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UTILIZATION OF SLAG FIBERS AS ECOMATERIAL II. Collection of Ultrafine Silica and Oil-Water Emulsion

by

IBAÑEZ Juan Patricio, Masaki MURAKAMI[†] and Hiroshi SASAKI^{††}

ABSTRACT

The collection of ultrafine silica particles (23 nm in diameter) and oil-water emulsion (500 nm in diameter) from low concentrated suspensions were studied by using an ecomaterial (slag fibers)-collector bed system. The collection efficiency was highly dependent on the sol's pH and less on the specific surface area ratio between collector and ultrafine particles. The highest collection efficiency was attained at pH 4 for silica and at pH 3 for oil-water emulsion. The experimental results were partially interpreted by the total interaction potential theory. In the case of the collection of ultrafine silica a second mechanism regarding flocculation by the dissolved fraction of the SF complemented the DLVO theory. In the case of the collection of oil-water emulsion effects regarding the deformable character of the oil drops as well as the hydrodynamic effects derived from the high molecular weight of the oil complemented the DLVO theory.

Key Word: collection, ultrafine particles, silica, oil-water fibers, ecomaterial, flocculation. emulsion, slag fibers, ecomaterial, flocculation.

1. INTRODUCTION

The constant and increasing technological development is producing the increasing in the volume of wastewater, process water and industrial effluents polluted with colloidal particles, which have overcome traditional cleanup treatment processes such as sedimentation or filtration (1). Besides, these unwanted products produce damage to several production processes. For instance, the presence of ultrafine silica in process effluents precludes their effective use and recycling in several industrial processes such as geothermal energy production (2), and others where boiler operations and steam generation are involved (3).

The common practice used to remove fine particles is to incorporate a precipitation or

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Institute for Advanced Materials Processing, Tohoku University, Katahira 2-1-1, Aoba-ku, Sendai 980-77, Japan.

[†] Present Address: Toyo Engineering Co., Akanehama 2-8-1, Narashino, Chiba 275, Japan.

^{††} Present Address: School of Science and Engineering, Waseda University, Ohkubo 3-4-1, Shinjuku-ku, Tokyo 169, Japan.

flocculation stage in the process that can be followed by flotation (4); however, it is a source of additional contamination, which should be cleaned later on. Furthermore, by this practice increases the requirement of equipment, space, reagents and time, i.e., an increment of the production cost.

The removal of ultrafine particles (UFP), colloids under 500 nm, is based on to alter their stability condition by treating the solid-liquid interface with either electrolytes or surface active agents (5, 6). The collapsed dispersion of UFP produces effects such as flocculation, where the new entities can settle down producing deposition or they are suitable for filtration or flotation. Nevertheless, when the UFP suspensions are extremely low concentrated this procedure loses effectiveness, then the collection of UFP may show better features.

The collection process, attachment of UFP onto the surface of a collector, should not be understood as a simple filtration effect but as a process where both collector and UFP interact by electrostatic (attractive and repulsive nature) and chemical phenomena.

There is a wide variety of works where collection or deposition of UFP onto spherical and cylindrical collectors is based on the estimations of the London-van der Waals (attraction) energy and the overlapping of the electrical double layers (repulsion) energy (7-12). Nevertheless, the chemical effect produced by the dissolution of collectors and formation of layers has not been properly discussed.

The aim of this work is to show the behavior of slag fibers in aqueous media as a collector of two common pollutants; ultrafine silica and oil-water emulsion. Their removal from low concentrated suspensions by using a SF-collector bed system is based in the surface chemical properties of this ecomaterial. The column bed system was chosen because of its simplicity, which makes it easy to scale-up to industrial operations.

2. MATERIALS AND METHODS

The slag fibers (SF) used in this research work were obtained by high speed spinning technique by Pacific Metals Co. after ferronickel and ferromanganese smelting processes. A full physical and chemical characterization of this ecomaterial is available on reference (13). All chemicals were analytical reagent grade obtained from Wako Pure Chemicals Ind., which were employed without further treatment. All aqueous solutions were prepared with double distilled water, the first in a stainless steel boiler and the second in a Pyrex glass one. The chemical analysis were performed by using an inductively coupled plasma-emission spectrometer (SPS 1200 A, Seiko Intr. Co.). The oil concentration measurements were performed by using an oil content microanalyzer (OCMA-220, Horiba Co.).

The ζ -potential measurements were performed by using an electrophoretic light scattering spectrophotometer (ELS-800, Otsuka Elec. Co.), the supporting electrolytes used were aqueous 1 mmol dm⁻³ KNO₃ solutions.

2.1 Preparation and Characteristics of the Sols: Commercially available colloidal silica "Ludox HS-40" was employed without further treatment. The composition given by several x-ray fluorescence analysis made on freeze dried samples were as follows; SiO₂: 71.40 ± 2%, Na₂O: 14.75 ± 2%, CaO: 8.7 ± 2%, MgO: 2.15 ± 2.5%, Al₂O₃: 1.07 ± 1%, K₂O: 0.58 ± 2%, Fe₂O₃: 0.12 ± 1% and others: 1.23 ± 1%. The mean diameter of ultrafine silica particles was computed to be approximately 23 nm by using electron micrographs. This value was used in the geometrical computation of the colloidal silica' specific surface area, which was approximately 118.6 m² g⁻¹. Several diluted

silica sols were chemically analyzed and the silica concentration was approximately 0.5 kg dm^{-3} . The sols were prepared just before the beginning of the experiment by mixing a given volume, $\mu \text{ dm}^3$ order, of concentrated silica (as received) with 1 dm^3 of aqueous $1 \text{ mmol dm}^{-3} \text{ KNO}_3$ solution. The pH of the solution was adjusted using drops of concentrated HNO_3 and KOH . The sols pH's were fixed at 4, neutral and 10; this range of pH was considered to avoid its homocoagulation, which is expected occur approximately at pH 3 that correspond to its isoelectric point (IEP), and to avoid silica dissolution, which will mainly occur approximately above pH 10. Moreover, the pH of the common industrial effluents and wastewaters polluted with UFP lie within the experimental range. The neutral pH corresponds to the solution's pH that was obtained when the given volume of concentrated silica was added to the aqueous $1 \text{ mmol dm}^{-3} \text{ KNO}_3$ solution. Due to the small size of the silica particles the electrokinetic measurements (microelectrophoresis and laser doppled electrophoresis (14) and light scattering) are inapplicable. For this reason the ζ -potential of approximately 5 times bigger silica particles (15) were assumed to be representative of this sol, which is shown in figure 1.

The oil suspensions corresponded to oil-water emulsions, which were prepared just before the beginning of the experiment by mixing a given volume, $\mu \text{ dm}^3$ order, of n-Decane and 1 dm^3 of aqueous $1 \text{ mmol dm}^{-3} \text{ KNO}_3$ solution, drops of HNO_3 and KOH were used to adjust the pH. This mixture was mechanical emulsified for 10 minutes and then dispersed using an ultrasonic homogenizer for 30 minutes. The diameter of the oil drop was found to be approximately 500 nm by using the light scattering method. With this value the geometrical specific surface area of the emulsion was

Figure 1. ζ -potential curves of Silica particles, n-Decane emulsion and SF particles as a function of pH in 1 mmol dm^{-3} of KNO_3 solution. The isoelectric point of Silica particles, n-Decane emulsion and SF particles were found to be around pH 3.

computed to be approximately $16.5 \text{ m}^2 \text{ g}^{-1}$. The oil content in the emulsion was fixed at approximately 200 ppm.

The collection of oil-water emulsion was carried out in the pH range 3 to 11. The ζ -potential of silica, n-Decane and SF are shown in figure I as a function of pH. The SF particles used in the ζ -potential measurement were obtained by grinding in a ball mill during 24 h.

2.2 Preparation of the Collector Bed : A given amount of SF (15 to 75 g) was soaked in 0.75 dm^3 of aqueous $1 \text{ mmol dm}^{-3} \text{ KNO}_3$ solution for approximately 30 minutes. It was conducted to eliminate the air present in the SF, which produces zones of different flow rate and porosity inside the collector bed. This was followed by hand compactation of the SF inside a glass column to reach the porosity required. The porosity was fixed at 85% volume per volume (i.e. 15% v/v of the total bed's volume were occupied by SF) for the silica collection, and 85, 90 and 95% v/v for emulsion collection. These porosity values were set as above to minimize the trapping of particles by mechanical effects. Then the collector bed was rinsed with approximately 1 dm^3 of aqueous $1 \text{ mmol dm}^{-3} \text{ KNO}_3$ solution to remove particles and broken fibers from the bed, which were generated during compactation. The above step was carried out only for the silica collection experiments due to the presence of this oxide (SiO_2) in the collector's composition (SiO_2 in SF $\approx 48 \text{ wt.}\%$).

Since one the most important parameters of the collection process by using a column bed system is the bed, it was studied from 2 different points of view. The first one was by evaluating the effect of the bed porosity on the OIW collection efficiency. In this case a fixed amount of SF (15 g) was used. Variation of the porosity was achieved by controlling the collector bed's height. The second point of view was by evaluating the effect of the specific surface area ratio (SSAR) between SF and ultrafine silica on the silica collection efficiency. Several SSAR Were obtained by controlling the amount of SF (15 to 75 g) in the bed and the content of ultrafine silica in the sol. Table 1

Table 1 : Amount of slag fiber and silica used for each specific surface area ratio and pH of the sols.

Run	SSA _R	SF ¹ [g]	SiO ₂ [ppm]	Sol's pH
01	0.7610	15	189.8	3.99
02	3.098	15	46.65	3.99
03	6.156	25	39.13	4.02
20	10.23	25	23.54	10.04
04	10.44	25	23.07	4.01
10	13.54	50	35.58	6.14
05	15.06	50	31.99	3.96
21	18.70	50	25.76	9.74
11	18.79	50	25.64	5.91
06	23.01	50	20.94	3.99
12	24.81	50	19.42	5.75
22	31.43	50	15.33	10.03
13	45.59	75	15.85	5.54
14	61.10	50	7.885	5.57
23	81.59	75	8.857	10.01

¹The SF¹ specific surface area is $0.8 \text{ [m}^2 \text{ g}^{-1}\text{]}$

shows the SSAR used and the sols' pH as well.

2.3 Experimental Procedure: The experimental set up used for collection of ultrafine silica and oil-water emulsions are shown in figure 2 a) and b), respectively. During collection of ultrafine silica the sol was kept in an ultrasonic bath to avoid aggregation of UFP. During the collection of emulsion the above set up was not necessary due to its longer stability than ultrafine silica. Samples of the solution passed through the SF-collector bed were taken at different times, and analyzed by silicon and oil concentrations. The silica contents were computed by stoichiometric calculations. The pH of each sample was also registered. The linear velocities were fixed at 0.33 and 0.85 mm s^{-1} for ultrafine silica and emulsion experiments, respectively.

Figure 2. Schematic representation of the glass column systems used in the experimental work. a) for silica sol and b) for oil/water emulsion.

3. EXPERIMENTAL RESULTS

3.1 Collection of silica: Figures 3 to 5 summarize the collection efficiency as a function of the dimensionless time (θ) for acidic, neutral and alkaline environments, respectively, at different values SSAR. The collection efficiency was computed as $(C_o - C_i)/C_o$, where C_o indicates the initial concentration of silica and C_i indicates the silica concentration of the i^{th} sample in the outlet. The dimensionless time was computed as t_i/t_o , where t_i is the time of i^{th} sample and t_o is the time required for the solution to flow through the collector bed. t_o was found to be 0.17, 1.16, 3.15 and 6.23 min, by using Cu ions as indicator, when the SF in the bed was 15, 25, 50 and 75 g, respectively. The dissolved silica from SF was discounted from the C_i values, which was considered as the value found in the samples obtained before t_o . The highest collection (100%) was obtained at low pH when the SSAR was approximately above 4.3. Figure 6 a) and b) are the electron micrographs of the collector before and after this experiment, respectively. The collection efficiency decreased dramatically to approximately 2 to 6% and 3 to 10% for neutral and alkaline environments, respectively.

3.2 Collection of oil: Figures 7 to 9 summarize the collection efficiency at several pH's as a function of the dimensionless time for porosities 85, 90 and 95% v/v, respectively. Collection efficiency and dimensionless time were defined in 3.1. The highest collection occurred at pH 3 (95-99%), it decreased close to 70-80% at neutral values; while at high pH it reached around 5-10% only. The effect of porosity was negligible at low and neutral values of pH, while at high pH its increment produces a decrement in the efficiency.

Figure 3. Collection efficiency of ultrafine silica particles $((C_o - C_i)/C_o)$ as a function of the dimensionless time (θ) at several values of SSAR at acidic condition.

Figure 4. Collection efficiency of ultrafine silica particles $((C_o - C_i)/C_o)$ as a function of the dimensionless time (θ) at several values of SSAR at neutral condition.

Figure 5. Collection efficiency of ultrafine silica particles $((C_o - C_i)/C_o)$ as a function of the dimensionless time (θ) at several values of SSAR at alkaline condition.

Figure 6. Electron micrographs of the SF surface : a) before and b) after run 03.

Figure 7. Collection efficiency of n-Decane emulsion $((C_o - C_i)/C_o)$ as a function of the dimensionless time (θ) at several conditions of pH for 85% v/v of porosity in the SF bed.

Figure 8. Collection efficiency of n-Decane emulsion $((C_o - C_i)/C_o)$ as a function of the dimensionless time (θ) at several conditions of pH for 90% v/v of porosity in the SF bed.

Figure 9. Collection efficiency of n-Decane emulsion $((C_o - C_i)/C_o)$ as a function of the dimensionless time (θ) at several conditions of pH for 95% v/v of porosity in the SF bed.

4. DISCUSSION

The interaction between two solids in an aqueous medium is related to the total interaction potential, V_T , as a function of their separation distance, x . V_T corresponds to the summation of the London-van der Waals potential, $V_{A(x)}$, and to the overlapping of electrical double layer potential, $V_R(x)$, known as DLVO theory (16, 17).

For the condition of constant surface potentials the calculations of the total interaction energy between SF-UFP and between UFP-UFP were based on the plate-sphere and sphere-sphere models, respectively. Equations (1) and (2) were employed in the computation of the total interaction potential between SF and UFP, which were taken from Takiwa et al. (18) and Kuo and Matijevic (19).

$$V_R(x) = -\frac{A_{132}}{6kT} \left\{ \frac{2a(x+a)}{x(x+2a)} - \ln\left(\frac{x+2}{x}\right) \right\} \quad (1)$$

$$V_R(x) = \frac{\varepsilon a}{4} \left\{ (\phi_1 + \phi_2)^2 \ln(1 + \exp(-\kappa x)) + (\phi_1 - \phi_2)^2 \ln(1 - \exp(-\kappa x)) \right\} \quad (2)$$

A_{132} represents the Hamaker's constant for the system SF-H₂O-UFP, k is the Boltzmann's constant, T is the absolute temperature, a is the UFP's radius, x is the shortest separation distance between SF and UFP, ε is the dielectric constant, ϕ_1 and ϕ_2 are the SF and UFP' surface potentials (assumed as ζ -potentials), respectively, and κ is the Debye reciprocal length. Equations (2) and (4) as written implies e.s.u. units.

The total interaction potential between UFP-UFP was computed by using equations (3) and (4), which were taken from Hunter (20) and Hogg et al. (21).

$$V_A(x) = -\frac{A_{232}}{6\pi kT} \left\{ 1 + \frac{x}{2a+x} + \frac{x}{a} \ln\left(\frac{x}{2a-x}\right) \right\} \quad (3)$$

$$V_R(x) = \frac{\varepsilon a \phi^2}{2} \ln\{1 - \exp(-\kappa x)\} \quad (4)$$

A_{232} represents the Hamaker's constant for the system UFP-H₂O-UFP and ϕ represents the UFP' surface potential. In this case x correspond to the shortest separation distance between UFP.

A_{SF-H_2O-UFP} and A_{UFP-H_2O-UFP} were computed by equations (5) and (6), respectively, which were taken from Visser's work (22).

$$A_{132} = (\sqrt{A_{11}} - \sqrt{A_{33}})(\sqrt{A_{22}} - \sqrt{A_{33}}) \quad (5)$$

$$A_{232} = (\sqrt{A_{22}} - \sqrt{A_{33}})^2 \quad (6)$$

A_{11} , A_{22} and A_{33} represent the individual Hamaker's constants of SF-SF, UFP-UFP and water in vacuum, respectively. The computed values of A_{11} , A_{132} and A_{232} were summarized in table 2.

Table 2: Computed values for the Hamaker Constant in [J].

System	Value	Eq.
$A_{\text{SF-SF}}$	14.15E-20	7
$A_{\text{SF-H}_2\text{O-SiO}_2}$	3.26E-20	5
$A_{\text{SF-H}_2\text{O-Oil}}$	2.39E-21	5
$A_{\text{SiO}_2\text{-H}_2\text{O-SiO}_2}$	3.83E-20	6
$A_{\text{Oil-H}_2\text{O-Oil}}$	9.95E-22	6

Due to the no existence of individual Hamaker's constants for polyoxide materials, it was necessary to define a mechanism that can provide a value for SF, which should take into account the contribution from each oxide present in the SF to the global Hamaker's constant. As a first approximation, without experimental verification, the Hamaker's constant for SF was estimated by equation (7),

$$A_{\text{SF-SF}} = \prod_{i=1}^n A_{11i}^{\chi_i} \quad (7)$$

χ_i and A_{11i} represent molar fraction and individual Hamaker's constant of the i^{th} oxide present in the SF composition, respectively. The main oxides present in the SF are SiO_2 , MgO , Al_2O_3 , Fe_2O_3 and CaO , which standardized mass percentages are 51.09, 25.68, 20.26, 1.67 and 1.31%, respectively. All individual Hamker's constants were taken from Visser's tabulation (22).

Figures 10 and 11 summarize the total interaction potential curves, V_T , for the systems SF- SiO_2 and SF-emulsion, respectively. This figures also include V_T for the system UFP-UFP. In both figures solid and dashed lines indicate SF-UFP and UFP-UFP interactions, respectively.

When the energy barrier, $V_{T\text{max}}$, is larger than 25 kT it is widely accepted that coagulation or attraction is prevented (17). On the other hand, when there is no barrier, i.e., $V_{T\text{max}} \leq 0$, rapid coagulation or attraction may take place (17, 20).

Figure 10 shows that homocoagulation of the ultrafine silica may occur only at pH 4, $V_{T\text{max}} \approx 0$. Furthermore, the attraction between SF and ultrafine silica was also favored at this pH ($V_T < 0$), thus, the collection of ultrafine silica onto the SF' surface was expected, which is in agreement with the experimental results shown in figure 3 when the SSAR was above 2.1. Figure 10 also show that the homocoagulation will not occur in neutral and alkaline conditions because $V_{T\text{max}} > 45$ kT. On the other hand, the attraction SF-UFP may occur but not spontaneously because $0 < V_{T\text{max}} < 25$ kT. Since $V_{T\text{max}}$ increases with pH, the collection is expected to decrease; the results in figures 4 and 5 show that the collection decreased in comparison with those found in acidic condition. The extremely low collection found at both neutral and alkaline conditions may correspond to a certain grade of dissolution of silica particles, which may also occur in acidic condition. A complete study of the dissolution of silica is available on the Iler's work (23). In alkaline condition, collection

Figure 10. Total potential energy (V_T) curves for $\text{SiO}_2\text{-SiO}_2$ (solid line) and SF-SiO_2 (dashed line) interactions at different pH conditions as a function of the separation distance (x).

Figure 11. Total potential energy (V_T) curves for O/W-O/W (solid line) and SF-O/W (dashed line) interactions at different pH conditions as a function of the separation distance (x).

efficiencies were slightly higher than neutral pH, when similar SSA_R Were used, which is not in agreement with the predictions of DLVO theory. This discrepancy may be related to chemical effects, which are not incorporated in this theory. The effect of SSA_R is also not considered; nevertheless, its effect on the overall collection process is evident. The increment in SSA_R Produces an increment in the efficiency. Therefore, there are aspects of the UFP collection by SF that can not be explained by the interaction energy between SF and UFP. These aspects shall be related with dissolution of the collector, even in atomic order layers, as will be explained later.

Figure 11 shows that the homocoagulation of oil-water emulsion may only occur at pH 3 because $V_{Tmax} \approx 0$, and for $pH > 3$ the energy barrier increased and is more than 500 kT in neutral and alkaline conditions. The attraction SF-emulsion was favored only at pH 3 ($V_T < 0$); over it the energy barrier arise more than 250 kT. This was in agreement with experimental results shown in figures 7 to 9, where the highest collection was obtained at pH 3. Nevertheless, when the system was at pH 5 the collection efficiency reached approximately 75%. Even at pH between 9 and 11, when the energy barrier was highest (> 1000 kT), there was collection. Both cases are not in agreement with the DLVO theory. Therefore, the performance of SF as a collector of ultrafine silica and O/W emulsion can not be sufficiently explained only by the total potential analysis.

To comprehend the effect due to the chemical dissolution, even in atomic order layers, of the collector on the collection phenomena it is necessary to understand what it is occurring in the collector-solution interface at different conditions. Figure 12 shows a schematic view of the effect on the SF surface in acidic and alkaline aqueous environments.

The SF surface is formed by both positive and negative sites as shown figure 12; thus, when the SF is placed in acidic condition its positive sites makers (Mg, Al, Ca, and Fe) quickly pass to the solution phase and negative sites maker (Si) mainly remain on the surface due to their different dissolution ratios, as was demonstrated in our previous work (13). To maintain the electroneutrality condition protons are adsorbed on the SF surface, forming a static plane, surrounding fibers. The global electroneutrality is reached approximately at pH 3, which correspond to SF's IEP, measured by electrophoresis of SF as particles. On the other hand, when the SF is placed in alkaline conditions its negative sites maker (Si) passes to the solution phase and the positive sites makers remain on the surface. The Si dissolved will be polymerized by OH^- ions and, simultaneously, OH^- ions will adsorb onto the SF surface. The hydroxyl ion concentration required to reach both thermodynamic (Si forming polymers with OH^-) and electrical (positive sites of the SF' surface neutralized by OH^-) equilibrium, is close to $10^{-3.2}$ mol dm^{-3} g^{-1} of SF, which correspond to the point of zero charge (PZC) of SF, measured by microtitration of SF as particles and as fibers.

Figure 13 shows the dissolution ratio of SF as a function of initial pH at 25 °C (13). The dissolution ratio was defined as the ratio between the concentration (in ppm) of a given element in the bulk solution and in the SF before experiment. This figure summarizes the behavior of SF in aqueous media.

Baes and Mesmer (20) indicated that mainly simple cations, type M^{+n} are dissolved when oxides are placed in simple acid solutions. In case of the SF these are mainly Mg^{+2} , Al^{+3} and Ca^{+2} ions; which are well-known to function as flocculating agents. This fact is interpreted as the dissolved fraction of the collector, even in atomic layers, acts as a flocculating metal cations between the SF surface and UFP, and, in less magnitude, between UFP in the nearest of the collector surface. In

Figure 12. Schematic representation of the effect on the SF surface of the aqueous media. In acidic environment: all elements are passing to the solution phase; however, by difference in their dissolution ratios mainly Si remain on the surface. In alkaline environment: mainly Si is passing to the solution phase, being polymerized by OH^- , thus the positive sites on the SF surface increases.

Figure 13. Dissolution ratio of Si, Mg, Al, Ca and Fe at 25 °C as a function of initial pH in aqueous 10^{-3} mol dm KNO_3 solution. Dissolution ratio of X = $\frac{[\text{Xppm}] \text{ soL}}{[\text{Xppm}] \text{ SF}}$ (13).

the same way as the flocculation of silica particles by Na^+ (23). Even, if silica particles are partially dissolved they shall be flocculated and collected by SF.

At neutral and alkaline conditions the dissolved fraction of the collector becomes negligible (13), i.e., there are no cations that can act as flocculating agents. The experimental results show collection, when the SSA_R increased. Since there is a negligible dissolution of the collector, the positive sites makers remain in the SF' surface where the negatively charged particles shall be collected, moreover, the increase in the SSA_R increases the positive sites, i.e., the collection efficiency. On the other hand, at these conditions the possible dissolved fraction of silica particles can not be flocculated and collected, which shall produce the low collection efficiencies found.

The slight higher collection of ultrafine silica observed at pH 10 is expected due to polymerization of the silica particles by OH^- ions (25), which may produce silica network and shall be trapped by the SF-collector bed.

The collection of oil found in neutral and alkaline conditions may be explained as follows : since the oil's drops are deformable spheres they can spread onto the SF surface generating not point contact but areas of contact. This film of unknown thickness may partially fill-up the interstice of the first layers of the SF bed, which increase as the sol is fed, thus, the oil content in the outlet decreases and the efficiency increases. Moreover, the high molecular weight of the oil and large volume of the drop in comparison with ultrafine silica may produce a hydrodynamic effect related to the speed and energy of the particles during their flowing within the bed, as a synergism, to

overcome the energy barrier favoring collection. Further experiments would be required to elucidate this point.

5. SUMMARY

The collection of two different ultrafine particles by using the SF-collector bed method was investigated. The main results can be summarized as follows :

- i) The slag fiber-collector bed method is promising to be a very effective system to collect ultrafine particles of silica and oil-water emulsion in acidic environment from low concentrated suspensions.
- ii) The collection phenomenon of ultrafine silica was interpreted in terms of the DLVO theory, which was complemented by effects regarding the dissolved fraction of the SF. This fraction acted as flocculating metal cations between SF and UFP.
- iii) The collection phenomenon of oil emulsion was partially explained by the DLVO theory, which was complemented by effects regarding the deformable character of the oil's drops and the energy acquired by the emulsion due to its high molecular weight and drop's volume during its flowing through the SF collector bed.
- iv) The porosity of the collector bed, in the range studied, seems no play a relevant role in the collection efficiency at low pH.

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