Enhancing Electrofiltration with the aid of an Electro-osmotic Backwashing Arrangement

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The way in which higher filtration flows can be obtained from crossflow electrofiltration membranes by using an electro-osmotic backwashing arrangement has been studied. The electro-osmotic flow with a polarity reversal arrangement, provides pulsed flow conditions and an increase in filtration flow rates. More study is needed on the operational parameters before the technique can be applied on an industrial scale.

Among existing solid-liquid separation techniques, membrane technology, especially crossflow microfiltration (CFMF), offers an appropriate alternative to conventional filtration and centrifugation processes. However, its extensive use in industrial application is limited due to membrane fouling problems. In recent years, the crossflow electrofiltration (CFEF) process has come to be considered as an economic anti-fouling technique during the filtration of solutions containing charged particles and colloids. This process enables the accumulation of particles and colloids on the membrane surface to be reduced and leads to a higher filtration flux.

CFEF is generally used in two configurations[1-6]: (a) tubular and, (b), plate and frame. Tubular modules have a disadvantage in that as the electrodes make direct contact with the feed solution, problems related to electrodialysis occur leading to gas formation. In addition, the phenomenon of deposition of particles and colloids on the electrode surface due to electrodeposition is also encountered. These secondary effects are, however, eliminated in a plate and frame module, where the electrodes are separated from the feed solution, and filtrate by an ion permeable cellulose membrane.

Plate and frame CFEF module studies were conducted in a single stack form. However, in practical applications, a multiple stack arrangement can be equally applied as shown in Fig 1(a). The major drawback of this module arrangement is that it does not provide the most economical membrane area/volume ratio (packing density). Apart from this, when the particles and colloids are charged due to electrophoretic effects they migrate from the membrane surface and part of them gets deposited on the ion permeable membrane placed on the opposite side of the flow channel. This process of migration of particles in the opposite direction to the convective pressure driven force, leads to a reduction of resistance to mass transfer at the membrane/solution interface, and to higher filtration flows. Meanwhile, the deposited layer of particles and colloids on the ion permeable membrane surface results in a high increase of resistance to the current flow, boosting the energy consumption. This phenomenon leads to the limiting current effect[4-5].

To overcome this drawback, an alternative arrangement is proposed as shown in Fig 1(b), which gives nearly twice the filtration area per unit volume of equipment, a higher filtration flow rate and also reduces the problem of limiting current. In this module arrangement, the ion permeable membrane on the anode side of the flow channel is replaced by a microfiltration membrane. Here, the electrophoretically migrated negatively charged particles and colloids get deposited on its surface resulting in the formation of a cake layer. This phenomenon leads to a heavy reduction of the filtration flux on the anode side of the membrane. In addition, these negatively charged colloids and particles lead to the phenomenon of electro-osmotic flow. This flow is in the opposite direction to the filtration flux (towards cathode-7) thus further reducing the filtration flux. Whereas, when the polarity of the electrodes is changed (where the cathode becomes anode and anode becomes cathode) in a regular frequency, this excessive deposition of particles and colloids on the membrane surface can be avoided and the electro-osmotic flow can be used to backwash the membrane surface and create a perturbation of the laminar sublayer. Eventually, this process permits higher filtration flow to be obtained in comparison to the CFMF or conventional CFEF processes.

Experimental Studies

The efficient performance of a double membrane CFEF with frequent polarity reversal process depends on the following operational parameters:

- Applied electric field strength;
- Frequency of the polarity reversal;
- Crossflow velocity and applied pressure.

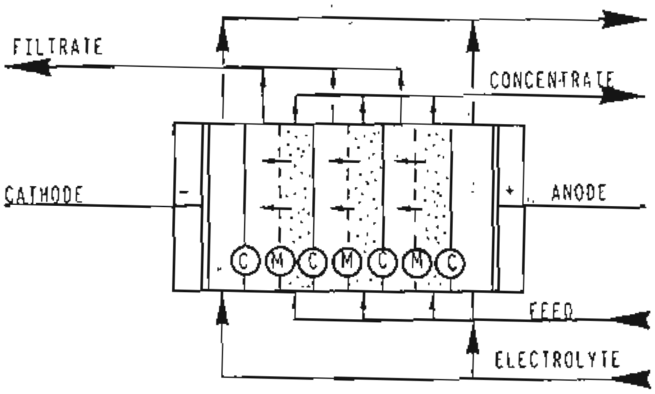
Our experimental studies were carried out using a plate and frame type electrofiltration cell assembly using two platinum coated titanium electrodes. This module was used in two operational modes:

- CFEF with a double membrane (Versapore Gelman 200, with an average pore size of 0.2μm and without any surface charge) and frequent polarity reversal (Fig 2);
- Conventional CFEF or CFMF (without the application of the electric field strength) with one membrane.

In the latter operational mode the membrane on the anode side of the flow channel was replaced with the ion permeable cellulose (cellophane) membrane. For the experimental studies, a combination of 100mg/l of colloid free granular rounded silica particles (Serva Feinbiochemica) with an average diameter of 3.0μm and 1.0g/l of Ludox HS-40 (El du Pont de Nemours & Co) stable colloidal silica with an average diameter of 12nm were used as the feed solution. These colloids and particles were negatively charged at the working pH condition of 9.45. A detailed description of the experimental procedures has been summarised elsewhere[8].

Results

The influence of the crossflow velocity on filtration flow rate was studied for three different polarity reversal frequencies of 1Hz, 0.2Hz and 0.1Hz. This is graphically illustrated in Fig 3, which shows that there is no significant influence of frequency of polarity reversal on the filtration flow rate in this range of frequencies. These results point out that in these conditions, one can easily eliminate the deposited layer of particles and colloids from the membrane surface using the electro-osmotic flow. However, when decreasing the frequency in the order of 0.01Hz a notable filtration flow reduction was noticed. This is due to the fact that during relatively large time intervals, large and compact cake layer deposition occurs on the membrane situated on the anode side, which could not be easily backwashed by the small electro-osmotic flow. These results indicate the existence of an optimum polarity reversal frequency value for the given operating condition.



M - MEMBRANE
C - ION PERMEABLE CELLULOSE MEMBRANE

Fig 1(a). Conventional multiple stack CFEF arrangement

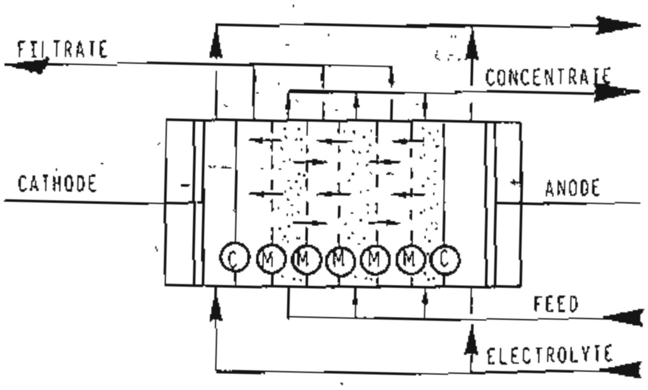


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Fig 1 (b). Modified multiple stack CFEF with frequent polarity reversa arrangement

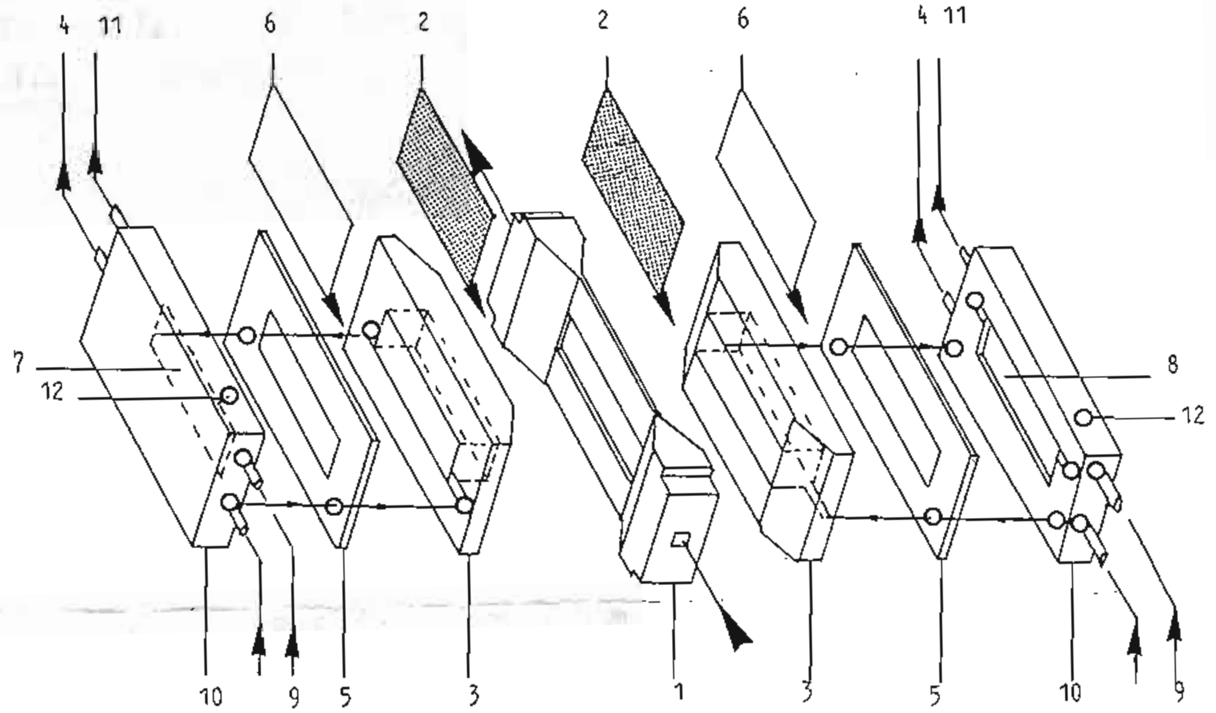

Fig 2. Crossflow electrofiltration cell assembly. 1. Feed flow channel; 2. Microfiltration membrane; 3. Filtrate collection chamber; 4. Filtrate outlet; 5. Intermediate spacer; 6. Ion permeable cellulose membrane; 7. Cathode; 8. Anode; 9. Electrolyte inlet; 10. Electrode supporting plate; 11. Electrolyte outlet; 12. Electrode connection

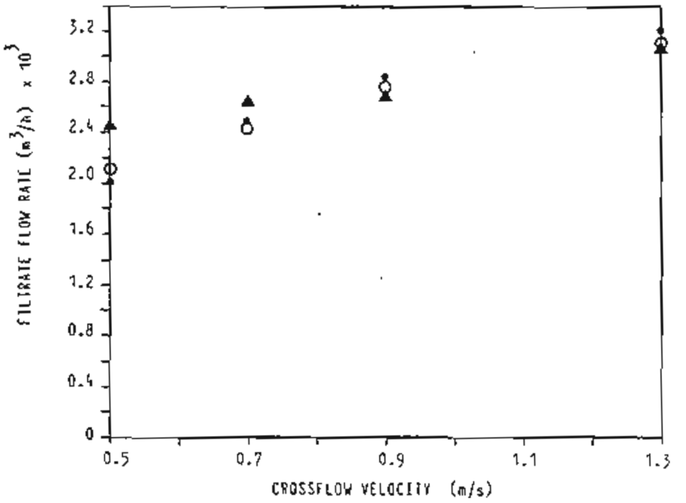

Fig 3. Filtrate flow rate vs crossflow velocity at different frequency of polarity reversal for a pressure of 0.27 bar and electric field strength of 14.45V/cm (● – 1Hz, ○ – 0.2Hz, ▲ – 0.1Hz)

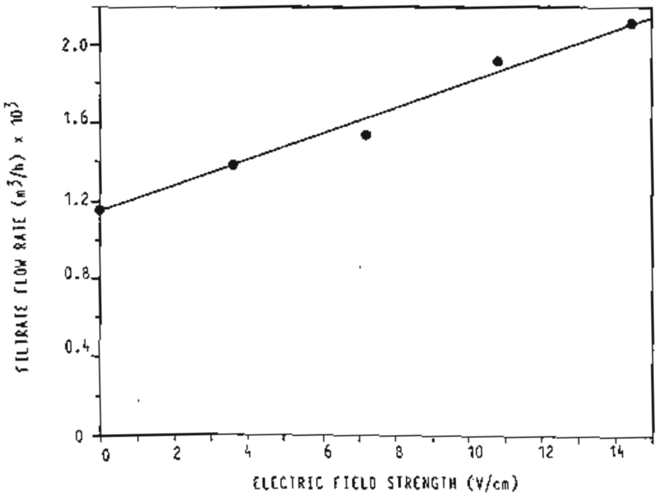

Fig 4. Relation between filtrate flow rate vs applied electric fields strength, for a frequency of polarity reversal 0.2Hz (pressure = 0.27 bar, and crossflow velocity = 0.5m/s)

Fig 4 shows a linear relationship between filtration flow rate and applied electric field strength for a polarity reversal frequency of 0.2Hz. Our maximum applied electric field strength was limited to 14.45V/cm due to a cell electroheating problem. However, on an industrial scale, this cell electroheating problem could be eliminated by a proper electrolyte cooling system, permitting operation at higher field strength values and resulting in higher filtration flow rates.

Fig 5 shows the relationship between filtration flow rate and crossflow velocity at two different pressures for three operating conditions: CFMF, conventional CFEF and CFEF with reversal of polarity at a frequency of 0.2Hz. These results show that the conventional CFEF gives a higher filtration flow rate when compared to the CFMF operation. However, CFEF with polarity reversal arrangement gives a much higher filtration flow rate than the conventional CFEF. Apart from this, in a conventional CFEF operation an increase of crossflow velocity gives a negligible improvement of filtration flow rate and the increase of pressure leads

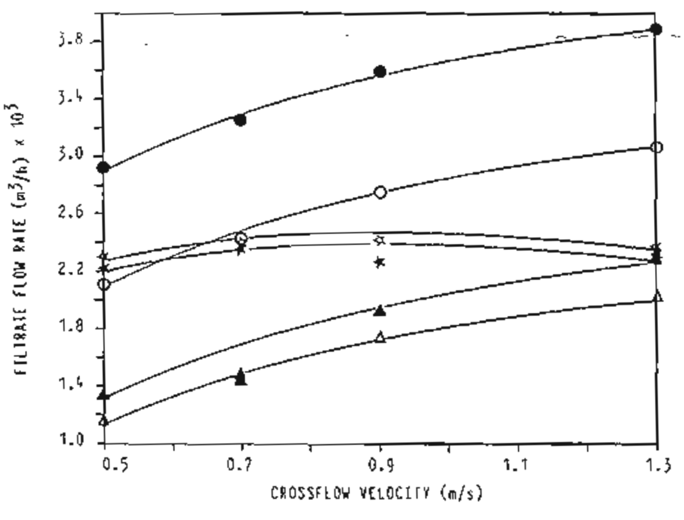

Fig 5. Effect of filtration flow rate on crossflow velocity at three different operational modes of CFMF.
At pressure of 0.27 bar: △ = CFMF; ☆ = conventional CFEF at E = 14.45V/cm; ○ = CFEF with a frequency of polarity reversal of 0.2Hz, and E = 14.45V/cm.
At pressure of 1.0 bar; ▲ = CFMF; ★ = conventional CFEF at E = 14.45V/vm; ● = CFEF with a frequency of polarity reversal of 0.2Hz, and E = 14.45V/cm

to a small reduction of filtration flux. These results are quite similar to those observed in ultrafiltration processes due to polarisation phenomena: the presence of colloids can explain this kind of behaviour.

In the case of CFEF with a polarity reversal arrangement, an increase of crossflow velocity and pressure leads to an eventual increase in the filtration flow rate. In this process, the electro-osmotic backwashing flow creates a disorder at the laminar sublayer thus helping the crossflow velocity to carry away more of the colloids and particles from the membrane. This process results in the formation of a relatively less dense and compact (higher permeability) deposit at the membrane surface. This phenomenon leads to a reduction of resistance to the mass transfer at the solution/membrane interface, and the increase in pressure leads to an increment in the filtration flow rate.

Conclusion

This technique of CFEF with polarity reversal has significant advantages over the conventional CFEF: (a) Module arrangement significantly increases the packing density (filtration area per unit volume); (b) High filtrate flow rate; (c) Reduction in limiting current problem, thus trimming down the energy consumption and making this technique highly competitive compared to other anti-fouling techniques. However, careful consideration of the operational parameters, like electric field strength, frequency of polarity reversal, crossflow velocity and pressure have to be studied before applying it on an industrial scale.

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Crossflow separation of fuel

Exclusive UK rights to develop marine applications of a high efficiency fuel filtration system based on crossflow membrane separation, has been granted to Vokes by Separation Dynamics Inc. (SDI), who developed the system for treatment of aviation fuel.

The technique removes both particulates and water from the fuel in a single operation, and is said to offer a more efficient yet economic solution than conventional filters and coalescers. It is believed to be the first time that crossflow separation has been applied to the filtration of fuels.

The method makes use of a phenonenom in fluid dynamics whereby water and particles suspended in a fluid stream passing at certain velocities and shear rates through a cylindrical geometry (eg. a hollow membrane fibre) will tend to concentrate near the centre of the stream.

The SDI technology employs modules comprised of many hollow membrane fibres of about 2mm diameter and a pore size of 0.2 micron. While the contaminants concentrate in the centre of each fibre (eventually to be dumped into a reservoir) the clean, dry permeate flows adjacent to the walls and is encouraged by the pressure differential to migrate through the membrane.

Hence, with a single pass through a module, particle removal said to be superior to that of a cartridge filter is combined with effectively 100% water removal.

Because the device depends on fluid dynamics and not on pore size *per se*, the separation modules can remain in service for extended periods without clogging. Any particulate matter that may occasionally collect on the membrane can be readily freed with a simple back pulse of a few seconds' duration.

Capable of operating at relatively low pressures, normally around 30psi, clean fluid and fuel flow rates can range from a few gallons to several hundred gallons per minute. Tests have shown that the system can handle solids loadings of a few ppm to 15% over long periods without significant reduction in the flow rate.

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