SEPARATION SCIENCE AND TECHNOLOGY, 37(13), 3053–3064 (2002)

EXPERIMENTAL STUDIES ON THE EFFECT OF ELECTRODE CONFIGURATION IN ELECTROFILTRATION

Ayten Genç[1] and İsmail Tosun[2,*]

[1]Department of Environmental Engineering, Zonguldak Karaelmas University, Zonguldak 67100, Turkey
[2]Department of Chemical Engineering, Middle East Technical University, Ankara 06531, Turkey

ABSTRACT

Results from the electrofiltration of anatase (TiO_2) particles in a water suspension and using three different electrode configurations are presented. The three electrode configurations studied were spot, foil, and mesh. For the first two configurations, the electric field was perpendicular to the direction of flow while for the mesh configuration it was opposite to the direction of flow. The percent gain volume filtrate and power consumption were measured for each electrode configuration. For a given percent gain volume filtrate, it was observed that the foil electrode configuration consumes the least power.

Key Words: Filtration; Electrofiltration; Electrode configuration

*Corresponding author. E-mail: itosun@metu.edu.tr

INTRODUCTION

Electrofiltration is a technique that has been developed to enhance the performance of traditional pressure filtration. The application of an electric field to slurry retards the formation of cake at the surface of the filter medium and thereby increases the filtrate flow rate. Two electrokinetic phenomena are important in electrofiltration, namely, electrophoresis in which solid particles migrate towards an oppositely charged electrode, and electroosmosis, which enhances liquid flow through the cake and the filter medium.

Much research has been conducted on electrofiltration in cross-flow filter systems where the slurry with a high velocity flows tangentially over the filter medium. Depending on the geometry of the filter, different electrode configurations have been studied. For example, in the work of Visvanathan and Ben Aim,[1] Bowen and Sabuni,[2] and Chuang and Hsu[3] parallel rectangular plate electrodes were used, while in the work of Tarleton,[4] twin concentric cylinders were investigated.

In the case of electrofiltration in dead-end filter systems, the most common electrode configuration to have been studied is that of two plates, placed at either end of the filter chamber.[5,6] In the electrophoretic separation experiments of Majmudar and Monahar,[7] a different electrode configuration was used in which six carbon rods were placed radially about a central cathode. Recently, Ho and Chen[8] used a rotating anode in an electroosmotic dewatering process.

The primary objective of the aforementioned studies was to determine experimentally the improved filter performance of electrofiltration over standard pressure filtration. In none of these studies were different electrode configurations compared. In the present work, a number of different electrode configurations in the electrofiltration of an anatase–water suspension are studied and compared on the basis of percent gain volume filtrate. The power required for generating the different electric fields is also discussed.

EXPERIMENTAL APPARATUS AND PROCEDURE

For each of the three electrode configurations studied, the same experimental arrangement and procedures were used. Slurry at a constant pressure of 1.7 atm was forced through a filter chamber having a cellulose acetate membrane with 0.2 μm pore size for a fixed period of time (30 min). During the experiments, the position and the surface area of the membrane (37.39 cm^2) were not changed.

The slurry used for the experiments was 1% by weight of anatase (TiO_2) particles (average particle size 0.3 μm) in water. The percent gain volume filtrate was determined by measuring the mass of the filtrate collected. These measurements were performed at 10-sec intervals during the experiments. The power consumption was determined by measuring the current flow through the electrodes while the applied voltage was kept constant. Current measurements were taken at 60-sec intervals throughout the experiments. For each electrode configuration studied, the filtration experiments were performed when the electrodes were placed in the filter chamber and no electricity was supplied.

For the spot and foil configurations, experiments were conducted at four different voltages: 0, 50, 100, and 200 V; the case of zero voltage being equivalent to standard pressure filtration. For these two electrode configurations, the electrode geometry was kept constant. For the mesh configuration, on the other hand, the separation distance between electrodes was also considered as a variable. Two different separation distances were considered: 3 and 5 cm. Results from an experiment in which the separation distance was varied while keeping the voltage constant at 200 V were also reported.

Experimental Set-Up

The experimental set-up consisted of a slurry tank, a filter chamber, a wash tank, a compressor and air tank, a DC power supply (400 V and 10 A) with ampere meter, and an electronic balance connected to a computer schematically as shown in Fig. 1. The filter chamber was made of a 10 cm length of cylindrical plexiglas with an 8 cm internal diameter. The three electrode configurations are now described.

Spot Electrode Configuration

Two groups of three steel spot electrodes (diameter = 2 mm) were inserted through the cylindrical wall of the filter chamber at a radial distance of 2.5 cm. The two groups were separated by 180° in the circumferential direction and spaced 2 cm apart in the axial direction as shown in Fig. 2. The electric field generated by such an electrode configuration is perpendicular to the direction of the slurry flow.

Foil Electrode Configuration

Two aluminum foils were arranged to line the entire length of the inner surface of the filter chamber, with a 3-cm circumferential gap between them as

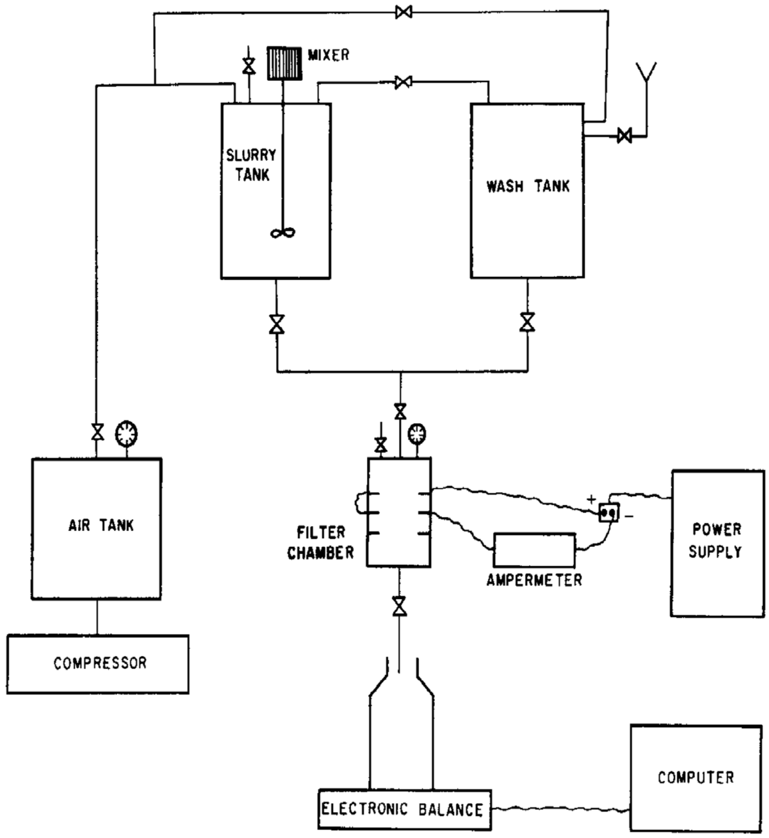


Figure 1. Experimental set-up.

shown in Fig. 3. The electric field generated is again perpendicular to the direction of the slurry flow.

Mesh Electrode Configuration

A stainless steel plate was used as the cathode and was placed 1 cm below the filter medium. The anode was a constructed wire mesh by using 284-cm long steel wire (see Fig. 4) and its axial position within the filter chamber was adjustable. This configuration is similar to that used by other workers[5,6] but differs in that a wire mesh is used rather than a solid plate.

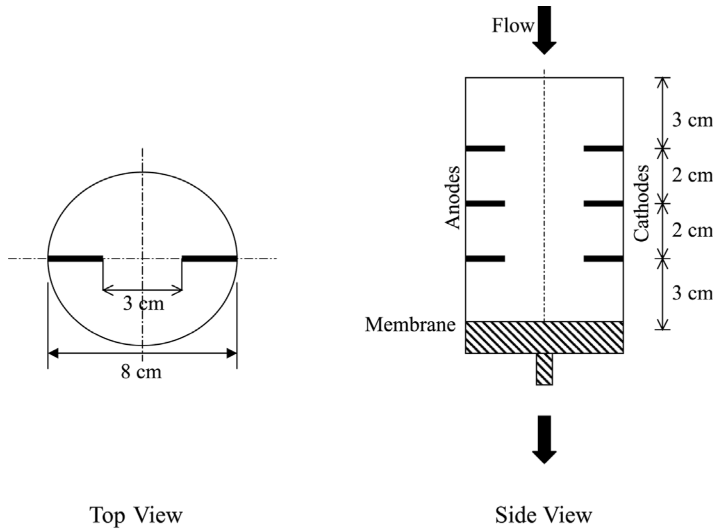


Figure 2. Spot electrode configuration.

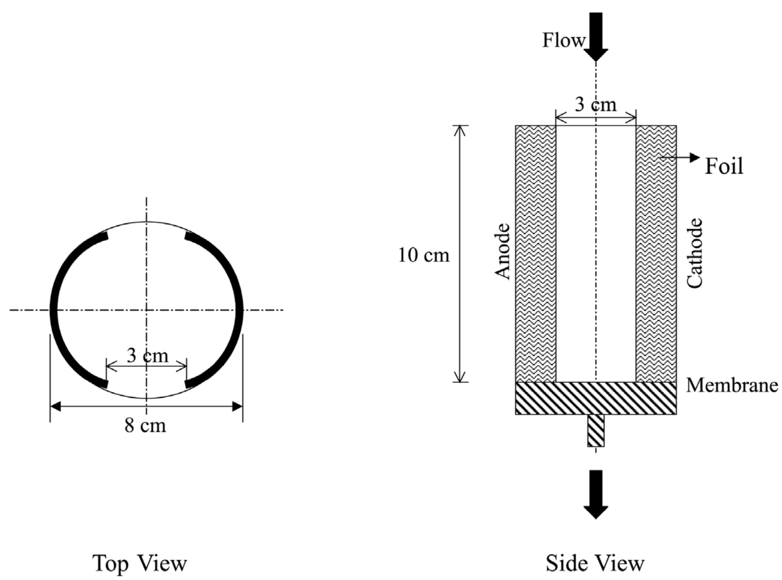


Figure 3. Foil electrode configuration.

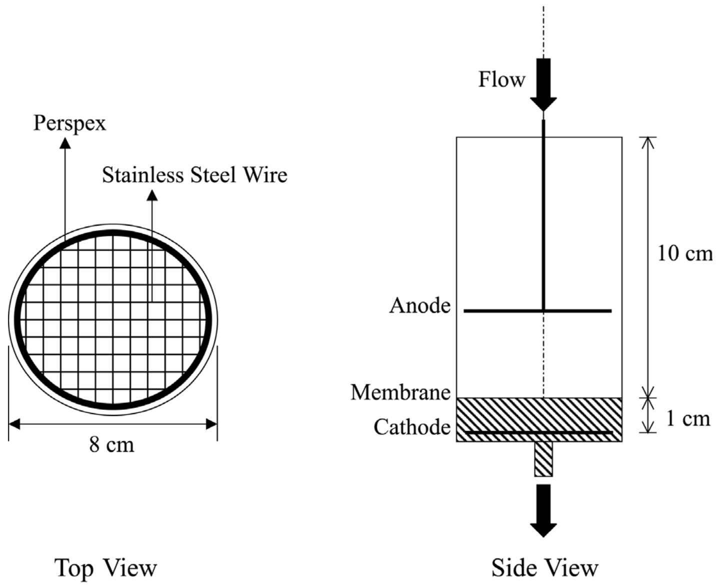


Figure 4. Mesh electrode configuration.

The electric field generated by this electrode configuration is in the opposite direction to the slurry flow.

RESULTS AND DISCUSSION

The evaluation of the electric field strength depends on the electrode configuration. In the case of the wire mesh and the spot electrode configurations, the electric field strength, E, is evaluated by dividing the applied voltage, V, to the distance between electrodes, L, i.e.,

$$E = \frac{V}{L} \tag{1}$$

Therefore, for both electrode configurations, it is assumed that the generated electric field is uniform in the filter chamber. In the real case, however, the current density at different parts of the electrodes will vary and, therefore, the electric field will not be uniform.

The distance between the aluminum foil electrodes changes in the radial direction with a concomitant variation of the electric field in the radial direction.

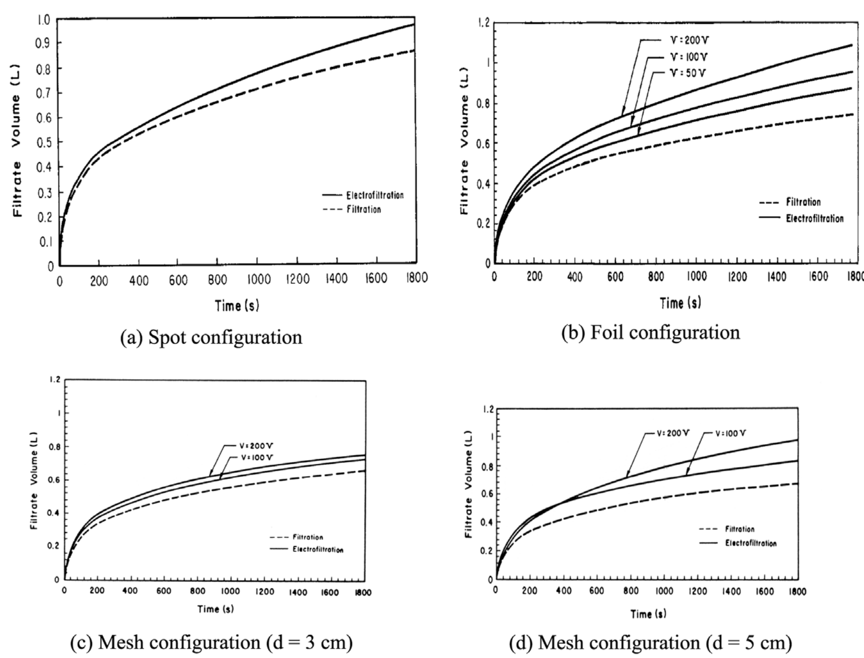
The radial variation of the electric field strength can be obtained by solving Laplace's equation in the cylindrical coordinate system and the result is

$$E = \frac{4V}{\pi R}\sum_{n=1}^{\infty}\left(\frac{r}{R}\right)^{n-1}\sin n\theta \tag{2}$$

where R is the inner radius of the filter chamber.

As a result of the nonuniformity of the electric field strength for the aluminum foil electrode configuration, it was decided to compare the studied electrode configurations on the basis of the applied voltage values. The results will therefore be presented in the form of curves of filtrate volume (V_F) as a function of time (t) for a given constant applied voltage.

The curves of filtrate volume as a function of time for the different voltages studied and for the three electrode configurations are shown in Fig. 5. In these graphs, the dashed lines show the filtrate volume obtained for zero applied voltage. For the mesh electrode configuration, the curves for 0 and 50 V are virtually coincident and for this reason, those for an applied voltage of 50 V are not given.



(a) Spot configuration
(b) Foil configuration
(c) Mesh configuration (d = 3 cm)
(d) Mesh configuration (d = 5 cm)

Figure 5. Filtrate volume vs. time curves for three electrode configurations.

In order to quantify the increase in efficiency of electrofiltration over standard pressure filtration, the percent gain volume filtrate, as defined by Tarleton,[4] is used:

$$\text{Percent gain volume filtrate} = \left(\frac{V_F^* - V_F}{V_F}\right)100 \qquad (3)$$

where V_F^* and V_F are the total filtrate volumes collected at 1000 sec with and without the application of an electric field, respectively.

For the spot electrode configuration, the curves for the three different voltages are very close to the curve for zero applied voltage. For this reason, only the curve for 200 V is shown in Fig. 5(a). The percent gain volume filtrate for an applied voltage of 200 V is found to be 7.8%. In further studies reported by Genç,[9] the number of active electrode pairs was varied and it was found that this had no significant effect on the result reported in this paper.

The filtrate volumes obtained for the foil configuration at three different applied voltages are shown in Fig. 5(b). It is seen that the application of an electric field results in a significant increase in the filtrate volume for this electrode configuration. The percent gain volume filtrate for an applied voltage of 200 V is found to be 38%.

The curves for the mesh configuration are shown in Fig. 5(c) and (d) for the electrode separation distances of 3 and 5 cm, respectively. For an applied voltage of 200 V, the percent gain volume filtrate are 23 and 50%, respectively, for separation distances of 3 and 5 cm. Although the percent gain volume filtrate values for the same applied voltage vary depending on the electrode configuration used in the experiments, a common observation can be reached by analyzing the results of Fig. 5(a)–(d), i.e., an increase in the applied voltage causes an increase in the filtrate volume. This observation coincides with the studies on the electrofiltration in the literature[2,4,5] and is usually explained as the result of improvement in the migration of solid particles, and electroosmosis through the cake and the filter medium due to the electric field.

It is clear from the results that the electrode separation distance is a significant factor affecting the percent gain volume filtrate for the wire mesh electrode configuration. For this reason, a further graph showing curves of filtrate volume as a function of time for a constant voltage of 200 V and for electrode separation distances of 3, 4, 5, 6, and 8 cm is given in Fig. 6. The values of percent gain filtrate volume for these electrode separation distances (L) are compared with those for each of the other electrode configurations in Table 1.

It is observed from Table 1 that the values of percent gain filtrate volume show a sharp increase with an increase in the separation distance up to $L = 5$ cm. For the values of L higher than 5 cm, altering L has almost no effect on the values of percent gain volume. According to Eq. (1), the corresponding values of electric

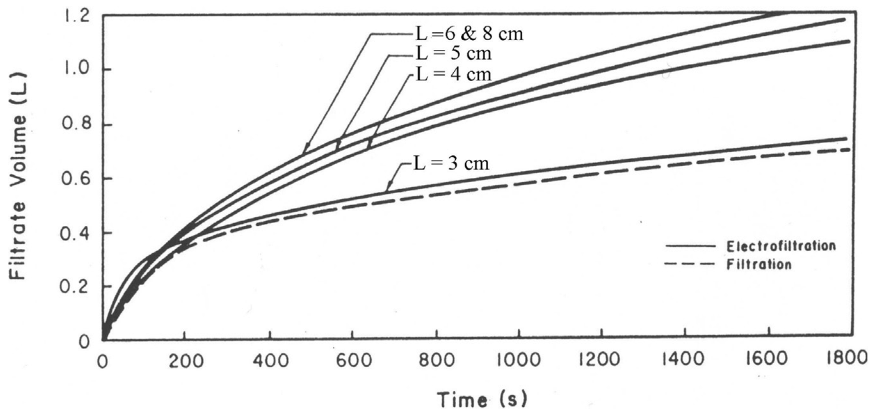


Figure 6. Filtrate volume vs. time curves for the mesh electrode configuration.

field strengths for $L = 3$ and $L = 5$ cm are 66.7 and 40 V/cm, respectively. Despite this decrease in the electric field strength, high filtrate volumes were obtained at $L = 5$ cm. This fact is explained on the basis of the migration of solid particles in the presence of electric field. As it was stated earlier, L was adjusted by changing the position of the anode electrode in the filter chamber. With the increase in L, the anode electrode gets away from the filter medium, hence the volume of slurry that is exposed to the electric field increases. Therefore, more solid particles move away from the filter medium and accumulate around the anode electrode. This causes a decrease in solid concentration of the slurry filtered. For the values of L greater than 5 cm, it seems that the generated electric field strengths are not high enough to migrate and accumulate solid particles around the anode electrode to provide an additional decrease in the solid concentration of the slurry.

When the filter medium is placed between the electrodes, another effect caused by the electric field is electroosmosis, i.e., the movement of a liquid relative to a stationary charged surface induced by an electric field. It is known

Table 1. Percent Gain Volume Filtrate Values for All Electrode Configurations ($V = 200$ V)

			Mesh L (cm)				
Electrode Configuration	Spot	Foil	3	4	5	6	8
% Gain	7.8	38	23	43	50	51	53

that under the same operating conditions, the electroosmotic flow of liquid is directly proportional to the electric field strengths.[2,4,6] Therefore, the electroosmotic flow of liquid through the filter medium and the cake decreases with the increase in L.

During the electrofiltration experiments, for the three studied electrode configurations, a slight increase in the temperature of slurry had been observed. On the other hand, the formation of gas bubbles was only seen at the foil electrodes.

On the basis of the results shown in Table 1, it is evident that the spot electrode configuration performs least well. Comparing the results for the foil with the mesh electrode configurations shows that while the foil configuration performs better than the mesh configuration for small separation distances, the reverse is the case for large separation distances.

While the percent gain volume filtrate is an important parameter for judging the efficiency of an electrode configuration, it is not the only one. The power consumed in the system is also important. It is necessary to point out that the present power consumption analysis for comparing the electrode configurations is preliminary because some of the important parameters in the design of an electrode configuration such as the electrode separation distance are not included in the calculations.

The power consumption is assessed by determining the work required to obtain a fixed filtrate volume and is calculated in the following manner.

The total work required in electrofiltration is the sum of the pump work to force the liquid through the filter medium, W_p, and the work required to generate the electric field within the filter chamber, W_e. These work terms are determined as

$$W_p = V_F \Delta P \tag{4}$$

$$W_e = VI\Delta t \tag{5}$$

where V_F is the filtrate volume, ΔP the pressure difference across the filter medium, V the applied voltage, and I the average value of the current over the time interval Δt.

For a constant filtrate volume and applied pressure, the pump work will be the same for all electrode configurations. The work required to generate the electric field, on the other hand, will vary between the different configurations. The total work required to obtain a filtrate volume of 862 cm^3 is compared for the foil electrode configuration and for the mesh electrodes with a separation distance of 8 cm. The time taken to obtain this filtrate volume was 1000 and 960 sec, respectively, for the two configurations. The average current flowing during these periods was determined as 7.05 and

30.2 mA, respectively. Thus, for an applied voltage of 200 V, the electrical work required by each configuration is:

$$W_e = \begin{cases} (200)(0.0302)(960) = 5798\,\text{J} & \text{for wire mesh electrodes} \\ (200)(0.00705)(1000) = 1410\,\text{J} & \text{for aluminum foil electrodes} \end{cases}$$

These calculations show that the electrical work for the mesh electrode configuration is almost four times greater than that required by the foil configuration.

CONCLUSIONS

In terms of the percent gain volume filtrate alone, the mesh electrode configuration is shown to perform better than the spot and foil configurations. For this configuration, the percent gain volume filtrate is seen to be a function of the electrode separation distance. However, the percent gain volume filtrate is not the only criterion that may be used in assessing the performance of an electrode configuration. Energy consumed in filtration can be equally important. For the same percent gain volume filtrate value, the foil configuration is shown to consume less energy than the mesh configuration. Thus, based on both the percent gain volume filtrate and the power consumption values, the foil electrode configuration is shown to be the most efficient electrode configuration amongst those to have been studied in this paper.

ACKNOWLEDGMENTS

This work was supported by the Turkish Scientific and Technical Research Council (TUBITAK) Grant KTCAG-100.

REFERENCES

1. Visvanathan, C.; Ben Aim, R. Application of an Electric Field for the Reduction of Particle and Colloidal Membrane Fouling in Cross-Flow Microfiltration. Sep. Sci. Technol. **1989**, *24*, 383–398.
2. Bowen, W.R.; Sabuni, H.A.M. Electrically Enhanced Membrane Filtration at Low Cross-Flow Velocities. Ind. Eng. Chem. Res. **1991**, *30*, 1573–1579.
3. Chuang, C.J.; Hsu, C.W. Hydrodynamics in a Flat-Plate Crossflow Filter and Particle Trajectory with Electric Fields Imposed on the Filter. J. Chem. Eng. Jpn. **1998**, *31*, 407–416.

4. Tarleton, E.S. How Electric and Ultrasonic Fields Assist Membrane Filtration. Filtr. Sep. **1988**, *30*, 402–406.
5. Moulik, S.P. Physical Aspects of Electrofiltration. Environ. Sci. Technol. **1971**, *5*, 771–776.
6. Iritani, E.; Ohashi, K.; Murase, T. Analysis of Filtration Mechanisms of Dead-End Electroultrafiltration for Proteinaceous Solutions. J. Chem. Eng. Jpn. **1992**, *25*, 383–388.
7. Majmudar, A.A.; Monahar, C. Electrophoretic Separation of Dilute TiO_2 Suspension. Sep. Sci. Technol. **1994**, *29*, 845–854.
8. Ho, M.Y.; Chen, G. Enhanced Electro-osmotic Dewatering of Fine Particle Suspension Using a Rotating Anode. Ind. Eng. Chem. Res. **2001**, *40*, 1859–1863.
9. Genç, A. Effect of Electrode Configuration in Electrofiltration. Ph.D. Thesis, Middle East Technical University, Ankara, Turkey, 1996.

Received September 2001
Revised January 2002