Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

Retention of Bentonite in Granular Natural Pozzolan: Implications for Water Filtration

K. Ndi[ab]; D. Dihang[ab]; P. Aimar[a]; G. J. Kayem[b]
[a] Laboratoire de Génie Chimique de l'Université Paul Sabatier, Toulouse, France [b] Industrial Filtration and Water Treatment Group, ENSAI, University of Ngaoundere, Ngaoundere, Cameroon

To cite this Article Ndi, K. , Dihang, D. , Aimar, P. and Kayem, G. J.(2008) 'Retention of Bentonite in Granular Natural Pozzolan: Implications for Water Filtration', Separation Science and Technology, 43: 7, 1621 — 1631
To link to this Article: DOI: 10.1080/01496390801974712
URL: http://dx.doi.org/10.1080/01496390801974712

Separation Science and Technology, 43: 1621–1631, 2008

ISSN 0149-6395 print/1520-5754 online
DOI: 10.1080/01496390801974712

Retention of Bentonite in Granular Natural Pozzolan: Implications for Water Filtration

K. Ndi,[1,2] D. Dihang,[1,2] P. Aimar,[1] and G. J. Kayem[2]

[1]Laboratoire de Génie Chimique de l'Université Paul Sabatier, Toulouse, France
[2]Industrial Filtration and Water Treatment Group, ENSAI, University of Ngaoundere, Ngaoundere, Cameroon

Abstract: Slow sand filtration is wide spread as a rural drinking water treatment process in most of the developing countries, and is well known to become effective after a long period of filtration. This study evaluates the efficiency of granular pozzolans from Djoungo and Koutaba (Cameroon), at the beginning of a slow filtration process, using bentonite as a model colloid, under different physicochemical conditions. Experiments were conducted at various pH (5–9), different ionic strengths ($10^{-4} - 3 \cdot 10^{-2}$ M KCl) and various flow velocities up to 0.24 mm/s, with a filter grain size of 400–500 μm. The results show that the pH variation (5–9) has little influence on the retention of bentonite clay when the ionic strength is less than 10^{-2} M KCl; whereas conditioning the grains at 10^{-2} M KCl and pH 5 improves the efficiency of retention, increasing flow velocity results in a small decrease in retention efficiency. The three pozzolans tested gave similar retention efficiencies.

Keywords: Bentonite, deep bed, particle capture, pozzolan, slow filtration, water treatment

INTRODUCTION

When the concentration of dissolved substances in raw surface water is low, the turbidity of the water is mainly dependent on the suspended colloidal

Received 7 February 2008, Accepted 11 February 2008
Address correspondence to K. Ndi, Laboratoire de Génie Chimique de l'Université Paul Sabatier, 118 route de Narbonne, Toulouse 31062 cedex 4, France. E-mail: ndikoungou@yahoo.fr

matter content, of which clay is the major fraction. Its removal is often realized by classical clarification processes, involving coagulation, sedimentation, and filtration steps. For low turbidity waters as can be the case with low charge surface waters, the coagulant can be omitted for reasons of cost. When the coagulant is not used, the water can be clarified by filtration performed in deep bed sand filters at low velocities (<0.24 mm/s). This is the case for small systems for rural water supply, especially in developing countries, where slow rate sand filtration is the most appropriate technology for drinking water production (1, 2). In this process, initial filter performance is poor, and a huge amount of water is not filtered at the beginning, because a biofilm needs to form at the grain surfaces to promote particle retention. The consequence is a waste of the water produced initially. Since this maturation phase depends on the type of media used, recourse to another type of material could solve the problem.

Several types of other filter materials (anthracite, biolite, ilmenite, pearlite, pozzolan, and pumice) are used in granular filtration. Their choice, beyond their effectiveness, depends, in particular, on their availability and the cost (3). Natural pozzolans are materials of volcanic origin found in several countries and in particular in Cameroon where a significant deposit is located in the Njombe area (Graben of Tombel). Like other heterogeneous materials such as pumice, their varied oxide composition (4, 5) and high bed porosity (6), potentially enable the filtration of water over a long period of time whilst maintaining a high particle retention efficiency (6). Clays such as bentonite and kaolinite are model colloids for testing filter material performances (6–8).

This study is aimed at determining the retention efficiency of colloidal bentonite particles in granular beds of pozzolan, and for this purpose, the initial physicochemical conditions of the suspension and of the water used for washing the bed are varied. The initial steps of granular filtration being the most critical, as this is when leaks are generally observed, the filtration tests were carried out on clean beds, that is, beds having few or no particles retained on their surface at the start.

Theoretical

Granular or depth filtration of colloids is a process involving transportation and attachment. The colloidal particles are transported from the bulk of suspending fluid to the vicinity of the filter grain surface, then, attachment of particle on grain is mediated by hydrodynamic and chemical forces (9, 10).

There are two theoretical approaches to depth filtration, namely, the phenomenological and the trajectory ones. The phenomenological theory is based on the description of filtration via mass balance operations, but has the important drawback that it does not provide information on the mechanisms of deposition or capture and cannot be generalized. The trajectory theory is based on particle motion along streamlines near grain surface and therefore affords understanding of mechanisms and grain material performance. It is this latter theory which will be exploited herein (11).

Colloid breakthrough curves from packed bed experiments can be used to determine single grain collector efficiency and colloid deposition rate coefficient (12–14), but only single collector efficiency and attendant relationships will be considered here. Two filtration (particle retention) parameters will be focused on, η, the single grain collector efficiency and α, the attachment (collision) efficiency (15). η, can be obtained from Equation (1), where a_g is the grain radius, L is the column length, ε is the bed porosity or fractional voidage, and C/C_0 is the value of the normalized column effluent concentration at the initial stages of deposition.

$$\eta = \frac{C}{C_0}\exp\left[\left(-\frac{4}{3}\frac{a_g}{(1-\varepsilon)}\right)\right]\frac{1}{L} \tag{1}$$

α is related to η by, $\eta = \alpha\eta_0$, where η_0 is the overall contact efficiency determined experimentally.

$$\alpha = BN_{Col}^{n}, \text{ with } N_{col} = kA/\varepsilon_0\varepsilon_r\zeta_P\zeta_g,$$

whence

$$\alpha = \frac{C}{C_0}\exp\left[\left(-\frac{4}{3}\frac{a_g}{(1-\varepsilon)}\right)\right]\frac{1}{L\eta_0} \tag{2}$$

B and n are constants; N_{col} is a dimensionless parameter accounting for chemical interactions; A is the Hamaker constant of the system (bentonite-water-pozzolan); ε_0 is the permittivity of vacuum ($8.854 \cdot 10^{-12}$ F $\cdot$ m^{-1}); ε_r is the dielectric constant of the suspending fluid (78.25 for water at 25°C); ζ_p is the particle zeta potential (mV); ζ_c is the collector zeta potential (mV).

MATERIALS AND METHODS

Bentonite Colloids

Bentonite clay was chosen for use as colloidal material in this study because it represents a typical natural colloid found in raw surface waters. It was purchased from CLARSOL FB2 (France). A stock suspension of the colloid was prepared as follows. Bentonite powder (40 g) was added under rapid stirring to distilled water (1 L). In order to prevent microbial growth during storage, sodium azide was added to the suspension under agitation to achieve a concentration of 10 ppm. After thorough agitation, the suspension was allowed to settle for at least 4 hours and the supernatant was drawn off for further settlement. This operation was repeated until a suspension showing no visible settling over 4 hours was obtained. This stock suspension, having a concentration of 20 g/L, was kept under refrigeration at 4°C until required for use. For filtration experiments, the stock suspension was used to prepare dilute colloidal suspensions of turbidity 30 NTU (bentonite concentration = 0.03 g/L). The particle size and zeta potential of the colloidal suspension entering the filtration column under the different chosen physicochemical conditions was determined respectively by dynamic light scattering and laser Doppler microelectrophoresis using ZETASIZER 4 (MALVERN Instruments, USA). The mean particle size was 800 nm and the zeta potential (ζ) showed negatively charged particles ($|\zeta| \geq 30$ mV) in all cases investigated. No significant changes were observed in particle size or zeta potential of the influent colloidal suspension during filtration.

Pozzolan Grains

The granular pozzolan material, used as packed bed filter medium, was obtained by crushing natural rock from quarries at Djoungo and Koutaba in Cameroon using a RETSCH (Germany) jaw crusher and then sieving. The grains were angular in shape and the fraction retained for experiments had a sieve size of 0.4–0.5 mm. The grains were washed with tap water to remove loose dust and rinsed thoroughly with distilled water until clean. The surface and bulk chemical compositions of the pozzolan, determined by X-ray photo electron spectroscopy and X-ray diffraction, showed that the material was a heterogeneous oxide containing essentially, SiO_2, Al_2O_3, Fe_2O_3/Fe_3O_4, and TiO_2 as insoluble phases. Only small differences in oxide content were observed for the materials from the two quarries (Djoungo and Koutaba). The granular materials had a solid density around 3000 kg/m^3 and specific surface area less than 3 m^2/g. The zeta potential of the pozzolan grains, under the various physicochemical conditions studied, was determined as described above after reducing the grains to fine powder in a ball mill and it was found to be highly negative ($\zeta \geq 50$ mV) throughout the pH range and at all ionic strengths used.

Filtration

Filtration was carried out in an upward flow mode. The setup used consisted of two feed tanks; a peristaltic pump (ISMATECH, France); a PHARMACIA glass filtration column of length 25 cm and internal diameter 2.5 cm, packed with pozzolan; a fraction collector (PHARMACIA LKB, USA), and a conductimeter. The filtration flow rate was determined by measuring the quantity of suspension which entered the column as a function of time using an electronic balance (OHAUS Adventurer, USA, precision, ±0.01 g) and a digital stop watch. The conductivity was measured on line using a

Phillips cell. The monitoring of the bentonite concentration at the exit of the column was realised with a HACH Ratio XR turbidimeter (HACH Instruments, USA). Before use, the pozzolan packed bed column was first water saturated and thoroughly flushed with distilled water, then adjusted to a desired pH and ionic strength with NaOH, HCl, and KCl. Colloid capture efficiency in the column was deduced from deposition rate transport experiments performed at different pH, ionic strengths and flow velocities. The plateau values of C/C_0 were used for calculating capture efficiency.

RESULTS

Hydrodynamic Properties of the Pozzolan Beds

Table 1 shows that the pozzolans are very similar in hydrodynamic properties. Glucose tracer tests on the beds showed no axial dispersion effects (16). The minimum fluidization velocities as well as the bed expansion coefficients are high. This indicates that backwashing of pozzolan filter beds must be handled with great care to avoid transport out of the column.

Influence of pH and Solution Ionic Strength on Colloid Capture Efficiency

The grain single collector efficiency obtained from the results of colloid transport experiments at different ionic strengths and pH are shown in Fig. 1 for a Reynolds number of 0.6 (0.2 mm/s). It is generally low at all ionic strengths below 10^{-2} M KCl. In particular, for all three pHs investigated,

Table 1. Some physical properties of the pozzolans

	PZNK (Black Pozzolan Koutaba)	PZND (Black Pozzolan Djoungo)	PZRD (Red Pozzolan Djoungo)
Density (kg/m^3)	2997	2729	2932
Porosity	0.50	0.54	0.56
Minimum fluidisation velocity $(m/s) \cdot 10^{+3}$	3.8	3.2	3.2
Permeability $m^2 \cdot 10^{+10}$	2	2	2
Bed expansion coefficient	2.7	3.25	3.49
Hamaker constant $(J) \cdot 10^{+20}$ Bentonite-water-pozzolan system	3.68	1.09	1.86

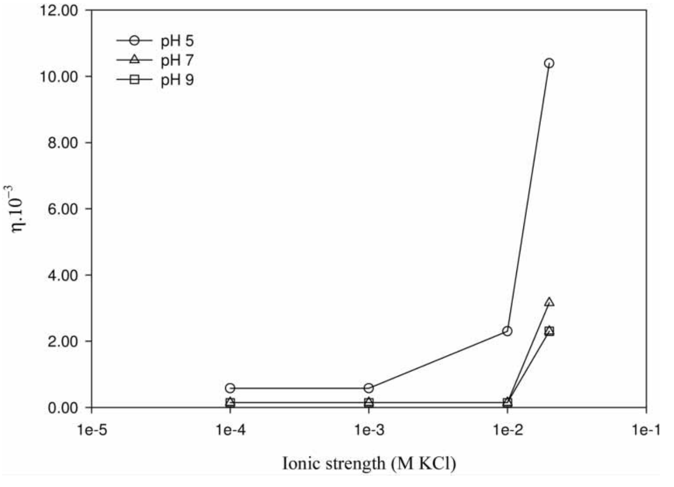

Figure 1. Effect of suspension ionic strength and pH on single collector efficiency for bentonite particle capture on pozzolan (PZND).

collector efficiency is independent of ionic strength below 10^{-3} M KCl. For pH 7 and 9 this applies up to 10^{-2} M KCl, above which, the capture efficiency increases rapidly with ionic strength. Retentions at pH 7 and 9 are similar and show the same trends. Capture at pH 5 stands out; it is higher than at pH 7 and 9 and the difference is even more remarkable at ionic strengths equal to or higher than 10^{-2} M KCl. It is deduced that under conditions prevalent in natural waters, colloid retention in pozzolan beds will be quite low but slightly acidic waters will give better retention.

Influence of Backwashing Electrolyte pH on Capture Efficiency at Constant Ionic Strength

Typical curves demonstrating the influence on capture efficiency of conditioning (backwash) solution pH at 10^{-2} M KCl are presented in Fig. 2 for deposition at pH 5 and 9. In general, backwashing the pozzolan bed in slightly acidic conditions (pH below 7) improves retention whereas washing at basic pH has little or no effect. Again, during filtration, better capture is obtained at pH 5 than at pH 9, confirming the results in Fig. 1.

Influence of Filtration Velocity on Capture Efficiency

Figure 3 presents capture efficiency versus flow Reynolds number (Re) in 10^{-2} M KCl, the Reynolds number being linearly dependent on the velocity

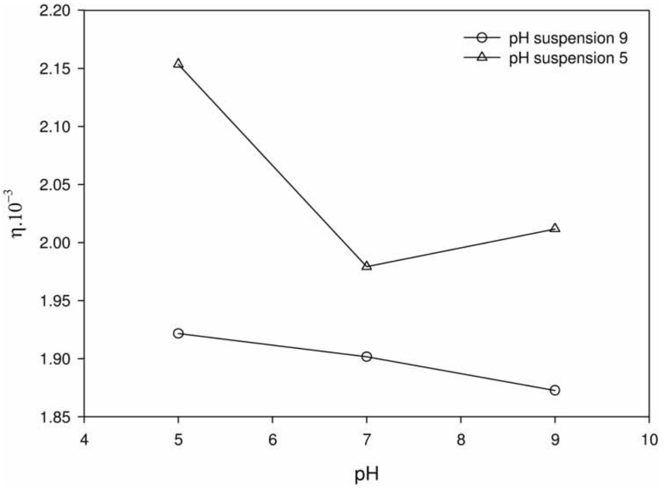

Figure 2. Effect of backwash solution pH used for conditioning grains on collector efficiency in 10^{-2} M KCl and pH 5 and 9 for bentonite particle capture on pozzolan (PZND).

only in these experimental conditions. The graph shows that capture efficiency decreases slightly as Reynolds number (velocity) increases in the range studied, the decrease being about 10% for filtration at pH 9 and 20% at pH 5 at the highest velocity used (Re = 0.8, velocity = 0.27 mm/s).

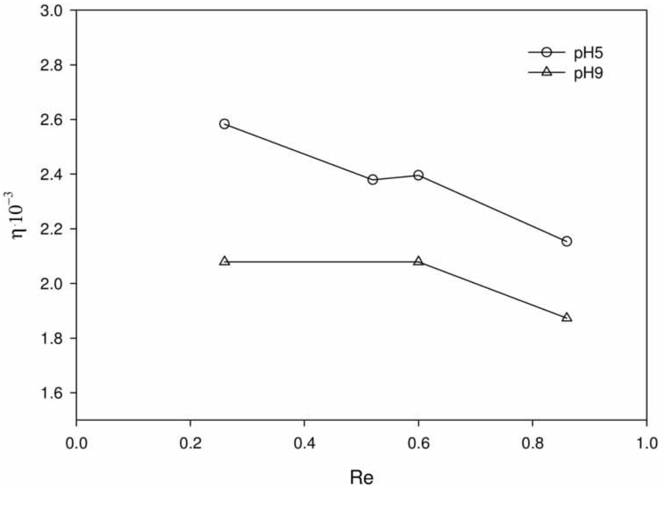

Figure 3. Effect of flow rate (Reynolds number) on collector efficiency in 10^{-2} M KCl at pH 5 and 9 for bentonite particle capture on pozzolan (PZND).

Comparison of Different Pozzolan Filter Media

Three pozzolans, namely, PZND (black pozzolan from Djoungo), PZRD (red pozzolan from Djoungo), and PZNK (black pozzolan from Koutaba) of same grain size were tested in filtration under the same conditions as shown in Fig. 4. It is evident that all three pozzolans give quite similar retentions, with capture efficiencies in the range $1.8-2.5 \times 10^{-3}$. Thus the type and origin of the pozzolan does not seem to greatly affect performance. However, PZNK has higher collector efficiencies than the other two (PZRD, PZND), and this can be ascribed to chemical effects.

Figure 5 shows the energy barrier between colloid and grain calculated by the Derjaguin Landau Verwey Overbeeek theory (17). Qualitatively, the DLVO model shows that trends in capture will decrease in the order PZNK > PZRD > PZND and this is in accord with the trends in Figure 4. But, since the differences in capture efficiencies are in the range of 5–25%, the pozzolans for practical purposes can be considered to exhibit roughly similar capture properties.

DISCUSSION

The results presented clearly show that colloid retention on pozzolan is better for filtration at slightly acidic pH (5) than at neutral or basic pH (7 and 9). Backwashing at pH 5 improves retention but backwashing at pH 7–9 depresses retention. The remarkable difference between pH 5 and pH 7–9 can be ascribed to differences in surface chemical properties. It is

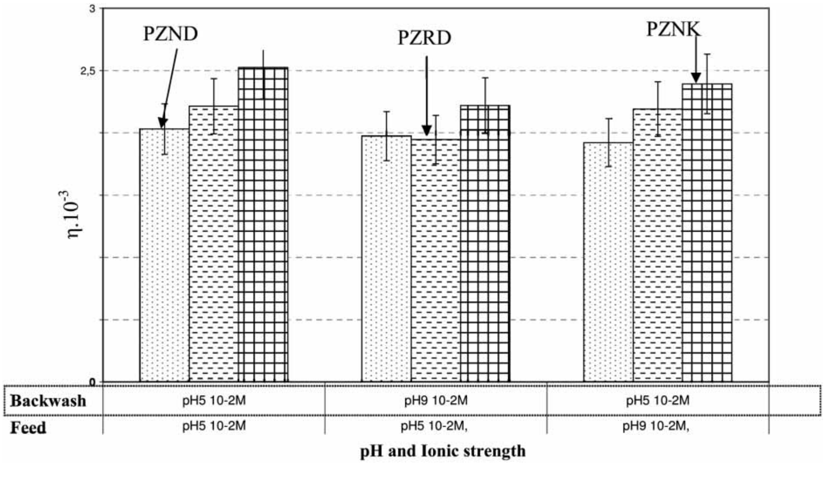

Figure 4. Comparison of pozzolan media performance under different conditions.

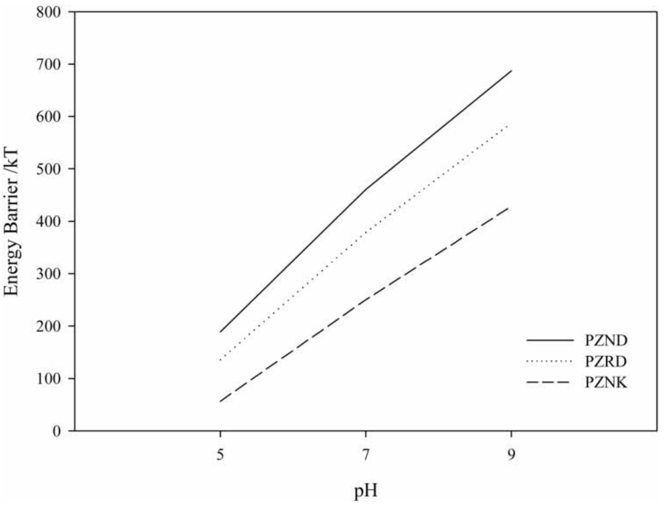

Figure 5. DLVO Maximum energy barrier for interaction of bentonite-pozzolan in 10^{-2} M KCl.

suggested that at pH 7–9, the pozzolan grains are entirely negatively charged and so interaction with the bentonite which is also negatively charged leads to repulsion between the grain and the colloid. At pH 5, some of the natural oxides in the pozzolan grain having an isoelectric point below pH 7, such as TiO_2 (pH 6), may become positively charged, thereby allowing patchwise adsorption of colloid on the grain. Such behaviour by heterogeneous oxide filter materials has been reported by (18, 19).

It has also been seen in Fig. 1 that the colloid retention is low at low ionic strengths as will be the case in natural waters. This poor retention can be attributed to the effect of double layer repulsion between colloids and grains due to their highly negative charge. For higher ionic strengths, suspended particles may undergo rapid aggregation due to particle mixing in the bed, and retention in the filter the bed will occur by sieving as happens in sand filters.

CONCLUSION

Under normal conditions of operation, pozzolan granular filters will show low retention of clay colloids in natural water as do sand filters. However, washing the pozzolan at pH 5 before slow filtration of natural water should accelerate the maturation of the filter, whereas, the same operation will not be expected to have any effect on a sand filter.

REFERENCES

1. Huisman, C. and Wood, W.E. (1974) Slow sand filtration. Report World, Health Organisation, Geneva, Switzerland.
2. Cleasby, J.L., Hilmoe, D.J., and Dimitracopoulos, C.J. (1984) Slow sand and direct in-line filtration of a suface water. *Journal American Water Works Association*, 12: 44–55.
3. Joussain, G., Mazet, M., Bonnet, E., and Couillault, P. (1987) La Filtration directe dans le traitement des eaux de consommation (Direct filtration in drinking water treatment). *Trib. Cebedeau*, 523–524: 3–16.
4. Nkouathio, D.G., Wandji, P., Tchoua, F.M., and Kagou, A. D., and Menard, J.J. (1999) Revalorisation et intérêt economique des projections des volcans holomagmatiques du graben de tombel (Ligne volcanique du Cameroun) (Revaluation and economic potential of holomagmatic volcanic projections of the graben of tombel (Cameroon line)). *GEOCAM*, 2: 339–345.
5. Petrangeli, M.P., Yassin, D.K., Troia, B., and Majone, M. (1999) Adsorption of lead at variable pH onto a natural porous medium: Modelling of batch and column experiments. *Environmental Science & Technology*, 33: 4457–4464.
6. Farizoglu, B., Nuhoglu, A., Yildiz, E., and Keskinler, B. (2003) The performance of pumice as a filter bed material under rapid filtration conditions. *Filtration & Separation*, 40: 41–45.
7. Huang, C., Pan, J.R., and Huang, S. (1999) Collision efficiencies of algae and kaolin in depth filter: The effect of surface properties of particles. *Water Research*, 33: 1278–1286.
8. Zhuang, J., Jin, Y., and Flury, M. (2004) Comparison of Hanford colloids and kaolinite transport in porous Media. *Vadose Zone Journal*, 3: 395–402.
9. Amirtharajah, A. and Wetstein, D.P. (1980) Initial degradation of effluent quality during filtration. *Journal American Water Works Association*, 72: 518–524.
10. O'Melia, C.R. (1985) Pretreatment and performance in water filtration. *Journal of Environmental Science & Technology*, 111: 874–890.
11. Logan, B.E., Jewett, D.G., Arnold, R.G., Bouwer, E.J., and O'Melia, C.R. (1995) Clarification of clean-bed filtration models. *Journal of Environmental Engineering*, 121: 869–873.
12. Rajagopalan, R. and Tien, C. (1979) The theory of deep bed filtration. In *Progress in Filtration and Separation*; Wakeman, R.J. (ed.); Elsevier Scientific Publishing Company: New York, pp. 180–266.
13. Elimelech, M. (1992) Predicting collision efficiencies of colloidal particles in porous media. *Water Research*, 26: 1–8.
14. Litton, G.M. and Olson, T.M. (1993) Colloid deposition rates on silica bed media and artifacts related to collector surface preparation. *Environmental Science & Technology*, 27: 185–193.
15. Elimelech, M., Gregory, J., Jia, X., and Williams, R. (1995) *Particle Deposition & Aggregation: Measurement, Modelling and Simulation*; Butterworth Heinemann: London, UK.
16. Ndi, K.S. (2007) *Mécanismes et Modélisation de la rétention de la latérite et de la bentonite dans les lits filtrants de pouzzolane granulaire (Mechanisms and Modelling of the retention of laterite and bentonite particles in pozzolan granular beds)*; Ph.D Thesis, Université Paul Sabatier, Toulouse (France) and University of Ngaoundere (Cameroon).

17. Van de Ven, T.G.M. (1989) *Colloidal Hydrodynamics*; Academic Press: London, UK.
18. Kretzschmar, R., Robarge, W.P., and Amoozegar, A. (1994) Filter efficiency of three saprolites for natural clay and iron oxide colloids. *Environmental Science & Technology*, 28: 1907–1915.
19. Truesdail, S.E., Lukasik, J., Farrah, S.R., Shah, D.O., and Dickinson, R.B. (1998) Analysis of bacterial deposition on metal (hydr)oxide-coated sand filter media. *Journal of Colloid and Interface Science*, 203: 369–378.