Growth of Colloidal Particles in an Electrokinetic Separation Technique

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Abstract

The growth of colloidal particles of alumina in an aqueous suspension as it passes through an electric field is investigated. It is shown that the particle growth depends on the time the colloidal particle spends in the electrical field and is independent of the flow of the suspension. The relevance of this effect in the clarification of liquids without any additives is pointed out.

INTRODUCTION

Separation of colloidal particles from a suspension in aqueous and nonaqueous media is of importance in several applications like water clarification (1), coal liquefaction (2), effluent treatment (3), etc. In addition to conventional separation techniques like coagulation, flocculation, sedimentation, and flotation, modern methods such as electrokinetic techniques have recently been successfully attempted (4). In some situations there is need for removal of colloidal particles from the primary liquid medium without contaminating with additives such as coagulants. One such case is the clarification of heavy water used as coolant and moderator in nuclear reactors (5). The utility of the electrokinetic technique in this case has been discussed by Boyd (6). Recently the group lead by Wasan at IIT, Chicago, has made valuable contributions to the use of these techniques in the field of coal liquefaction (7, 8), and Verdegan has demonstrated the use of this technique for petroleum oils (9).

The basic characteristic that is exploited in these techniques is the charge on the colloidal particle. The colloidal dispersion is passed through an electric field and the charged colloidal particle migrates to the oppositely charged electrode while the clear liquid moves through the other electrode (which is porous) out of the system. Such a simple-minded description hides several of the complex phenomena occurring at the electrode–colloid interface which are crucial for a successful separation. Some of the phenomena are the adherence and detachment of collodial particles from the electrode during the flow of liquid, the growth of the colloidal layer at the electrode, and the growth of individual particles at the electrode due to the discharge of the surface charge. While the first two phenomena have been discussed (*10*), there does not seem to be any study of the growth of particles at the electrode. In the present work we address ourselves to this aspect.

EXPERIMENTAL DETAILS

The colloidal dispersion was prepared by discharging two aluminum electrodes in water. The resulting colloidal dispersion was aged at 70°C in an oven for 5 h. This dispersion was stable, and it did not coagulate for several days. This concentrated stock dispersion was diluted so that transmittance was about 82% at the start of each experiment. When filtered through filter paper with a pore size of 5 μm, this dispersion did not show any increase in transmittance, indicating that the colloidal particles were less than 5 μm.

The experimental set up used is shown in Fig. 1 and consisted of a breaker containing the feed, a slurry pump (with variable speed), the electrode assembly, the receiving beaker, and the voltage source. The feed was pumped through the electrode assembly into the beaker at various flow rates. When all the feed liquid was completely transferred to the receiving beaker, it constituted a cycle. This liquid was again poured back into the feed tank for the next cycle. A sample was taken at the end of each cycle and filtered through the 5 μm filter. The transmittance was measured at 390 nm. The linearity of the logarithm of transmittance at 390 nm with alumina content was shown by Hatcher and Rae (*5*). A transmittance of 82%, mentioned above, corresponds to about 10 μg/mL aluminum. The electrode assembly consisted of two concentric stainless steel tubes of 25 cm length. The inner tube had an outer diameter of 0.315 cm, and the inner diameter of the outer tube was 0.440 cm. Thus, the gap between the electrodes was 0.0625 cm. The electrical contact between the
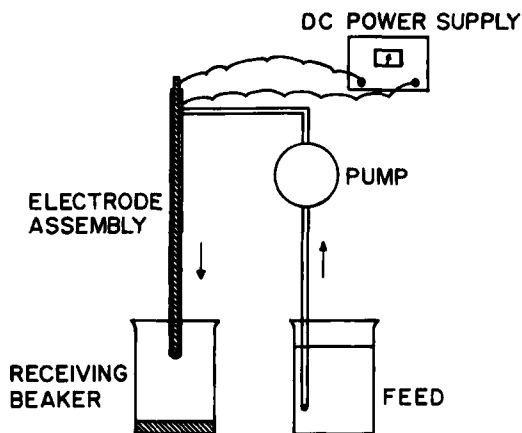
FIG. 1. The experimental set-up used for the separation technique.

electrodes was avoided by Teflon spacers at the top and the bottom of the tubes. A dc potential of 2.8 V was applied to the cell with the central tube as the positive electrode. This voltage was chosen to keep the hydrogen evolution to a minimum, so that void formation on the electrode due to gas bubbles was avoided.

RESULTS

Experiments were performed on 12 samples. Figure 2 shows typical results for 4 of the samples. The transmittance of the suspension filtered through a 5-μm filter paper at the receiving beaker after each cycle is shown. The transmittance of the dispersion as it came out of the electrode assembly was not steady due to large sedimenting particles. However, after filtration through the filter paper, the steady transmittance was measured. It should be pointed out that only the sample taken for analysis was filtered while the remaining liquid was transferred to the feed beaker for the next cycle. Without application of an electric field to the assembly, the transmittance remained constant after each cycle. However, after application of the field, the transmittance increased after each cycle, indicating growth of the particles. It can be seen that as the flow rate increases, the number of cycles required for the particles to grow to dimensions greater than 5 μm also increases. When the flow rate was
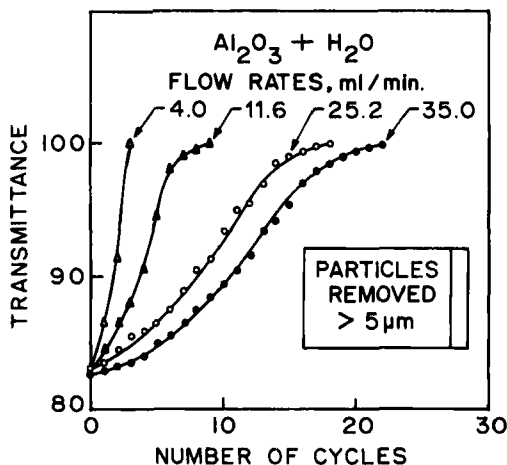
FIG. 2. The rate of removal of particles which have grown above 5 μm in size. The rate of removal slows down at higher flow rates.

smaller than 4 mL/min, the particles adhered to the electrode and came off as lumps once the field was cut off.

If Q is the volumetric flow of the feed, then the residence time of the liquid, τ, in the electrode assembly during each cycle is given by

$$\tau = \pi(R^2 - r^2)l/Q \tag{1}$$

where R is the inner radius of the outer tube, r is the outer radius of the inner tube, and l is the length of the tube. If n is the number of cycles required for the particles to grow to dimensions larger than 5 μm, then $n\tau$ gives the total time spent by the particles in the electric field to grow to dimension of at least 5 μm. Table 1 lists the various values of Q, T, n, and the average current. Figure 3 is a plot of total residence time $n\tau$ against the flow rate Q. It is seen that the flow rate increases by a factor of 9 while the total time remains almost constant, indicating that the size of the particle depends only on the time spent in the electrode assembly.

CONCLUSIONS

It is shown that the particle size of a colloid increases on passing through an electric field. The time spent by the colloidal solution in the

TABLE 1

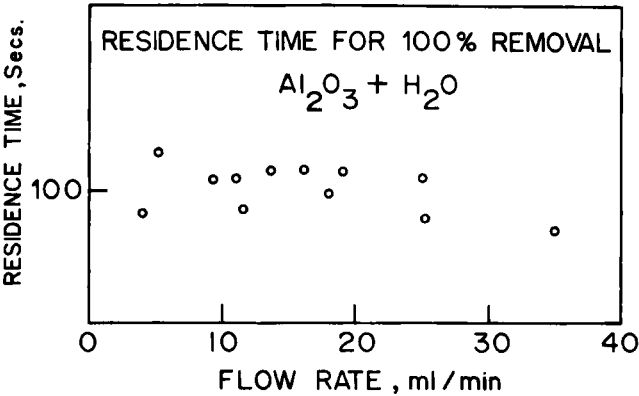| No.	Q (mL/min)	τ (min/cycle)	n (cycles)	I (mA)
1	4	0.46	3	2.64
2	9.2	0.20	9	2.85
3	11.6	0.16	9	3.07
4	13.5	0.14	14	2.9
5	18	0.10	16	2.67
6	25.2	0.07	18	2.85
7	35	0.05	22	2.39
8	5	0.37	6	4.7
9	11	0.17	11	4.3
10	16	0.12	17	4.0
11	19	0.10	21	4.2
12	25	0.07	26	3.9

FIG. 3. The residence time required for the growth of particles to 5 μm is independent of the flow rate and is dependent only on the time spent in the electrode region.

electric field appears to be the main parameter controlling the growth of the particle, which is independent of the flow rate.

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