STUDIA UNIVERSITATIS BABEŞ-BOLYAI, CHEMIA, XLVI, 1-2, 2001

ELECTROFILTRATION. THE INFLUENCE OF AN ELECTRICAL FIELD ON FILTRATION

A. GHIRISAN[*], K. WEBER[**] and W. STAHL[**]

**Faculty of Chemistry and Chemical Engineering, "Babes-Bolyai" University of Cluj-Napoca, Romania*
***Institute of Mechanical Process Engineering and Applied Mechanics, University of Karlsruhe (TH), Germany*

ABSTRACT. The combination of mechanical and electrical filtration was examined on a new laboratory filtration equipment (with a double-sided filtration cell) at the University of Karlsruhe, Germany. This method seems to lead to enhance of the filtration kinetics. The electrofiltration experiments with quartz sand (average particle size $d_{50\%} = 2\ \mu m$) in tap water of Karlsruhe (conductivity $\lambda \cong 700\ \mu S/cm$) showed that the electrokinetic effects (electrophoresis and electroosmosis) accelerate the kinetic of the pressure filtration. However, on the residual moisture the electrical field has only a very small influence (the residual moisture remains as in the case of simple pressure filtration around 33-35%).

KEYWORDS: electrofiltration, electrokinetic effects, electroosmosis, electrophoresis, and pressure filtration.

INTRODUCTION

The separation of solids from liquids by filtration may be divided into three broad areas of interest:

1. *Surface filtration* of dilute suspensions where the liquid is usually the desired product.
2. *Depth filtration* in which small contaminants are retained in the filter medium itself.
3. *Cake filtration* where the solids quickly "take over" and act as the filter medium.

By the cake filtration, which was used in this work, the liquid flows through a filter medium, on which the solids deposited gradually increase in thickness. The particles form the cake, which then act themselves as a filter. It is generally accepted that the filtration resulting in a filter cake takes place by bridging mechanism over the surface pores within a filter medium. This helps to prevent the medium from clogging with fine particles.

The influence of electrical field on the solid-liquid separation of fine particles was in the attention of the researchers all over the world. The main research goal was usually the influence of the electrical field on the reduction of the moisture in the filter cakes, as an alternative to thermal procedures [1].

In the present work the main goal of our research was focused on the influence of an electrical field on the kinetic of the filtration. If an electrical field is applied on the cake-building filtration, an acceleration of filtration kinetics appears because of the electrokinetic effects [2]. Electrofiltration, the combination of mechanical simple pressure filtration and electrical filtration, can be a useful technique for the filtration of fine suspensions to prevent usual problems like long filtration time or blocking of filter pores. The electrokinetic effects (electroosmosis and electrophoresis) were due to the developing of electrical double layer on the particle surface [3].

Formation of electrical double layer and the electrokinetic effects

If solid particles are in contact with electrolytic fluids, the dissociation of molecular groups and/or by specific adsorption of anions and cations cause a distribution of electric charge carriers at the phase boundary. The existing boundary charge attracts ions of opposite charge from the layer near the interface. Some of these dissolved ions are attracted so strongly to the surface that they can be regarded as fixed to the particle. The other ions form a diffusive layer around the particle (model of Stern [2]). The mostly negative boundary charge of the particles can be used to introduce a new force into the process by applying an electric field. According to the classical model [2] the wandering of the charged colloidal particles in the electric field is due to electrophoresis. Under electroosmosis take place the movement of the surrounding charged liquid of the diffusive double layer relative to the solid phase.

To describe the influence of the electroosmosis and electrophoresis on the electrofiltration process, Yukawa [4] based his model on Darcy's law:

$$\frac{dV_L}{dt} = \frac{\Delta p_H \cdot A}{\eta\left(r_C \cdot K \cdot \frac{V_L}{A} + R_m\right)} \qquad (1)$$

where V_L is the volume of filtrate (m^3), Δp_H the pressure drops of the system (bar), A the area of the filter (m^2), η the liquid viscosity (kg/m.s), r_c the resistance of the cake (m^{-2}), R_m the resistance of the filter medium (m^{-1}) and K the concentration factor.

For constant pressure Equation (1) may be integrated under the form:

$$\frac{t}{V_L} = \frac{\eta \cdot r_C \cdot K}{2 \cdot \Delta p_H \cdot A^2} \cdot V_L + \frac{\eta \cdot R_m}{\Delta p_H \cdot A} \qquad (2)$$

to give the resistance of the cake and the resistance of the filter medium R_m:

$$r_C = \frac{2\Delta p_H \cdot A^2 \cdot a}{K \cdot \eta} \qquad R_m = \frac{\Delta p_H \cdot A \cdot b}{\eta} \qquad (3)$$

where a is the slope and b is the intercept of the linear correlation t/V_L *versus* V_L.

Yukawa considered electroosmosis as an additional pressure added to the applied hydraulic pressure. In this way, the entire filtration pressure results from the overlapping of the hydraulic pressure Δp_H and electroosmotic pressure Δp_E. Electrophoresis, in addition, reduces the filtration velocity of the particles. If the electric field (E) reaches a critical value (E_{crit}), the electrophoretic velocity equals the filtration velocity, and the particles reach a stationary condition. The corresponding field strength is defined as the critical field strength (E_{crit}). The resulting velocity is zero, and there is no cake build up. Yukawa considered this effect using the electrophoretic coefficient (E_{crit}-E)/E_{crit}. This leads to a principal equation of pressure electrofiltration:

$$\frac{dV_L}{dt} = \frac{(\Delta p_H + \Delta p_E) \cdot A}{\eta \left(r_C \cdot K \cdot \left(\frac{E_{crit} - E}{E_{crit}} \right) \cdot \frac{V_L}{A} + R_m \right)} \quad (4)$$

The transformation and integration of this equation under the assumption that both the electroosmotic pressure as well the critical electrical field strength remain constant during the entire time of the experiment, provides the linear dependence of t/V_L to V_L:

$$\frac{t}{V_L} = \frac{\eta \cdot r_C \cdot K \cdot \left(\frac{E_{crit} - E}{E_{crit}} \right)}{2 \cdot (\Delta p_H + \Delta p_E) \cdot A^2} \cdot V_L + \frac{\eta \cdot R_m}{(\Delta p_H + \Delta p_E) \cdot A} \quad (5)$$

EXPERIMENTAL

The measurements were performed on new laboratory filtration equipment (Fig.1). The components of the laboratory equipment are: the computer with the EXCEL software tool, the power supply with the display control for the voltage, pressure manometer and pressure regular, the suspension container, the double-sided filtration cell and the balance. The laboratory filtration equipment from Karlsruhe offers a new possibility to analyse the filtration kinetics on the double-sided filtration simulating the filtration on a filter press.

The cumulative filtrate weight, the voltage and the current were recorded online by the computer and analysed by EXCEL software.

The main part of the equipment is the double-sided filtration cell (4 cm width), which consists of a middle part and two covers (Fig. 2). In both covers there is an electrode and a filter medium on a supporting lattice. On the specially designed pressure electrofiltration cell simulating the chamber of a filter press, the cake was built on two-sided. The filtrate flows from the middle part in two directions (to the left and to the right) similar to filter presses, through the filter medium and through the electrode, and then through the hoses onto the balance. At the beginning of each experiment the filter cell is filled with suspension and the covers are filled with water to ensure that the first drop of filtrate will be registered on the balance immediately. With this equipment, simple pressure filtration experiments (hydraulic pressure Δp_H = 4 bar) and electrofiltration experiments (Δp_H = 4 bar and the voltage between U = 20 V - 80 V) were performed. For the same experiment the equipment was operated at constant voltage and constant hydraulic pressure Δp_H = 4 bar.

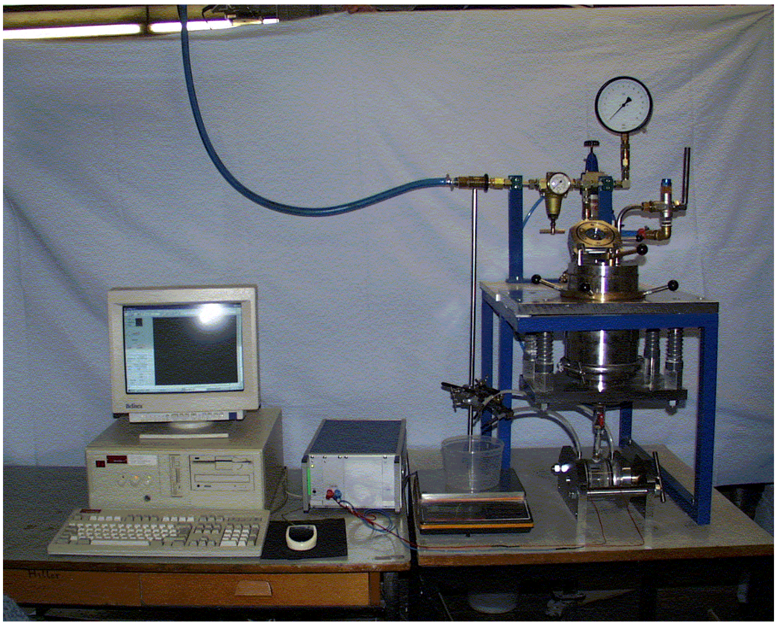

Fig. 1. Laboratory filtration equipment.

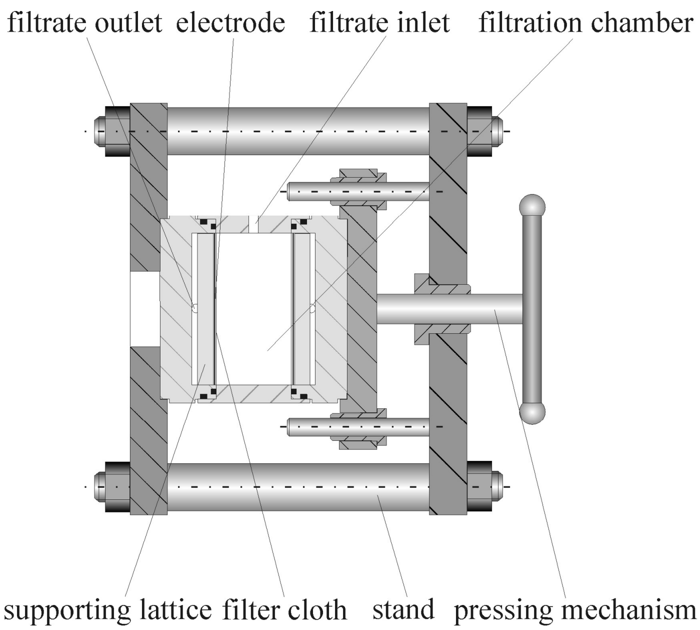

Fig. 2. The two-sided pressure electrofiltration cell.

Three to five replicate runs were carried out for each set of experimental conditions. The reproducibility of the experiments was for each case higher than 99.5 %. The surface of filtration totalises on both sided 51.5 cm^2.

Quartz sand SF 800 (density ρ_s = 2650 kg/m³ and average particle size $d_{50\%}$ = 2 µm) from Quarzwerke (Frechen) was suspended in tap water of Karlsruhe (conductivity λ = 700 µS/cm) for the cake filtration experiments. The volume concentration of the solid was c_v = 20 % for all experiments.

A filter cloth of the company Sefar with the designation 03-5/1 made of polyamide PA 6.6 with mean mesh size of 5 µm and an open filter surface of 1 % was used.

RESULTS AND DISCUSSION

To analyse the filtration kinetics, the amount of filtrate volume accumulation was plotted over the filtration time (Fig. 3). The rapid increase of the filtrate volume at the beginning of each experiment can be explained by the redusing cake resistance. When the filtration cake reaches the maximale width the filtrate volume reaches the finally equilibrium value and the curve becomes flat.

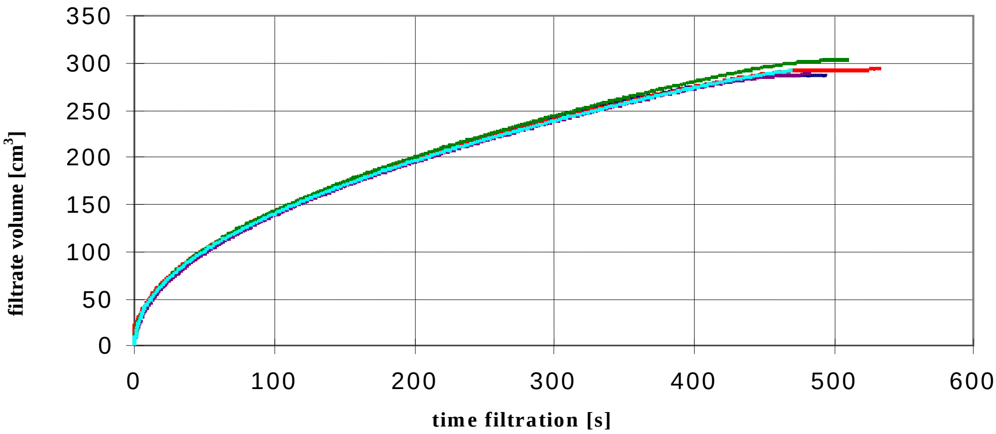

Fig.3. Filtrate volum *versus* time for filtration experiments with SF800, c_V = 20%, Δp_H = 4 bar and U = 80 V.

Five replicate runs of the experiments (carried out for electrofiltration with an electrical field of U = 80 V and the hydraulic pressure Δp_H = 4 bar) are shown in this diagramm. The reproductibility of the experiments was here and for each set of experimental conditions higher than 99.5%.

A direct comparison between simple pressure filtration and electrofiltration is shown in Figure 4 and 5. In Figure 4 the filtrate volume is plotted over the filtration time, in Figure 5 the time per filtrate volume is plotted over the filtrate volume. Figure 4 shows that the filtration kinetic was accelerated with increasing voltage. To reach for example, a filtrate volume of 250 g, it took 330 s without the use of an electric field. With an applied voltage of U = 40 V it lasted 295 s and 260 s with U = 80 V.

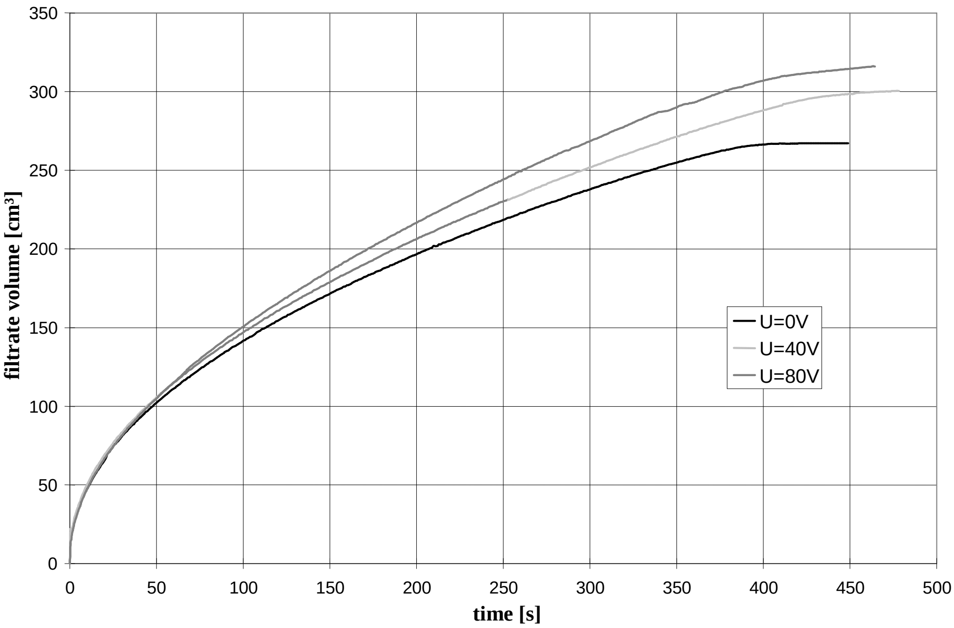

Figure 4. Comparison of three experiments for SF800, c_V=20%, Δp=4bar, b=4cm.

This kinetic acceleration can also be seen in the lower gradient of the plots with electric field in Figure 5. Based on equation (5) the specific filter cake resistance and the resistance of the filter medium can be determined by the gradient and the ordinate cut of the pressure filtration experiment with and without electric field. This calculation led to a specific filter cake resistance of $r_C = 5.3 \cdot 10^{14}$ m^{-2} and the resistance of the filter medium $R_m = 1.65 \cdot 10^{10}$ m^{-1} in the case of simple pressure experiment (U = 0 V). A value of the cake resistance $r_C = 4.35 \cdot 10^{14}$ m^{-2} was determined for the voltage of 40 V (E = 1000 V/m) and $r_C = 3.26 \cdot 10^{14}$ m^{-2} at 80 V (E = 2000 V/m). The gradient, and in this way the cake resistance, was reduced by using of the electric field.

For a two-sided cake building filtration electrophoresis reduces the cake build-up on the cathode side and increases it on the anode side [1]. In addition electroosmosis benefits the filtrate flow to the cathode, so that the bigger part of the total filtrate can be obtained on the cathode side. The results show that the negative effect on the anode side is covered by the positive effect of the cathode side. Thus the kinetic of electrofiltration has been accelerated.

The experiments with electric field showed that the electrolysis did not influence the results. The electrolytic gas did not penetrate the cake (the electrodes are situated outside of the cake) and so the electrolysis can be neglected. The influence of the electrolytic gas on the reducing of the moisture was also negligible (the residual moisture was around 34-35 % when the filtration was carried out with or without electric field, see Table 1). It turned out that the residual moisture could only be reduced minimally through the electric field [5].

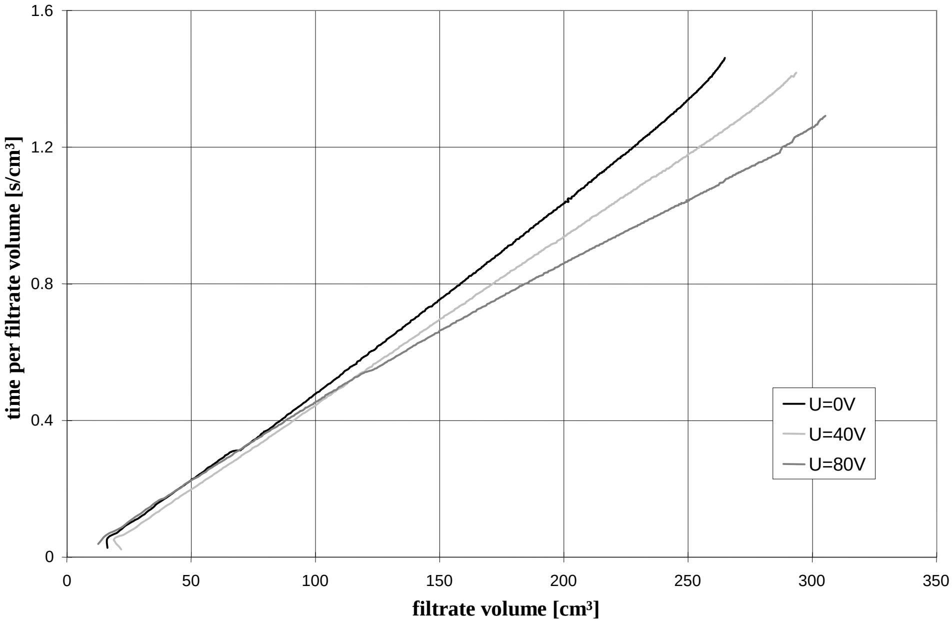

Figure 5. t/V_L vs. V_L for SF800, c_V=20%, Δp=4bar, b=4cm.

The separation of the thermal and the electrolytic processes showed that the electrokinetic effects represent the main influencing factors during the acceleration of the filtration kinetics [1]. From the same reason, the temperature is constant for a long time and only at the end of the experiment, when a very small volume of the filtrate flows trough the filtration chamber it increased slowly (2 - 5^o C). In this way the heating of the liquid during the filtration and the modification of the viscosity of the filtrate which can influence the flow of the filtrate can be negligible.

Table 1.

The residual moisture of the filtration cake with and without electric field.

Critical Number	Voltage of electric field (V)	Rest moisture
1.	0	0.323
2.	0	0.330
3.	20	0.333
4.	20	0.331
5.	40	0.332
6.	40	0.334
7.	50	0.345
8.	50	0.343
9.	60	0.350
10.	60	0.350
11.	80	0.350
12.	80	0.345

CONCLUSIONS

Based on an approch of Yukawa it was developed a model which could describe the two-sided pressure electrofiltration. In this way the combination of mechanical and electrical filtration is an effective method to enhance the filtration kinetics. With use of an electrical field the kinetics of cake building pressure of fine particles could be accelerated in a small laboratory filter cell with double-sided filtration surface. Due to the electrokinetic effects the filtration kinetic was inflenced strongly. The effect of the electrophoresis reduced the cake build-up on the cathode side and increases it on the anode side. In addition electroosmosis benefits the filtrate flow to the chatode. The positive effect on the cathode side covers the negative effect on the anode side.

REFERENCES

1. K. Weber and W. Stahl, *Filtrieren und Separieren*, 2000, **1**, 14
2. A. M. James, *Surface and Colloid Sience*, 1979, **11**, 121
3. H. J. Jacobasch, H. Kaden, *Z. Chem.,* 1983, **23**, 81
4. H. Yukawa, K. Kobayashi, Y. Tsukui, S. Yamano and M. Iwata, *J. Chem. Eng. Jap.,* 1976, **9**, 396
5. W. Bender, *Chem. Ing. Tech*., 1983, **55**, 823