentonite-Latex mixing ratio = 1:1	0.1	30±15	100±10 (1:10)
	0.3	70±30	150±10 (1:10)

600 μm, and clay particle from 1 to 100 μm). In contrary, latex suspension is characterised by a smaller particle, one which is showing a narrow size distribution (0.2 to 2.0 μm) [12].

The adding of ferric chloride was directly done into mineral and organic suspensions that had a great significant influence on clay and latex suspensions by particle size increasing with an appearance of size distribution narrowing. The intensification of this phenomena depends on ferric chloride concentration versus initial suspension concentration. For example, upon the settling criteria for a good clarification step defined a turbidity value of the settled water, minor than 3 NTU. A 1:10 ratio of ferric chloride concentration versus clay suspension was necessary to obtain settled water turbidity lower than 3 NTU. In these conditions, the clay floc size distribution was approximately in a range of 20 to 40 μm. However, for latex suspensions, a ratio of 1 to 1 was necessary to obtain an equivalent settled water turbidity value as mentioned. The size of flocculated latex suspensions was then in a range of 50 to 150 μm, i.e. 100 times larger than the initial natural latex particle size. The adding of ferric chloride had no effect on humic compounds.

3.2 Suspensions Filterability

Results of experiments realised on single synthetic suspensions are illustrated in Figure 2. At low concentration, a great evolution difference of t/V versus V appeared between mineral and latex suspensions.

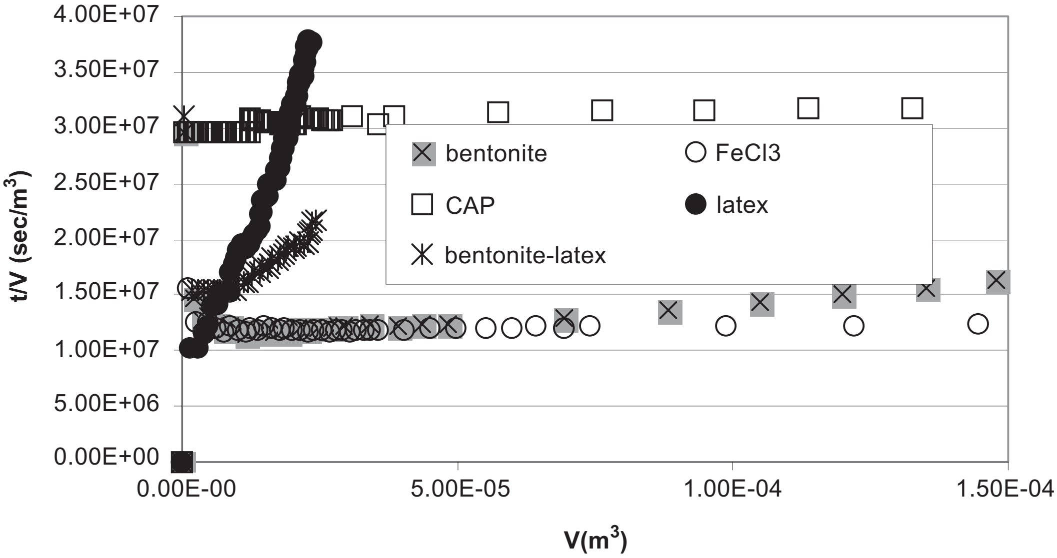
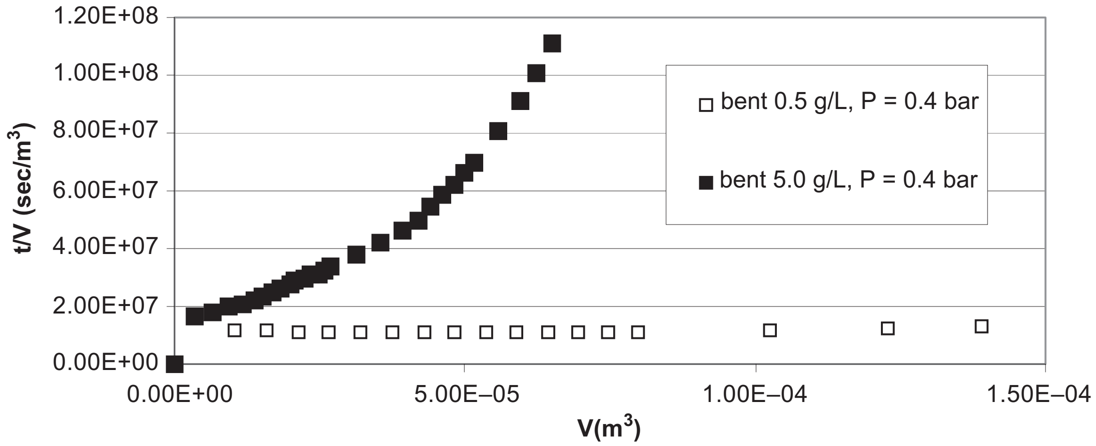


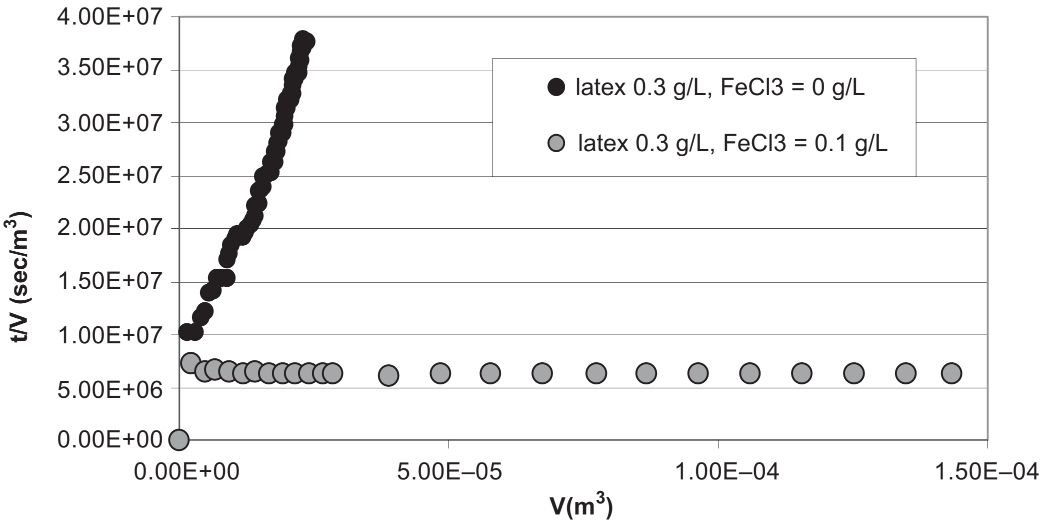
Figure 2 Evolution of t/V vs V for single and mixed synthetic suspensions (Suspension concentration = 0.3 g/L, pressure 1 bar)

The calculation of the (α.W, Table 4) parameter shows no actual differences between all mineral suspensions tested which does not present actual differences in particle size distribution. In the same condition, latex suspensions, composed by smaller elements, induced higher hydraulic resistance comparatively to a single mineral suspension, and it is mixed with latex suspensions. The (α.W) resistance coefficient values were ten to one hundred times greater than mineral suspensions' (Table 4) that is compatible with the difference in particle size range.

An increase of the hydraulic resistance (α.W) appeared when the suspended solids concentrations increased (Figure 3a and Table 4). In the opposite, a conditioning



(a) Influence of suspension concentration



(b) Influence of $FeCl_3$

Figure 3 Influence of suspension concentration and chemical coagulation (a) and (b)

Table 4 Values for the (α.W) according to experimental conditions

Suspension and condition	**Concentration ($g.L^{-1}$)**	**α.W (m^{-2})**	
		P = 0.4 bar	**P = 1.0 bar**
Bentonite	0.3	$1.7.10^{13}$	$2.6.10^{13}$
	0.5	$0.4.10^{13}$	–
	5.0	$2.0.10^{13}$	–
$FeCl_3$	0.3	$2.0.10^{12}$	$2.0.10^{12}$
PAC	0.3	$3.0.10^{12}$	$5.1.10^{12}$
Latex	0.1	–	$5.1.10^{13}$
	0.3	–	$25.5.10^{13}$
Latex + $FeCl_3$	0.3 (0.1- $FeCl_3$)	–	$0.77.10^{12}$
Bentonite+ $FeCl_3$ (ratio of [$FeCl_3$]:[conc susp] = 1:10)	0.5 5.0	$4.0.10^{12}$ $4.0.10^{13}$	–
Bentonite-Latex mixing ratio = 1:1	0.3	–	$1.0.10^{14}$
Bentonite-Latex + $FeCl_3$ 0.05 g/L mixing ratio = 1:1	0.3	–	$5.1.10^{13}$
Humic acid	0.01		$1.8.10^{14}$
Humic acid+PAC	0.01(0.01-PAC)		$1.5.10^{14}$

allowed a filtration intensification and a resistance coefficient reduction, notably when $FeCl_3$ was added in the latex suspensions (Figure 3b and Table 4) because the particle size was dramatically increased by flocculation (Table 3).

Experiments on humic acid solutions pointed out no apparent cake deposit on the membrane surface but a membrane fouling generally appeared during filtration. Nevertheless, this phenomenon could disappear in the presence of activated carbon in the suspension. The evolution of the filtering condition was then similar to the filtration of activated carbon suspension.

In the same way, a mixed suspension of clay and latex had the same comportment than a coagulated suspension, when a sufficient ferric chloride adding was realised.

In a submerged membrane system [12], where a continuous aeration was practised close to the membrane surface, the filtration of bentonite suspensions showed no notable difference of the (α.W) values between frontal and tangential filtration, when deposits were presented on the membrane wall. Therefore, it can be supposed that experiments developed in the frontal mode on the laboratory scale pilot can give a good prediction of the suspension filterability comportment, allowing an optimisation of suspension conditioning by coagulant salt or activated carbon adding.

3.2 Permeate Characteristics

The presence of soluble organic substance was observed in permeate when filtration was operated only with single humic acid solutions. Nevertheless, the quality of the filtered water was always excellent (turbidity less than 0.3 NTU, no solids in suspension, no absorbance or TOC), when the filtration was operated on single particular suspensions (clay or activated carbon) or organic suspensions added with ferric chloride and activated carbon.

4.0 CONCLUSION

To evaluate the role of the main compound fractions that can be found in raw water, experiments were successively carried on single or mixed particular mineral suspensions (clay, activated carbon, and ferric hydroxide suspension), colloidal organic suspension (latex suspension), and soluble humic acid solution. In frontal filtration mode, realised on porous membrane, experiments showed a great difference in a hydraulic resistance coefficient (α.W) between mineral and organic suspensions. The α.W increased with the suspended solids concentrations. Nevertheless, a $FeCl_3$ conditioning of the suspensions allowed a notably reducing of the hydraulic resistance coefficient. Since similar results were obtained in continuous immersed membrane system, it can be supposed that this methodology can be developed to characterise the filterability of natural suspensions and optimise their conditioning.

NOTATIONS

μ: dynamic viscosity of water (Pa.s)

α: specific hydraulic resistance of the cake deposit on membrane surface ($m.kg^{-1}$)

Ω: cross filter area (m^2)

ΔP: trans-membrane pressure (Pa)

R_m: Membrane hydraulic resistance (m^{-1})

t: time in s

V: permeate volume (m^3)

W: dried mass of cake deposit by permeate volume unit ($kg.m^{-3}$)

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