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Membrane fouling control using high-frequency power vibration, in an SMBR pilot system—preliminary studies

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ABSTRACT

Membrane bioreactors (MBRs) in wastewater treatment have gained significant popularity recently, especially due to reclamation needs. Submerged membrane bioreactors (SMBRs) are considered to be an extremely successful method for this purpose. However, membrane fouling is one of the most critical problems of the SMBR systems, and the used techniques to avoid this problem have the disadvantage of the high energy needed. The objective of this study was to introduce an alternative cleaning technique of submerged membranes, with reduced energy consumption. A lot of lab studies have been published concerning the impact of mechanical action in the removal of foulants from the membranes (e.g. vibration, buck-pulse, and ultrasound). In this preliminary study, the feasibility of high frequency power (or powerful) vibration (HFPV), as cleaning technique, on fouled membrane modules, in a small pilot-scale SMBR system, treating a novel synthetic wastewater was examined. This pilot-scale system comprised from small copies of commercialized filter modules working under low aeration mode, in order to study the membrane fouling in a relatively short time period. Two new membrane filter modules (hollow fiber (HF) and flat sheet (FS)) consisting of three filter elements each, were used in the SMBR unit. After working the unit for a long time period, where trans-membrane pressure (TMP) exceeded the specified values or where membrane fouling blocking phenomena were observed, various time-period HFPV schemes were applied on the filter modules, via two different in power commercial pneumatic vibrators. These vibration schemes give distinct vibration characteristics (frequency, displacement, acceleration, etc.) to the membrane modules and their effectiveness on filter fouling was monitored continuously via TMP and flux values vs. time, without interrupting the operating mode of the whole SMBR system. After a continuous working period of 19 d with HF filter module, where TMP values reaches the upper set point of 200 mbar, different HFPV schemes were implemented within a day. This results a considerably lower TMP values (to 100 mbar), while flux was recovered to initial values and the system after that, behaved similarly with that of having new filter modules in terms of TMP and flux values. Medium HFPV schemes were subsequently applied for about

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two-day period, giving a conservation of TMP values at previous levels. Similar promising results were obtained using various time-period HFPV schemes on FS membrane filter module. The above results confirm a clear influence of the HFPV technique on reducing the severe membrane fouling at first and then preserving the good membrane operating conditions. HFPV technique seems to be very promising with respect to energy savings, compared to conventional air cleaning systems in SMBRs because it contributes to a low air-scouring operation due to the periodic application of vibration. Additionally, this technique copes with the problem of membranes fouling in real time, by applying HFPV schemes without interrupting SMBRs operation mode.

Keywords: Membrane bioreactor; Synthetic wastewater; Membrane fouling; Vibration

1. Introduction

Wastewater treatment processes using membrane bioreactors (MBRs) have a variety of advantages over conventional biological processes. Additionally, stricter legislation on effluent disposal, in combination with the decrease in membrane costs affecting the overall operational costs, introduces the treatment process of MBRs, as a globally accepted technique in the last years [1].

Membrane fouling control remains the most critical problem in the successful application and cost-efficient operation of submerged membrane bioreactors (SMBRs), and it is the key for the steady operation of SMBRs [2–4] and one of the most challenging issues facing further MBR development [5–7]. Several necessary strategies are employed in order to reduce membrane fouling nowadays, such as applying appropriate pretreatment to the feed water, employing appropriate physical or chemical cleaning protocols, reducing the flux, increasing the aeration, modifying chemically or biochemically the mixed liquor [1]. All the above mentioned either lead to the increase of operating and maintenance costs or to the oversize the installation. The use of hydrodynamic shear stresses on the membrane surface is recognized as one of the most effective techniques on the limitation of the fouling formation [8]. The use of air bubbles in such a manner to induce flow circulation and shear stress on the membrane surface demonstrated as the most widespread and applied strategy by membrane manufacturers to reduce fouling effect since the first appearance of the SMBR systems [4]. However, air bubbling method has several limitations. The shear forces generated by air-scouring or cross-flow on the membrane surface are relatively weak and not effective in achieving and maintaining high fluxes due to hydrodynamic limitations [9]. Moreover in this process design, the mixed liquor recirculation is highly aerated by the membrane air scour system, and the rate of recycling is not set to optimize biological process requirements, but rather is selected to ensure optimum membrane performance. The consequence of these two obstacles in MBR designs is that the downstream of the biological process is highly aerobic and highly mixed so this can lead potentially to releasing ortho-phosphate to the plant effluent [10]. Finally, air-scouring in MBRs has proven to be energy intensive. Dynamic or shear-enhanced filtration, which consists in creating the shear rate at the membrane by a moving part such as a disk rotating near a fixed membrane, or rotating or vibrating membranes, permits to generate very high shear rates without large feed flow rates and pressure drops. This could be a viable alternative to cross-flow filtration [11].

The principle of “vibratory membrane filtration” was introduced from Pall Company 25 years ago as the Pallsep VMF filter. Since then a lot of ideas have been suggested in this direction on the combination of conventional purification techniques together with mechanical actions and methods. The concept of vibratory shear-enhanced processing (VSEP) was firstly proposed by Armando et al. [12] and has been commercialized by New Logic Research, Inc. The process utilizes torsional vibration to vibrate annular flat sheet (FS) membranes. In their work, Low et al. [13] showed with a VSEP L-series, that with high vibration amplitude/frequency applied in submerged hollow fiber (HF) membranes, the permeate flux could be maintained longer at higher fluxes. They evaluated the effect of vibration with a frequency of 70 Hz and 19 mm amplitude in a sludge feed with MLSS of 1,800 mg/L, and they found out that the mechanical vibration gave the HF membrane a relatively “clean” condition and kept the permeate flux close to that of the clean membrane. In another case of a vibrated HF module, Genkin et al. [14] evaluated the effect of vibration with a range of 0–10 Hz frequency and 0–40 mm amplitude in a feed solution of unwashed baker’s yeast and coagulant addition on the filtration performance of the submerged HF membranes. They found that the vibrational motion on the membranes has the potential to overcome the hydrodynamic limitations of the submerged concept. Beier et al. [15] also carried out experiments with a vibrating HF membrane module using suspensions baker's yeast in a frequency of 25 Hz and amplitude of 0.7 mm under low feed flow. They confirmed that critical flux can be increased with vibration frequency and amplitude as compared to air-scouring [16]. A slight variant of the foregoing technique, investigated by Altaee et al. [9], uses a vibrating mechanism consisting of a mechanical device attached to the top of the setup converting the rotating motion of the electric motor to vertical oscillations. The experiments carried out with a pair of HF membranes into a baking yeast solution with a vibration frequency varied between 1.67 and 6.68 Hz and amplitude of 40 mm. They concluded that the effect of membrane vibration on the critical flux was evident especially at high vibrating speeds. This was due to the increase of shear force at the membrane–water interface which in turn enhanced the particles back diffusion mechanism. Similarly Bilad et al. [17] created a magnetically induced membrane vibration (MMV) mechanism to apply vibration on the membrane. In the same work, two different FS membranes were used into a molasses wastewater solution with a vibration frequency varied between 0 and 60 Hz and amplitude of 2 mm. The vibration is created in the vibration engine by magnetic attraction/repulsion forces in a "push and pull" mode moves the membrane to the left and the right through a sinusoidal pattern. According to the authors, results of both the filtration and the critical flux measurements showed clear advantages of this system over conventional MBR processes in terms of realizable flux and fouling control. Li et al. [18] used a crank mechanism attached to a motor to create vertical reciprocating movement. HF membranes vibrating at moderate frequencies (0–15 Hz) and amplitudes (0–12 mm) were submerged vertically in a bentonite solution. Experiments were conducted at both constant permeate flux and constant suction pressure conditions. They concluded that the membrane performance can be greatly improved when the vibration frequency or the vibration amplitude increases beyond a threshold magnitude.

Although all the referred studies reported a significant improvement on both the permeate flux, suction pressure and the sustainability of operation, they face numerous limitations such as, the vibrating system is often restricted to a small range of vibration amplitudes and frequencies [17], due to the lack of anti-vibration devices on the holding system of the membranes; the shear rates were somehow reduced, due to energy loss resulting from the mechanical contacts and their friction [17]; in most cases, the filtration process was performed at a fixed vibration mode, without the ability of changing the vibration parameters during the filtration or cleaning process and addressing real application needs, where the mixed liquor might change over time [17]; in most studies, the offered vibration power was limited; in most studies, experiments were performed in a very short time span of few minutes or hours; in some cases, detection limits of the used measuring devices were limited or measurements based on estimations (e.g. measurements that relate to the speed of the suction pump and not the actual flow); in most cases, it was not used real or simulated waste water as an influent; little research was done to examine the impact on different material and type of membranes; the already examined systems and techniques are not feasible to be used in currently known SMBR modules, especially due to the large vibration amplitude; in some cases, the MLSS concentration was very low; in many cases, experiments were handled without the recommended by the manufacturers membrane relaxation period, that is essential due to the membranes construction material.

The purpose of this work was to introduce a new approach of applying high frequency powerful vibration (HFPV) in membrane modules via pneumatic vibrators and investigate the impact on the membrane fouling control. The experiments were carried out in a pilot-scale SMBR unit, treating simulated synthetic municipal wastewater operated previously for a period of 200 d giving steady operating conditions for this investigation.

2. Materials and methods

2.1. Synthetic wastewater

A new strong, in terms of organic load, synthetic wastewater (SWW) was chosen to develop biomass in the SMBR pilot unit. Activated sludge from a municipal wastewater plant was used, when needed, to inoculate the biomass of the pilot unit, in order to maintain the physicochemical and bacteriological values at the desired levels. The composition of the SWW (Table 1) was based on the theoretical contribution of each element to give a ratio of COD/N/P (approx. 100:5:1), and laboratory analytical tests were made to confirm this ratio. The synthesis of SWW was supplemented with minerals and trace elements such as K, Fe, Cu, Mn, Zn, Ca, and Mg.

2.2. Membrane module's properties

The specifications of the membrane used in the pilot plant unit are shown in Table 2.

Table 1
SWW composition

Component	Chemical formula	Concentration in SWW (mg/L)
D (+)-Glucose	$C_6H_{12}O_6\ H_2O$	400 ± 10
Peptone A	Peptone from soymeal	50 ± 2
Peptone B	Peptone from gelatin	150 ± 5
Urea	$CO(NH_2)_2$	50 ± 2
Ammonium sulfate	$(NH_4)_2\ SO_4$	50 ± 2
Ammonium chloride	$NH_4\ Cl$	50 ± 2
Potassium dihydrogen phosphate	$KH_2\ PO_4$	15 ± 1

Table 2
Specifications of the membranes

Manufacturer	Model	Filtration type	Membrane material	Pore size (μM)	Membrane area (M^2)	Membrane type
SINAP Tech. Ltd	SINAP 10	UF	PVDF	0.1	0.1	FS
Hangzhou Tech. Ltd	ZCM-MBR-LAB	MF	PP	0.2	0.2	HF

The FS membrane elements are the smallest production models, while the HF membrane elements are not production models, but special constructions adapted to our needs, both supplied from international manufactures. HF membrane elements were comprised of a closed tubular PVC header, holding horizontally the HF membranes. The ends of the HF membranes are adhesively retained with glue by the manufacturer on the vertical sides of the element. Each membrane filter module was equipped with an upper permeate collection pipe and a corresponding bottom air diffuser.

2.3. SMBR pilot system description

The SMBR pilot system consists of two parts. In the first part, concentrated SWW dosed at a constant rate, simultaneously mixed with reverse osmosis water, to the SWW preparation tank automatically giving the influent SWW. Then, it is pumped to the second part of the SMBR pilot system (Fig. 1) via a centrifugal pump, which is controlled by upper and lower level electrodes placed in the SMBR tank. The SMBR tank consists of an amphoteric (D1) and an aerobic (D2) compartment. The effective volume of the first compartment (D1) is 37 L, in which, the characteristics of biomass are online monitored using a pH meter, a dissolved oxygen (DO) meter, and an MLSS meter. $NaHCO_3$ solution was added automatically for adjusting the pH of biomass. In the second compartment (D2), there are two distinct sub-compartments (47 and 80 L) for the installation of HF or FS membrane modules, respectively. The above sub-compartments are connected with D1 compartment and also with a sludge recirculation circuit. In the first sub-compartment of D2, three HF membrane elements (comprising a membrane module) are placed each one with a separate suction line, and this set of three lines is connected in a common collector suction line with a variable speed peristaltic suction pump. The same arrangement is also presented in the second sub-compartment of D2 where three FS membranes modules are placed and connected in a second common collector suction line. On each separate collector suction line, a variable speed peristaltic suction pump is installed operating for 8 min and shutting down for 2 min (relaxation period of filtering process) for both type of membranes. A PLC control station was used for continuous recording and controlling the basic parameters such us MLSS, pH, DO, trans-membrane pressure (TMP), flux, and was operated remotely via website. The necessary amount of air for the biological process into D1 compartment could be supplied either by tubular medium size bubble diffuser or by air stone fine bubble diffusers fed from a diaphragm type blower. Air-scouring into D2 compartment was supplied by a diaphragm blower which feeds tubular medium sized bubble diffusers. The air flow to each set of diffusers is regulated by regulator valves and air flow meters.

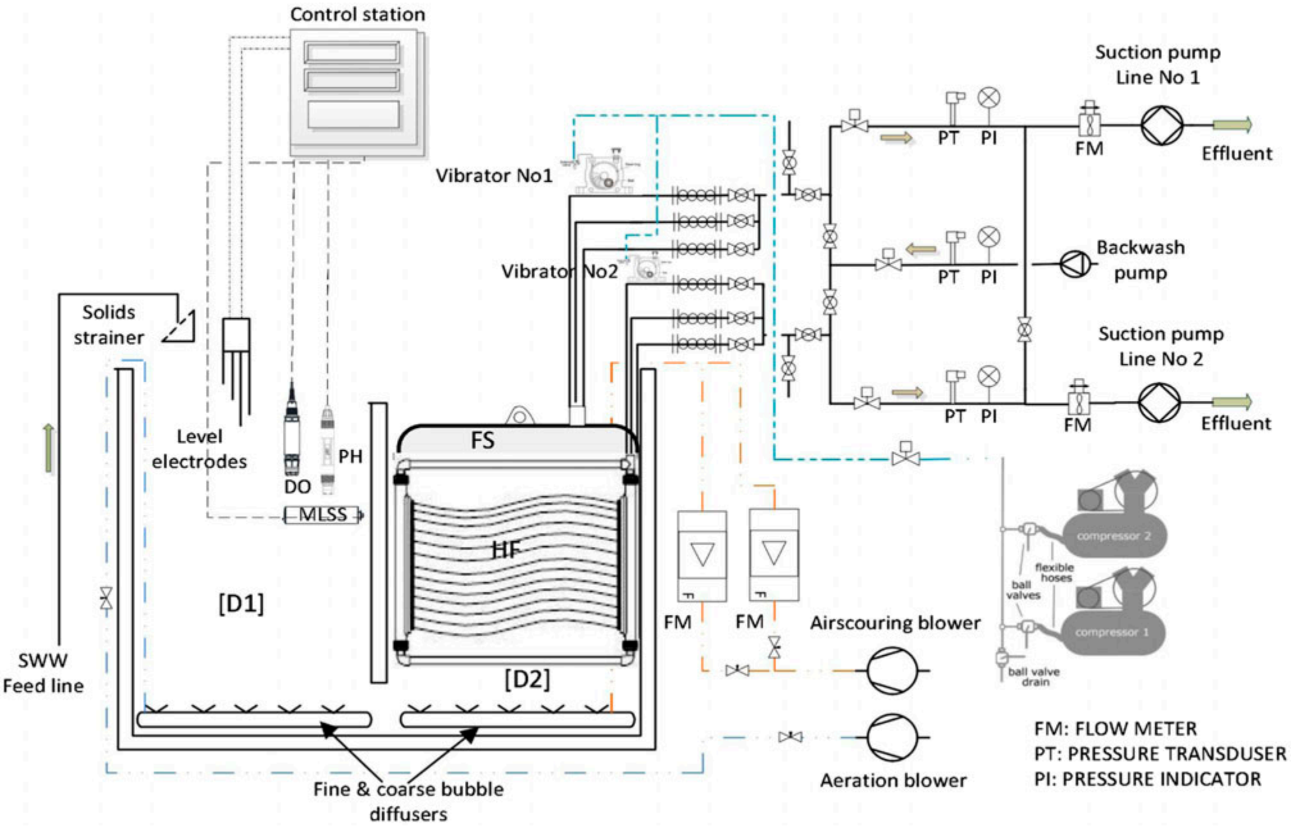

Fig. 1. Schematic overview of the second part of the SMBR pilot system.

The vibration system consists of the vibration header/s, air compressors, feed air pipes, regulation/control valves, and pressure measurement/control apparatus. A pneumatic ball vibrator header is fastened on each of the collector suction lines of the two membrane modules, in order to provide shear forces through powerful vibration. Each suction line is equipped with an anti-vibration flex connector for limiting the transmission of vibration from membrane modules to the rest of the system. Working principle of the vibrator header is very simple (Fig. 2). Compressed air drives an internal ball at high speeds around a highly finished and hardened steel race, creating high frequency vibration. Ball vibrator mounts tightly directly to the structure for minimize energy loss. Since the vibration is created only by the high speed rotation of the steel ball into the structure of the body, there are no complicated parts and suitable vibration adjustment can be easily performed.

Frequency and centrifugal force can be easily changed only by operating the pressure of compressed air. In the present experimental procedure, two types of pneumatic ball vibrators were used. The first type was a small vibrator (V8) in a range of frequencies of 425–583 Hz (25.500 rpm at 2 bar–35.000 rpm at 6 bar), and the second type was a bigger vibrator (V16) in a range of frequencies of 217–325 Hz (13.000 rpm at 2 bar–19.500 rpm at 6 bar) according to the manufacturer data. In this study, vibration experiments took place mainly during relaxation period of filtering process. The vibration moves the membrane in a powerful way to all directions.

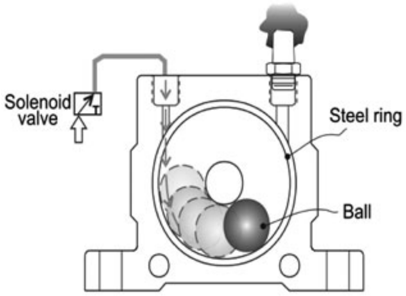

Fig. 2. Pneumatic ball vibrator header scheme.

Desired amplitude and frequency of vibration of each of the two vibrators used (V8 and V16) may be adjusted either by the pressure and/or by means of compressed air flow to the vibrator header. Vibration could be applied in a continuous or an intermittent scheduled mode.

2.4. SMBR experimental conditions

The SMBR pilot-scale system was operated for a period of more than 200 d, giving the biomass steady state operating conditions, for the running experiments in this study. MLSS was maintained in a range of 7,500–10,000 mg/L and TMP values, for membrane modules, were held lower than 200–250 mbar according to manufacturer's instructions, throughout all the experiments. The SMBR system was regulated to operate under low air-scouring conditions and at a fixed pump speed (i.e. under a constant flux), in order to achieve a simulated adequate membrane fouling in a relatively short time. According to the manufacturer's instructions, the membrane aeration rate for every HF membrane element should be 1.5–2 L/min. Throughout of all the experiments, the system was supplied with 1.5–2 L/min for all the three HF membranes per module, so the air-scouring flow was set to 1/3 of the manufacturer's instructions. Moreover, no backwash cleaning procedure took place in this study. Also, the membrane aeration rate for every FS membrane element should be 7–9 L/min but throughout of all the experiments, the system was supplied with 3–4 L/min of air for all the three FS membranes per module, so the air-scouring flow was set to almost 1/7 of the manufacturer's instructions. The membrane module's HFPV vibration characteristics, using the V8 and V16 vibrator types, were measured with special measuring equipment (Laser Doppler vibrometer) and are shown in Table 3.

3. Results and discussion

3.1. HFPV implementation on HF membrane module

The evaluation of HFPV application on HF membrane module was lasted 29 d (29 d experiment) divided in three phases monitoring continuously the TMP and permeate flux of effluent vs. time. The presented values of TMP are mostly mean hour values normalized to a standard temperature of 20°C. Moreover, flux and TMP values were additionally confirmed by measuring manually the effluent volume and by mechanical glycerin gauges, respectively.

Fig. 3 shows the resulting TMP and permeate flux data vs. time during the first phase of the experiment (days 1–18). It is observed an almost constant high flux value of about 6 L/m^2 h (close to the critical one for this type of membrane) for the first 15 d. In this phase, TMP highly increased in the first two days, from 7 to 40 mbar (day 2), cause of a rapid sludge layer formation to the membrane, reaching 70 mbar in the next four days (day 6), and then in the next 8 d up to 150 mbar (day 14). Subsequently in the following 5 d, a sharp increase on TMP values occurred, reaching 200 mbar (end of the day 18) which was the set pressure operation limit for this filter module, accompanied by a reduction in flux values (about 3 L/m^2 h) indicating a significant membrane fouling. Under these conditions, from this point, an HFPV procedure took place.

Fig. 4 shows the TMP and permeate flux data vs. time in the second phase of the experiment, (days 19–21). The HFPV implementation was started during day 19, where three different vibrating schemes were applied (depicted in Fig. 4), with intervals of 1 h, following each other as follows: (a) light vibration scheme (VT1) using a V8 vibrator working for 5 min, (b) medium vibration scheme (VT2) using a V16 vibrator working for 5 min, and (c) strong vibration scheme (VT3) using a V16 vibrator working for 10 min.

As it is seen (Fig. 4), the VT1 vibration scheme has a good contribution to TMP values (decrement about 15%) and a positive contribution to flux values (increment about 10.5%). After applying the VT2 vibration scheme, a more positive contribution effect to the above parameters was observed (lowering 27% the TMP and increasing 26.5% the flux values). Finally by applying the VT3 vibration scheme, TMP values are

Table 3
Membrane module's vibration types and characteristics

Vibrator type	Membrane type	Compressor's pressure (bar)	Vibrator's supply air pressure (bar)	Vibration frequency (Hz)	Vibration velocity RMS (mm/s)	Vibration acceleration RMS (g)	Vibration displacement p-p (mm)
V8	H.F	7	4	223	142	20	0.3
V16	H.F	5	3	76	134	6.6	0.78
V8	F.S	7	4	152	93	10	0.25
V16	F.S	5	3	58	140.2	5.5	1.0

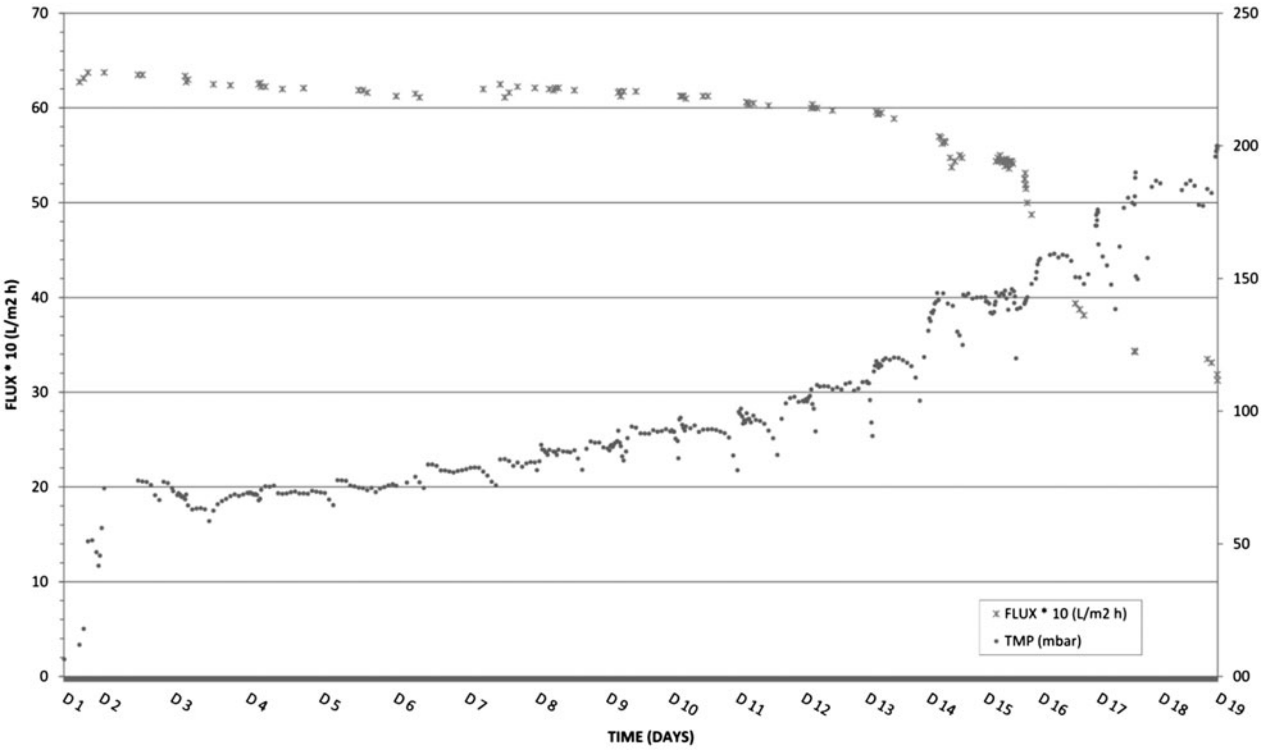

Fig. 3. TMP and permeate flux profiles vs. time on HF membrane module monitored in the first phase of the MBR experiment (days 1–18), before HFPV implementation.

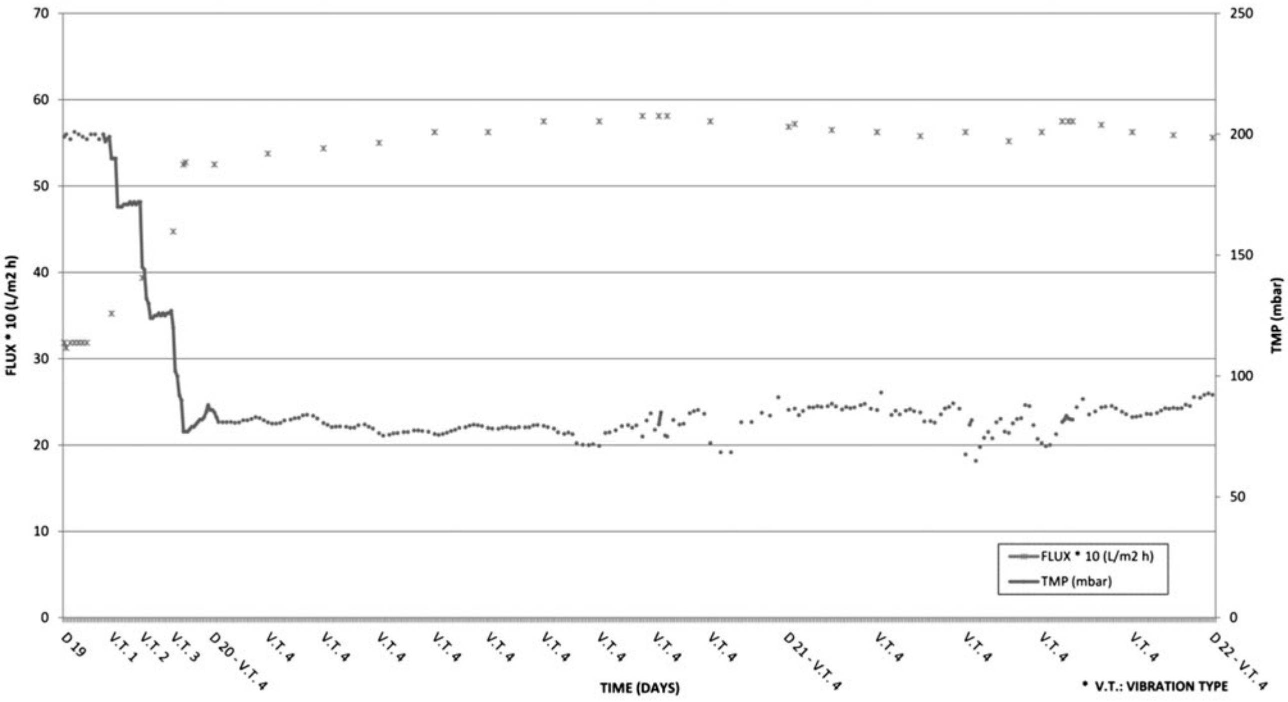

Fig. 4. TMP and permeate flux profiles vs. time on HF membrane module monitored in the second phase of the MBR experiment (days 19–21), during HFPV implementation.

reduced dramatically (almost at 75 mbar, that means a 39% additional decrement), while flux was recovered to initial values (5–6 L/m^2 h). The system after this last vibration scheme, at this point, behaved similarly with that of having new filter modules presented the same TMP values, after a working period of 8 d from the start of its installation in the unit (see Fig. 3).

In order to study the permanent filter cleaning hereafter during continuous operation of the SMBR system (preserving TMP values below 100 mbar), a new vibration scheme was applied after the last vibration scheme for the next three days (days 20–22). This vibration scheme VT4 (gentle vibration scheme) uses a V16 vibrator for a period of 2 min. Initially, vibration applied ten times (every 2 h) during the day 20, then applied four times (every 4 h) during the day 21, and finally applied four times (every 6 h) during the last day 22. The last vibration period (days 20–22) indicates the successful impact of this method on maintaining TMP and flux values at permanent low level with respect to the first day (start of the day 20). As it was expected, there was a slight increasing trend of TMP from day 20 to day 22 probably due to the increment of the vibrating time intervals. It should be noted that the operating time period of 2 min of VT4 scheme was selected to ensure that the vibration is performed during the relaxing period of MBR filter modules.

Fig. 5 shows the *third phase of the experiment*, when the vibration implementation stops in the middle of the day 22. A continuous deterioration of the filtration performance characteristics was observed in the next seven working days (days 23–29), and the system reaches progressively a steady fouling mode with TMP value of 200 mbar and a flux of about 3 L/m^2 h at day 29. So the HF module performance after this HFPV implementation period was almost the same of a new installed HF module after reaching the TMP values of 70 mbar for the next seven working days (see Fig. 3, day 12 till day 19).

This 29-d experiment was repeated one more time, with almost the same results.

3.2. HFPV implementation on FS membrane modules

The evaluation of HFPV application on FS membrane module was lasted 46 d (46 d experiment) divided in 5 phases monitoring continuously the TMP and permeate flux of effluent vs. time in a similar manner with HF module experiment. The filtration was conducted at a fixed pump speed adjusted at the start of the experiment. This experiment was performed having as a target, a mean value flux of about 18 L/m^2 h (critical flux was about 25 L/m^2 h). However, constant flux could not be achieved, due to the type of pump (peristaltic), the inability to control pump speed automatically and the significant sludge fouling after day 13. Declination of flux was observed as TMP values were highly rising till almost day 25. Then, it was observed an almost constant low flux simultaneously with a continuous increase in TMP values.

As it is seen (Fig. 6), during the *first phase* of the experiment (days 1 to 36), TMP was very low (till day 14), then increased exponentially in the next six days (till day 20) from 15 to 50 mbar and in the next seventeen days, the TMP value was increased at almost 105 mbar (day 37), due to the accelerating fouling process. Visual observation showed that after 25th day of the experiment, a permanent sludge cake layer started creating on the surface between the membranes. According to the attached photos (Fig. 7(a)) illustrating the state of the membranes before the application of vibration, a permanent sludge cake layer was formed between membranes, clogging them. TMP values were approximately 100 mbar, and flux was almost 3.5 L/m^2 h. Under these prescribed conditions, HFPV implementation procedure begins during the 37th day of the experiment with vibration schemes that depicted in Fig. 6. It should be noticed that the clogging membranes were attempted to unclog, using an intense air-scouring flow with negative results, before the HFPV application.

In the *second phase* of the experiment (day 37), a light vibration scheme VT1 was applied two times, following each other at time intervals of 1 h. As it is shown in Fig. 6, the first VT1 vibration scheme results a temporarily slight impact on TMP (9% decrement) as well as a good contribution on flux (20% increment) values. Almost the same impact had the second VT1 vibration scheme. Conclusively as it is seen in Fig. 6, the application of the VT1 scheme resulted a stabilization of TMP and flux figures in a sawtooth-like shape.

In the *third phase* of the experiment (day 37), a medium vibration scheme VT2 (between the second and third vertical dashed lines) was applied three times. After the last VT2 vibration, TMP values reduced significantly to less than 80 mbar (21.5% decrement), while flux was raised to almost 10 L/m^2 h (138 30.5% increment). At this point, the successful impact of the above vibration schemes on filter module, for unclogging and cleaning the membrane elements from a permanent and severe sludge cake deposition, is obvious in Fig. 7(b) and (c). Moreover, the application of the HFPV method prevents the pressure rise and helps to increase the membrane flow. The above results could be better when they are accompanied by a simultaneous increase of the

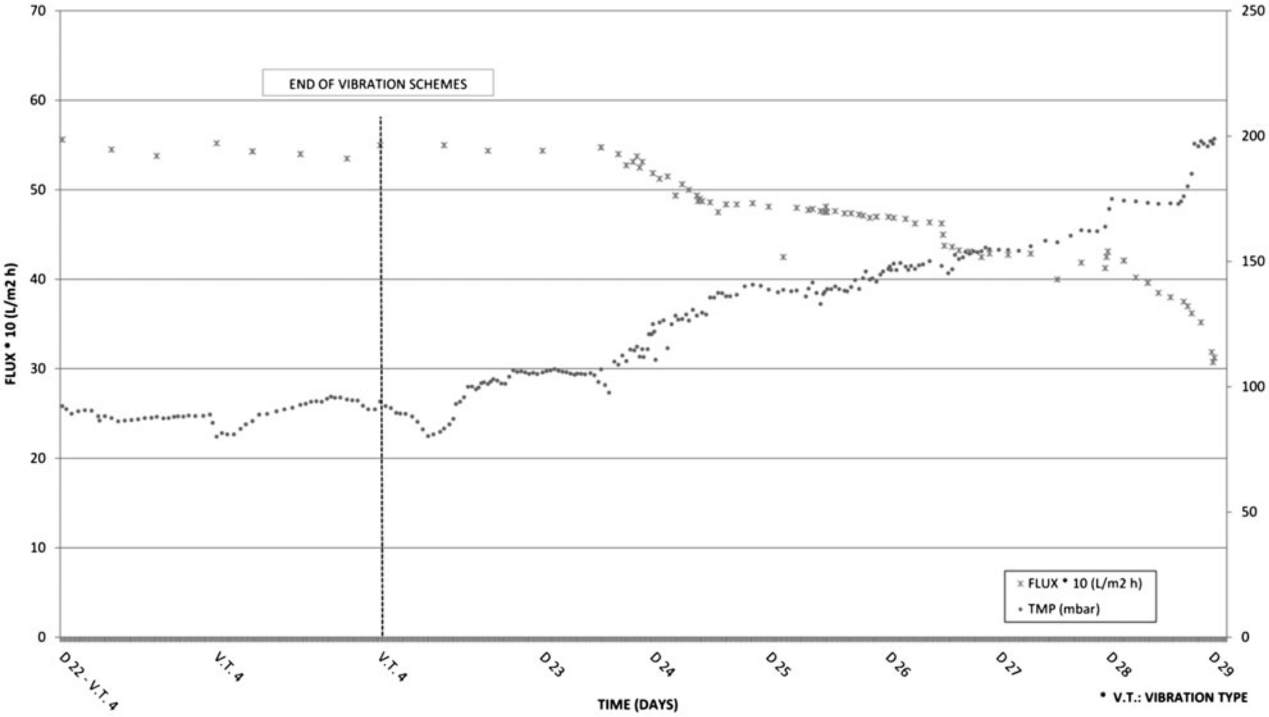

Fig. 5. TMP and permeate flux profiles vs. time on HF membrane module monitored in the third phase of the MBR experiment (days 22–29) after HFPV implementation.

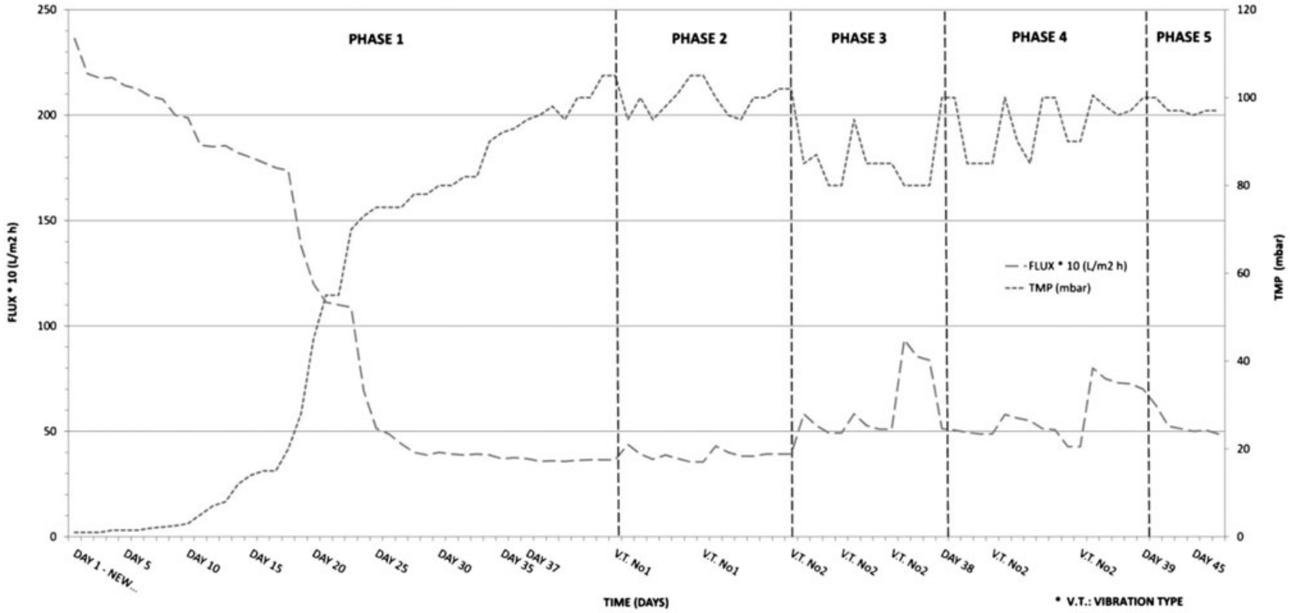

Fig. 6. TMP and permeate flux profiles vs. time on FS membrane module monitored, during the different phases of the experiment.

air-scouring or combined with an advanced operation computerized control system, equipped with the appropriate software. The HFPV method seems to work properly where the air-scouring cleaning method cannot reverse the condition of the fouled filter elements.

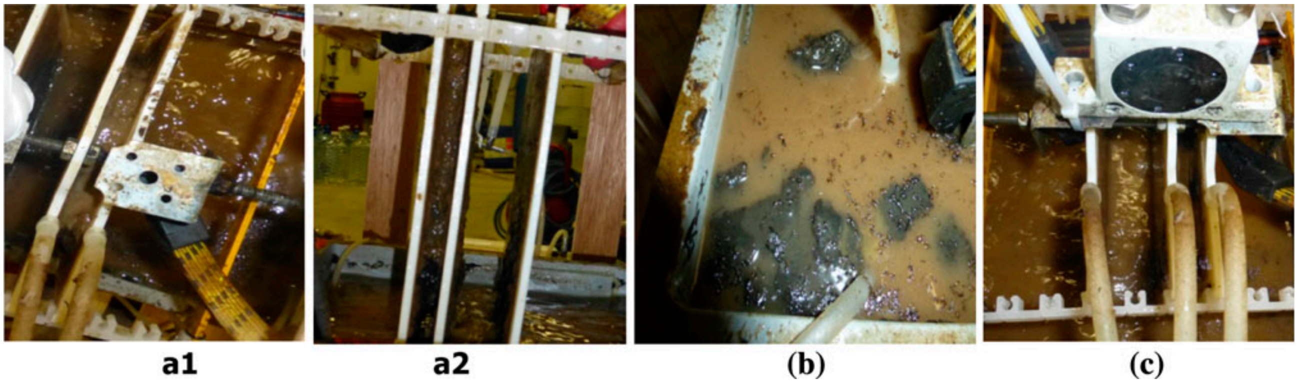

Fig. 7. FS membrane elements during the experimental phases: (a) membranes before HFPV implementation at the end of phase one (day 36) indicating the filter clogging (membranes in and out of the biomass compartment, a1 and a2, respectively), (b) pieces of broken sludge cake deposition in biomass, after the HFPV implementation at the end of phase three (day 37), and (c) unblocked membrane elements in the biomass compartment, after HFPV implementation at the end of phase three (day 37).

In the *fourth phase* of the experiment (day 38), a VT2 scheme was applied two times on membranes, with a time interval of 5 h, giving a sawtooth-like diagram (Fig. 6), due to the periodic application of vibration.

In the *fifth phase* of the experiment (days 39–45), where no vibration was applied, it is observed that the trend of TMP values was stabilized at about 100 mbar while flux values declined rapidly (Fig. 6). That indicates that when the system works under low air-scouring mode, it is necessary to apply HFPV method at shorter intervals, in order to keep TMP and flux values in acceptable limits.

4. Conclusions

The HFPV technique applied in this preliminary study on membrane modules in a small pilot-scale SMBR system treating SWW was found to be very promising. The results showed clear advantages of this vibrating technique over the air-scouring conventional MBRs cleaning processes, in terms of realizable flux and membrane fouling control.

The performance of the HFPV technique applied on HF membranes seems to be very high, turning the behavior of the fouling membranes almost to the cleaned ones, in terms of TMP and flux measuring values. HFPV method seems also very helpful and promising for FS membranes. This technique seems to both unblock and clean the membrane elements from permanent and severe fouling deposition, where the air flow cannot reverse the condition of fouled elements. The application of an intense HFPV in a short time period after the fouling problem on these membranes gave excellent results on fouling control.

The repeated regular vibrations continued after that, showed a stable management in terms of maintaining TMP and flux values in permissible and desirable levels, demonstrating the successful impact of vibration schemes used on fouled membranes. The energy benefit using vibration techniques for preventing membrane fouling seems to be very high, compared to the conventional process of an intense air-scouring used to clean membranes throughout the whole process. In addition, this lower aeration should also help to minimize the excess DO that returns to anoxic tank via the mixed liquor from membrane tank, which typically contains DO at high levels, decreasing significantly the denitrification efficiency. In addition, this preliminary study will contribute to the scale up methods for similar full scale SMBR systems.

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