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Backflushing, pulsation and in-line flocculation techniques for flux improvement in crossflow microfiltration

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Abstract−Crossflow microfiltration (CFMF) is a better technique for removal of particles from water suspension. Clogging is the main drawback of membrane application, which causes a drop in permeate flux. Numerous techniques are available for flux improvement. In this work, three such techniques backflushing, pulsation and in-line flocculation, are reviewed. Two experimental studies have been analyzed and compared. In both techniques, better flux was reported with cleaning frequency of 1 min. This shows that a longer interval causes increased internal clogging and deposition. However for the backflushing case, longer duration of backflushing produced higher flux improvement, while pulsating performed inconsistently with stop duration. Net permeate volume was observed higher in both experiments when T_f= 1 min, T_b=1 sec and T_f=1 min, T_s=1 sec. This is due to higher flux at T_f=1min and longer net operation time. Comparing the flux improvement in both techniques without flocculent addition, backflushing produced 200% increment at T_f=1 min and T_b=5 sec. This was 63% at T_f=1 min and T_s=1 sec with pulsating. Flux increment was 162% with backflushing at T_f=1 min and T_b=1 sec.

Key words: Microfiltration, Backflushing, Pulsation, In-line Flocculation, Permeate Flux

INTRODUCTION

Microfiltration (MF) is a pressure driven membrane process for the separation of particles, microorganisms, large molecules, and emulsion droplets. The filter medium is a microporous membrane with a separation limit in the range of 0.02 to 10 μm [Kwon and Vigneswaran, 1998; Al-Malack and Anderson, 1997; Lim and Park, 2004, 2005]. The application of high pressure to the feed side of the membrane enables the passage of water through the membrane.

In conventional filtration systems, the flow direction is perpendicular to the filter medium, which is known as direct filtration or dead-end filtration [Meier et al., 2002; Blanpain-Avet et al., 1999; Dharmappa and Hagare, 1999; Thiruvenkatachari et al., 2005]. In dead-end filtration solid particles settle on the membrane and block the membrane pores. This causes a significant reduction in permeate flux and possible damage to the membrane. To overcome this problem, the crossflow technique is used. In crossflow microfiltration, the feed is tangential to the membrane surface. Crossflow generates a shearing force and/or turbulence along the membrane surface. This reduces the deposition and increases the efficiency and life span of the membranes [Bhattacharjee et al., 2004].

However, in most cases, the filtrate flux decreases with time without the formation of a visible formation of cake, despite the feed tangential velocity [Thomassen et al., 2005]. A higher crossflow velocity (shear) generates higher drag on particles and improves the flux. However, this flux improvement also diminishes as crossflow velocity reaches a higher value [Li et al., 2005].

The decrease in membrane permeate flux is due to many factors, such as fouling, concentration polarization, and gel layer formation, deposition, internal clogging. Deposition reduces the permeate flux. In addition, it shortens the life span of a membrane as it may form a permanent layer of deposit. But, in general, deposits are mechanically reversible. Internal clogging causes a reduction in membrane pore size and reduces the permeate flux. It results in an increasing blockage of pores with time and the membrane becomes totally clogged after some time. Internal clogging is partially irreversible. This effect determines the membrane life in many of the cases. Since the CFMF range is similar to that of the pollutants appearing in water and wastewater, this process has become popular, and numerous research works have been focused on flux improvement techniques.

In order to improve the permeate flux, two actions can be undertaken, either to prevent the particles from reaching the membranes or to flush them out [Connell et al., 1999]. The prior one is named as 'anticlogging technique' and the latter as 'declogging technique' [Barlett et al., 1995; Guo et al., 2005; Gan et al., 1999]. The declogging techniques include:

- Backflushing with liquids and/or gas
- Pulsating of flux of flow
- Use of abrasives
- Chemical washing
- Sonication

The following would be classified under anticlogging techniques:

- In-line flocculation
- Electro-microfiltration
- Turbulent promoters
- Rotating crossflow modules
- High shear crossflow filtration
- Thermal stratification

Anti-clogging techniques, except in-line flocculation, need sophis-

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ticated modules and lead to high cost. Declogging techniques, such as backflushing or pulsating, are suitable for the application in water and wastewater treatment systems, considering the cost involved. Declogging with a simple in-line flocculation system would produce a better solution at a very reasonable cost. The present work compares two case studies of declogging techniques, pulsation of flux and backflushing, with/without in-line flocculation arrangement.

EXPERIMENTAL

1. Experimental Set-up for the Backflushing Technique

The experimental set-up for the backflushing technique is shown in Fig. 1. In this study ceramic tubular membrane (S. C. T. Co., Ltd.: France) of pore size 0.2 μm was used. The inner diameter and length of the tubular membrane were 0.7 cm and 25 cm, respectively (Fig. 2a). The suspension to be filtered was pumped from the base of the stock tank under pressure into the tubular membrane filter (1 path). The tubular membrane used in this set-up is detailed in Fig. 2. The permeate flow which passed the solenoid valves was collected in

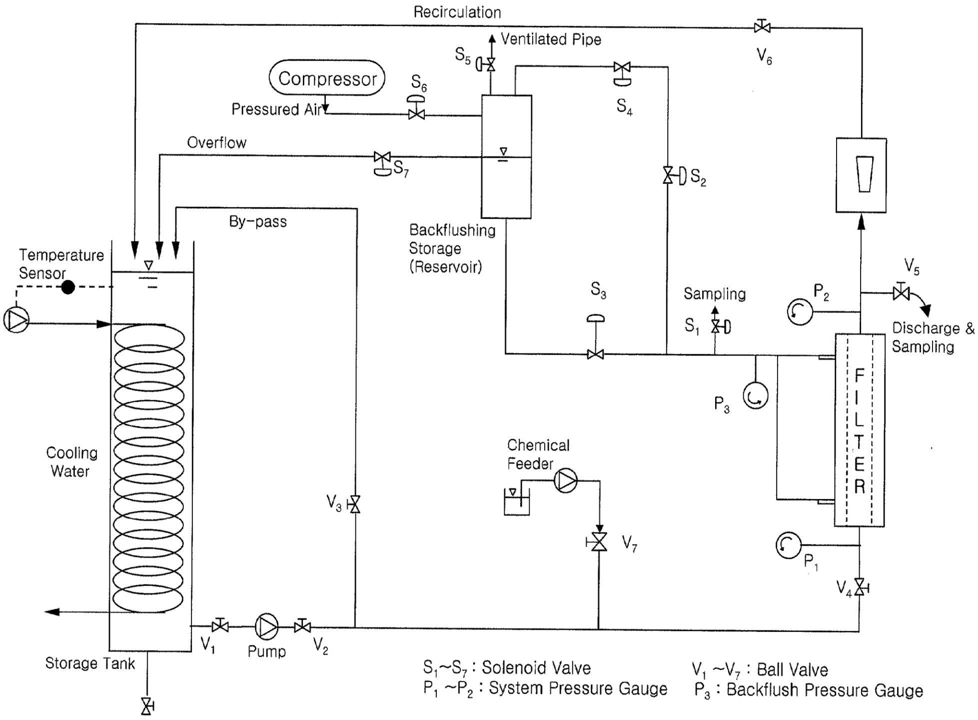

Fig. 1. Experimental set-up of laboratory-scale CFMF module with backflushing technique.

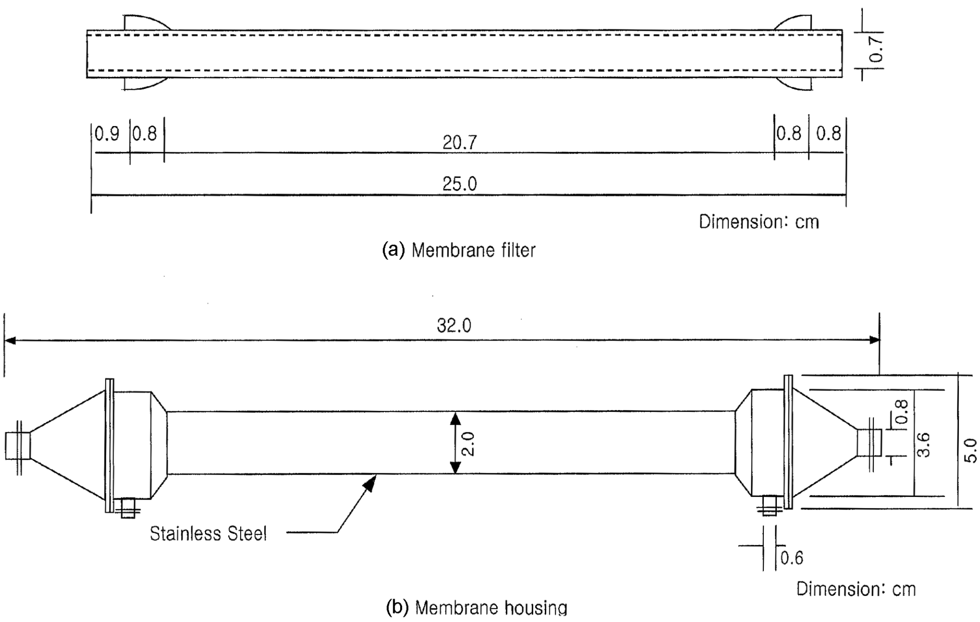

Fig. 2. Tubular membrane filter and housing (0.2 μm microfiltration membrane 45.5 cm^2 surface area).

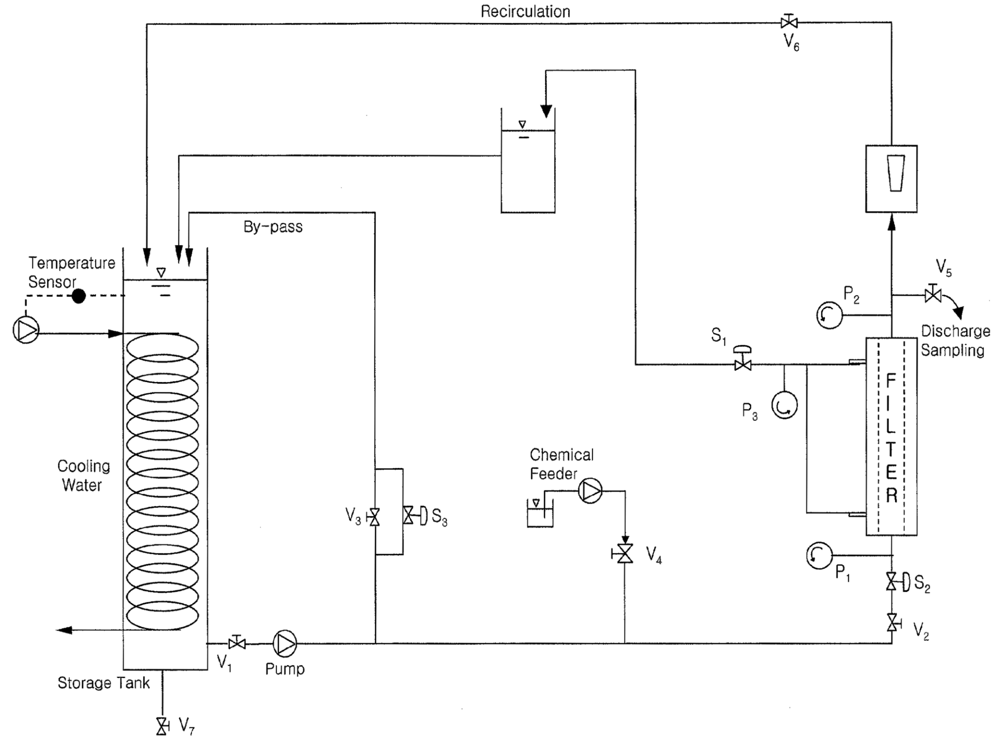

Fig. 3. Experimental set-up of laboratory-scale CFMF module with flow pulsation technique.

the reserve tank. The time programmer together with the solenoid valves were employed to vary and control the different duration and frequency of backflush. A cooling system was provided for keeping constant temperature. A by-pass system was necessary to control the operating pressure and flow rate. The system was timed to observe the membrane performance during 1 min, 2 min and 5 min filtration frequency with 1 sec, 2 sec and 5 sec, backflushing duration.

2. Experimental Set-up for Pulsation Technique

Fig. 3 shows the experimental set-up for the pulsation technique. Chemical feeder was connected in-line to add flocculent to the influent. Solenoid valves S_1, S_2 and S_3 were coordinated by a programmable controller. Details of this operation are given elsewhere [Barlett et al., 1995]. The valves were controlled by programmed timer to study the pulsation frequencies of 1 min, 2 min and 5 min., with 1 sec, 2 sec and 5 sec, operation 'stop' duration.

3. Membrane Filter Cleaning and Filterability Test

The same membranes were used in both experiments. Chemical cleaning was done to remove the particles causing clogging of the membrane. Concentrated HNO_3 and 5% NaOH solution were used as cleaning chemicals along with an air pumping system [Madaeni et al., 2001]. A filterability test was conducted to assess the cleaning performance and filterability of the tubular membrane filter before each experiment. A cartridge filter (0.2 μm) was installed in the set-up before the membrane unit in order to have clean water (~0.15 NTU). The applied pressure and crossflow velocity were kept constant to keep the same condition for each operation. Synthetic kaolin clay suspension was filtered in these experiments. In the first technique, different concentration of suspension was filtered without backflushing. With a fixed kaolin clay concentration of 50 NTU, different backflushing durations and frequencies were tested. Different backflushing durations and frequencies were attempted with kaolin clay (50 NTU) with SiO_2 colloids (125 NTU). In the second, filtration performance of kaolin clay suspension (55 NTU) was observed with and without alum in-line flocculation, with flow pulsating as flux improvement technique.

RESULTS AND DISCUSSION

In this discussion, the low cost membrane flux improvement techniques, which are suitable for water and wastewater treatment such as backflushing, pulsation of flow and/or flux and in-line flocculation, are reviewed. Then, the case studies and the experimental results are also discussed and compared.

1. CFMF and Backflush Technique

This technique was analyzed with four experimental conditions: effect of suspension concentration, backflushing, suspension particle size and flocculation. The results of these effects are as follows.

1-1. Effect of Suspension Concentration

In this experiment, a set of observations was made (Case A) to study the effect of influent concentration on flux without backflushing. The results are depicted in Table 1 and Fig. 4. It was observed that flux decreased more rapidly for the suspension with higher con-

Table 1. Variation of final flux with concentration influent kaolin clay suspension (no colloids, no back flushing), (Case A)

Concentration kaolin clay (NTU)	Final flux ($L/m^2 \cdot h$)
25	580
50	422
100	422
200	369

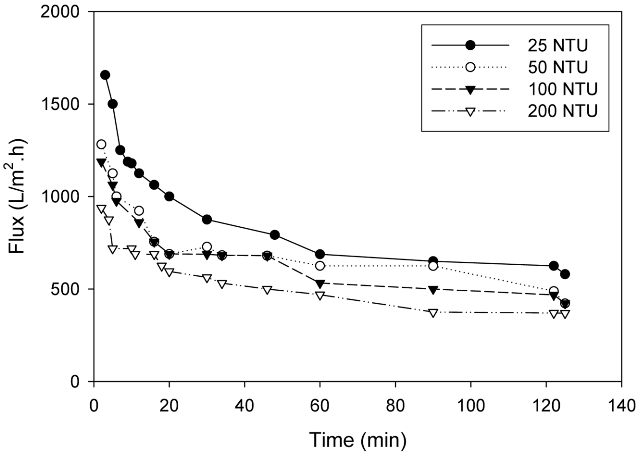

Fig. 4. Effect of influent concentration (kaolin clay: without backflush; U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm), (Case A). Note: U=crossflow velocity, P=operating filtration pressure, d_m=membrane pore size.

Table 2. Variation of final flux with backflush duration and frequency for only kaolin clay (Case B) and kaolin clay colloidal particulates mixture (Case C)

Concentration		Backflush		Final flux	Flux increment
Kaolin clay (NTU)	Colloids (mg/L)	Frequency (min)	Duration (sec)	(L/m²·h)	(%)
50	0			422	-
50	0	1	1	1107	162
50	0	1	2	1239	194
50	0	1	5	1265	200
50	0	2	1	766	81
50	0	2	2	897	113
50	0	2	5	1213	188
50	0	5	1	765	81
50	0	5	2	781	85
50	0	5	5	791	88
50	125			343	-
50	125	1	1	1054	207
50	125	1	2	1134	231
50	125	1	5	1213	254
50	125	2	1	607	77
50	125	2	2	633	85
50	125	2	5	1002	192
50	125	5	1	422	23
50	125	5	2	527	54
50	125	5	5	659	92

centration. This would be due to internal clogging and deposition, which is higher with a highly turbid suspension. However, the final flux values were not much different for 50, 100 and 200 NTU suspensions. Cake filtration might be dominant during the later stage of filtration.

1-2. Effect of Backflushing

In this study Ludox HS-40 (40% colloidal silica produced by Du Pont Co., Ltd.) commercial of 0.012 μm size and kaolin clay (plas-

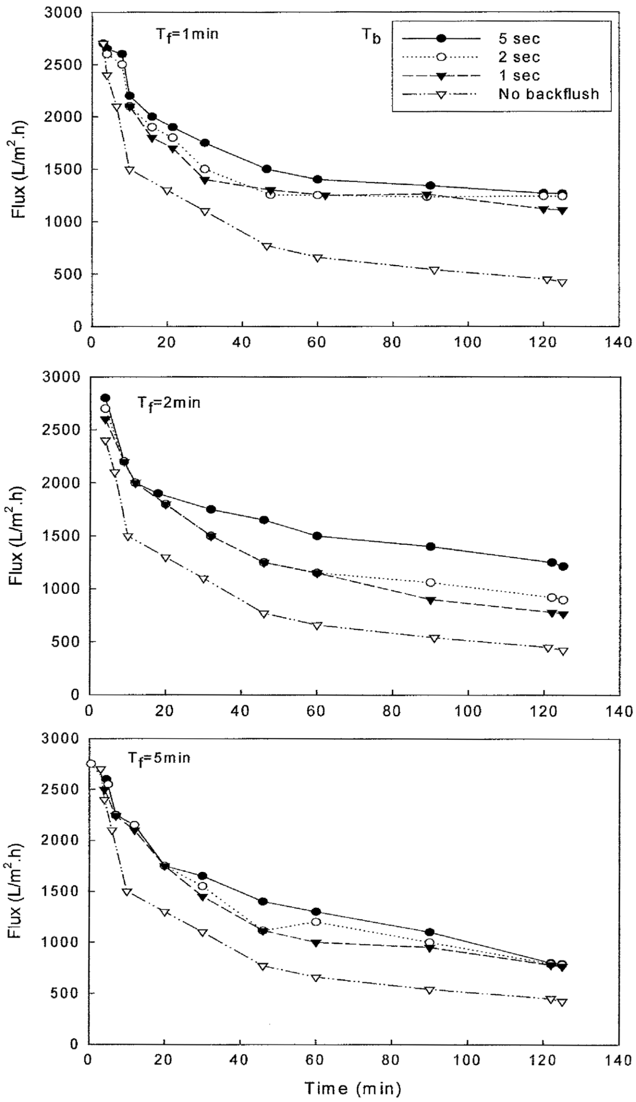

Fig. 5. Effect of backflush duration and frequency (kaolin clay: 50 NTU, U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm, ΔP_b =100 kPa), (Case B). Note: U=crossflow velocity, P=operating filtration pressure, d_m=membrane pore size, ΔP_b=operating backflush pressure.

tic clay supplied by cay and Mineral Thailand Co., Ltd.) suspension of 1.6 μm was used. This commercial colloid was added in known concentration of kaolin clay suspension, and the concentration of colloid was maintained at 125 mg/L. The influence of backflush frequency and duration was observed with only clay particles (Case B) and with a mixture of clay particles and colloidal particulates (Case C) in the influent suspension. Three different backflush durations (T_b=1, 2 and 5 sec) and three backflush frequencies (T_f=1, 2 and 5 min) are reported in Table 2 with corresponding values of flux. Fig. 5 shows the flux variations with time at different backflush frequencies and durations during the filtration of only kaolin clay suspension (Case B). From Fig. 5 and Table 2, it can be observed that the flux improvement was higher with backflushing at shorter intervals. For case B, flux increment was 200%, 188% and 88% for the backflush duration of 5 sec with backflush frequency of 1 min, 2 min and 5 min, respectively. Furthermore, the flux increment was

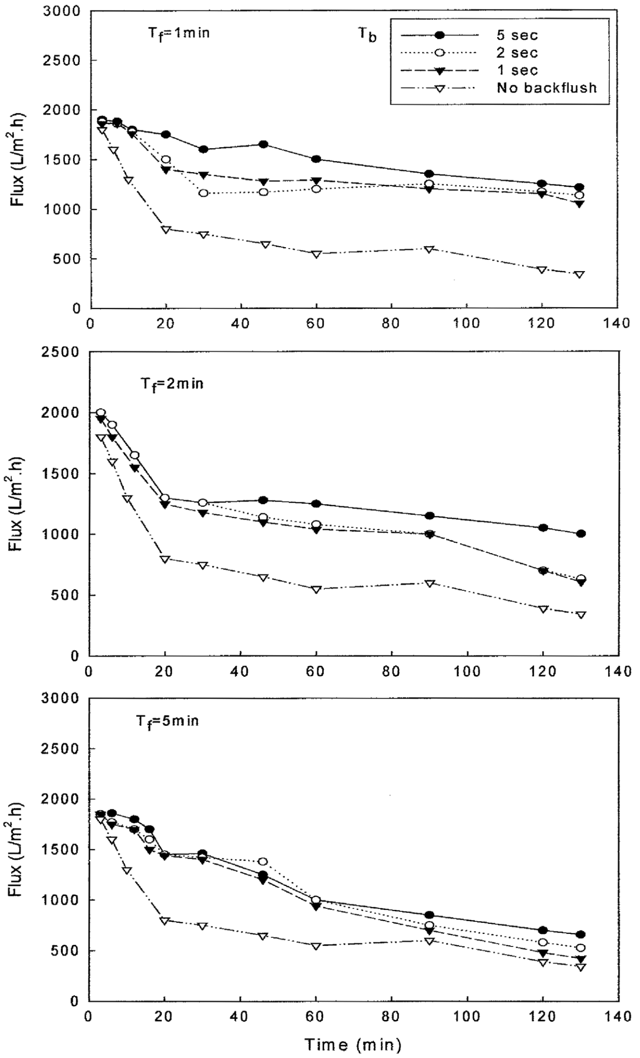

Fig. 6. Effect of backflush duration and frequency (colloids: 125 mg/L, kaolin clay: 50 NTU, U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm, d_{col}=0.012 μm, ΔP_b=100 kPa), (Case C).

decreasing with deceasing backflush duration. For instance, with a frequency of 1 min, the flux increment was 200%, 194% and 162%, respectively, with 5 sec, 2 sec and 1 sec backflush duration.

1-3. Effect of Suspension Particle Size

Variation of flux with time during kaolin clay and colloidal particulate mixture (Case C) is shown in Fig. 6. Observing Fig. 6, Fig. 5 and Table 2, a similar tendency could be identified. Flux increments were 254%, 192% and 92% for 5 sec backflush at 1 min, 2 min and 5 min, respectively. With 1 min backflush frequency, flux increment was dropping from 254% to 207% when backflush duration was varying from 5 sec to 1 sec. Based on this observation, one could conclude that higher backflush duration and shorter backflush frequency would produce better filtrate flux. In this experiment, kaolin clay (50 NTU, d_p~1.6 μm), colloidal particulates (125 mg/L, d_p~0.012 μm) and 0.2 μm membrane were used. Internal clogging would be very low for case B, whereas it would be higher for the case C due to colloidal particles. Therefore, the final flux was lower for the filtration of case C. Furthermore, one could compare the increment in final flux for case B and case C at the same backflushing condition

Table 3. Variation of final flux with and without backflush and alum coagulation (T_f=2 min, T_b=2 sec), (Case D)

Condition kaolin clay 50 NTU no colloids	Final flux (L/m^2·hr)	Flux increment (%)
No backflushing, no alum	422	
Backwashing, no alum	897	112
Backwashing and alum, (50 mg/L)	2320	450

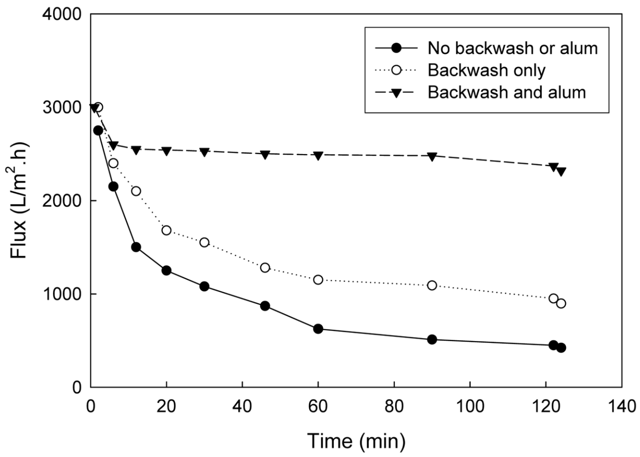

Fig. 7. Effect of coagulation and pulsation (kaolin clay: 50 NTU, with backflush, alum dose 50 mg/L, T_f=2 min, T_b=2 sec, U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm, ΔP_b=100 kPa), (Case D).

(T_f, T_b). The final flux for case B was always higher than that for case C. With this observation, one would guess that for longer backflush frequency, the internal clogging would be high and difficult to backwash completely. In these experiments, both for case B and case C the permeate turbidity was within 0.1 to 0.3 NUT i.e., more than 99.5% removal. Furthermore, net permeate volume and increment with backflush have also been reported by Chen [1990].

1-4. Effect of Flocculation

Kaolin clay particle suspension (50 NTU) in distilled water was coagulated with alum and filter to observe the effect of coagulants in membrane filtration [Barlett et al., 1995] (Case D). Table 3 and Fig. 7 show the performance of filtration with three conditions: only kaolin clay suspension without backwashing, kaolin clay suspension with (2 min, 2 sec) backwashing, and kaolin clay suspension with alum dose and backwashing (2 min, 2 sec). The result was more significant. Backwashing caused an increase in permeate flux from 422 L/m^2·h to 897 L/m^2·h, i.e., 112% increase. Combination of backflushing and alum addition produced an amazing increment of 450%, which was due to lower internal clogging, modification in deposit formation and easy washing because of coagulation of particles.

2. CFMF and Pulsation Technique

This technique was analyzed with two experimental conditions. In the first, the effect of pulsation was observed with three different pulsation frequencies and three 'stop' durations. The second part focused on the effect the combination of alum dose with pulsation technique.

2-1. Effect of Pulsation

In this part (Case E), pulsation frequency (T_f) was maintained at

Table 4. Variation of final flux with pulsation frequency and stop duration for kaolin clay suspension (55 NTU), (Case E)

Pulsation frequency (min)	Stop duration (sec)	Final flux ($L/m^2 \cdot h$)	Flux increment (%)
		300	
1	1	490	63
1	2	450	50
1	5	430	43
2	1	350	17
2	2	360	20
2	5	440	47
5	1	320	7
5	2	340	13
5	5	310	3

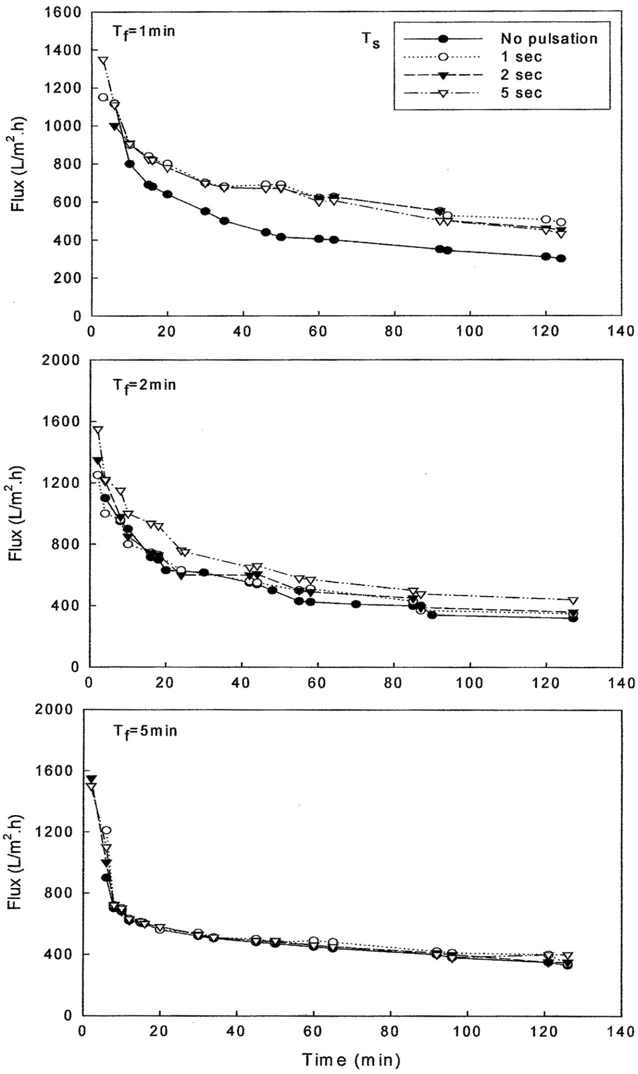

Fig. 8. Effect of pulsation frequency and stop duration (kaolin clay: 50 NTU, U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm), (Case E).

1 min, 2 min and 5 min, and the stop duration (T_S) was kept at 1 sec, 2 sec and 5 sec. The results are tabulated in Table 4. Fig. 8 shows the variation of flux with pulsation conditions. From the Table 4 and Fig. 8 one could observe that flux improvement increases with shorter pulsation interval. With 1 sec stop duration, the flux increment was, respectively, 63%, 17% and 7% for 1 min, 2 min and 5 min of pulsation frequency. Longer filtration time caused higher deposit and internal clogging, which was not much removed during pulsation. Variation of flux with and without pulsation did not show significant variation for longer frequency (Fig. 8). This shows that 5 min pulsation frequency is longer in this experiment. The effect of stop time for a fixed pulsation frequency was inconsistent in this experiment. In the case of T_f=1 min, flux increment decreased with increasing T_S. This was reversed with T_f=2 min. For T_f=5 min, the variation was observed to have a crest. With the available data, one could not make any conclusions on the phenomenon.

Table 5. Variation of final flux with alum coagulation (Pulsation T_f=1 min, T_s=1 sec)

Alum dose (mg/L)	Final flux ($L/m^2 \cdot h$)	Flux increment (%)
0	490	-
20	640	31
50	1090	124
75	1250	157
100	980	101

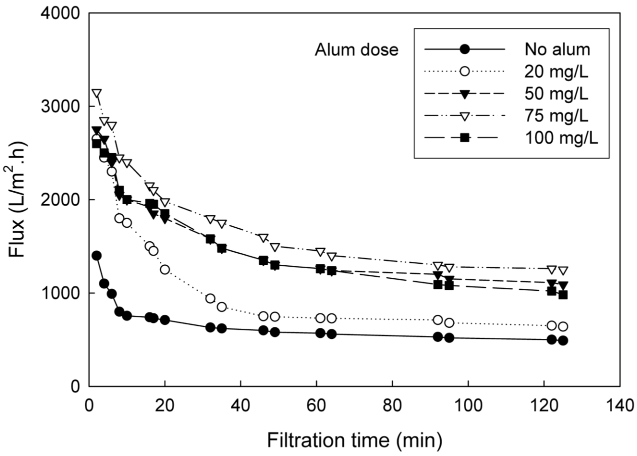

Fig. 9. Effect of alum dose (kaolin clay: 50 NTU, U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm, pulsation- T_f=1 min, T_s=1 sec).

2-2. Effect of Flocculation

Alum was added in different concentrations to observe the effect at 1 min pulsation frequency and 1 sec stop duration. Table 5 and Fig. 9 show the performance of the system. An alum dose of 75 mg/L performed well to produce higher flux i.e., an optimum was observed at 75 mg/L of alum. A jar test also produced the same optimum dose (80 mg/L). In order to observe the combined effect, alum was added with pulsation cleaning technique (Case F). Fig. 10 shows the effect of pulsation with and without 25 mg/L alum addition. The percentage increment of permeate flux by pulsation without alum dose was 63%, whereas with 75 mg/L alum dose it was only 16%. This indicates that the pulsation cleaning technique did not have a significant effect when alum was added to kaolin clay suspension, although the flux with alum was superior to that of without alum and pulsation cleaning technique. Table 6 summarizes the effect of pulsation cleaning technique with and without alum addition in ka-

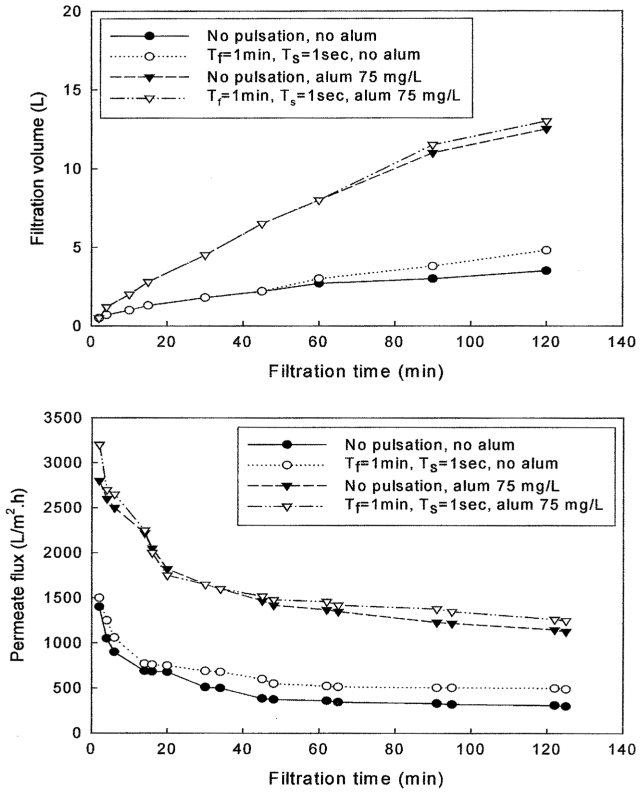

Fig. 10. Effect of coagulation and pulsation (kaolin clay: 55 NTU, U=3 m/s, P=100 kPa, d_m=0.2 μm, d_{caly}=1.6 μm), (Case F).

Table 6. Variation of final flux with and without pulsation and alum coagulation (T_f=1 min, T_s=1 sec), (Case F)

Condition kaolin clay 55 NTU	Final flux ($L/m^2 \cdot h$)	Flux increment (%)
No pulsation, no alum	300	-
Pulsation, no alum	490	63
No pulsation, alum (75 mg/L)	1130	-
Pulsation, alum (75 mg/L)	1250	16

olin clay suspension after 120 min filtration. As in the backflushing experiment, permeate flux turbidity was within 0.1 to 0.3 NTU. Net permeate volume (the volume of permeate for a particular interval of time) is also reported elsewhere.

3. Comparison

In both the techniques, the better flux was reported with a cleaning frequency of 1 min. This shows that a longer interval causes increased internal clogging and deposition. However, for the backflushing case, longer duration of backflushing produced higher flux improvement, while pulsating performed inconsistently with stop duration. Net permeate volume was observed higher in both experiments when T_f=1 min, T_b=1 sec and T_f=1 min, T_s=1 sec. This is due to higher flux at T_f=1 min and longer net operation time. Initial flux during no pulsation and no backflushing must be similar, since all other conditions are the same, except a slight difference in influent turbidity (50 NTU and 55 NTU). But these were different in the observations (422 $L/m^2 \cdot h$ and 300 $L/m^2 \cdot h$). This would be due to the difference in degree of compaction and to new or used membrane. Comparing the flux improvement in both techniques without flocculent addition, backflushing produced 200% increment at T_f=1 min and T_b=5 sec. This was 63% at T_f=1 min and T_s=1 sec with pulsating. Flux increment was 162% with backflushing at T_f= 1 min, and T_b=1 sec.

CONCLUSION

Crossflow microfiltration is appropriate for suspensions with mean particle size bigger than the membrane pore size. Colloids cause internal clogging and decreasing permeate flux. Backflushing and pulsation are suitable cleaning techniques for permeate flux improvement. A shorter interval between cleaning produces better result. Shorter frequency of backflushing or stop time before pulsation is better for higher net volume of permeate with lower level of internal clogging. In-line flocculation improves filtration flux by modifying deposit formation and possible internal clogging. A combination of in-line flocculation and cleaning technique produces more than 3-4 fold increment in flux and 2-3 fold increment in net permeate volume. From limited experience, one could consider that backflushing is better than pulsating during particle removal from the suspensions of low-medium concentration. This would be still true when combined with in-line flocculation.

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