Studying the effects of organic and hydraulic shock loads on the membrane bioreactor (MBR) by using GPS-X mathematical model

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Membrane Bioreactor (MBR) can be broadly defined as systems integrating biological degradation of waste products with membrane filtration. They have proven quite effective in removing organic and inorganic contaminants as well as biological entities from wastewater. Advantages of the MBR include good control of biological activity, high quality effluent free of bacteria and pathogens, smaller plant size, and higher organic load rates. This study aims to investigate the performance and treatment capability of Membrane Bioreactor (MBR) by using a powerful simulation program (GPS-X). Also the effects of organic and hydraulic shock loads on the MBR system were studied. The GPS-X (version 5.0) simulation program was used in this study to simulate the MBR plant. The GPS-X is a modular, multi-purpose modeling environmental for the simulation of municipal and industrial wastewater treatment plants. The results of this study showed that, the efficiency of the MBR system due to normal case of operation based on BOD removal was 95.0 %. Also, the MBR system has a sensitive ability due to the hydraulic shock load of operation and the treatment efficiency for the MBR plant due to this shock loads based on BOD removal were decreased up to 49.0 %. The MBR system has a good ability to receive the organic shock load of operation without a big loss of the treatment efficiency. The treatment efficiency for the MBR plant due to the organic shock loads based on BOD removal were slightly decreased up to 84.0%.

يعتبر نظام المعالجة البيولوجية باستخدام الاغشية المسامية (Membrane Bioreactor) ذو كفاءة عالية جدا في ازالة المواد العالقة والمواد العضوية والغير عضوية من المخلفات السائلة. ومع ازدياد استخدام هذا النظام علي نطاق واسع في الفترة الاخيرة في محطات المعالجة الصغيرة و المتوسطة تطلب ذلك عمل المزيد من الدراسات علي كفاءة هذا النظام. و يهدف هذا البحث الي دراسة تأثير احمال الصدم الهيدروليكية والعضوية علي كفاءة المعالجة باستخدام هذا النظام. وقد تم استخدام برنامج خاص بمحاكاة محطات معالجة المخلفات السائلة (برنامج GPS-X) وهو برنامج فائق الدقة ويمكن من خلاله محاكاة محطة المعالجة و كذلك أحمال الصدم المختلفة التي تتعرض لهـا. وقد أتضح من نتائج البحث ان كفاءة المعالجة في ازالة المواد العضوية من المخلفات السائلة في حالة التشغبل العادي لا تقل عن ٩٥%. بينما في حالات الصدم الهيدروليكية و العضوية قد انخفضت هذة الكفاءة الي ٤٩% و ٨٤% علي الترتيب. مما يدل علي ان نظام المعالجة البيولوجية باستخدام الاغشية المسامية ذو قدرة اكبر في تحمل احمال الصدم العضوية عن أحمال الصدم الهيدروليكية.

Keywords: Membrane bioreactor, GPS-X mathematical model, Organic shock loads, Hydraulic shock loads

1. Introduction

The Membrane Bioreactor (MBR) concept is a combination of conventional biological wastewater treatment plant and membrane filtration. The concept is technically similar to that of a traditional wastewater treatment plant, except for the separation of activated sludge and treated wastewater. In an MBR installation this separation is not done by sedimentation in a secondary clarification tank, but by membrane filtration [1-3]. The high performance of membrane technology has been proven in recent years in a wide range of field, such as chemical industry, medical technology, drinking water treatment, biotechnology and environmental technology. The continuous development of membrane materials and membrane design on the one hand and the knowledge of operational management on the other hand have fostered the growth of membrane technology in wastewater treatment [4, 5].

The first generation of MBRs consisted of external cross-flow operated membranes, which were installed outside the activated sludge tank. This method of cross-flow operation required large amounts of energy to generate the sludge velocity across the membrane surface to maintain both the high cross-flow velocity for membrane cleaning and the required pressure drop necessary for permeation. An important development for membranes came when it was proposed to submerge the membrane in the aeration tank. To achieve permeation the technique utilized a reduced pressure as opposed to an external installation in pressure tubes and the necessity for high over pressure. The energy consumption of the submerged membrane filtration was significantly reduced. The reduced pressure applied in permeate extraction was considerably lower than that required for cross-flow permeation. Furthermore an essential part of the cross-flow technique, the recirculation pump, was absent in the submerged MBR configuration [6- 8].

The modular program used in this study is GPS-X which is a modular, multi-purpose modeling environmental for the simulation of municipal and industrial wastewater treatment plants. GPS-X uses an advanced graphical user interface to facilitate dynamic modeling and simulation. GPS-X is also uses the most recent advances in process modeling, simulation technology, graphics and a host of productivity tools that simplify model construction, simulation and interpretation of results.

2. Materials and Methods

2.1. MBR plant configuration and operation conditions

The proposed Membrane Bioreactors (MBR) plant are composed of two primary parts, first part is aeration tank unit for the biological biodegradation of the waste compounds and second part is the membrane module unit for the physical separation of the effluent from aeration tank. Fig. 1 shows the MBR plant layout. The MBR system used in the plant can be known as the submerged MBR system because the skin membranes are submerged into the aeration tank. The driving force across the membrane is achieved by creating negative pressure on the permeate side. Cleaning of the membrane is achieved through frequent permeate back pulsing and occasional chemical backwashing. A diffuser is placed directly beneath the membrane module to facilitate scouring of the filtration surface. Aeration and mixing are also achieved by the unit.

The MBR plant was modeled by using the GPS-X version 5.0 program. The operation conditions of the MBR plant were as follows:

- Numbers of reactors = 4, each reactor volume = 125 m^3, total reactors volume = 500 m^3.
- Average flow rate = 2000 m^3/d.
- Hydraulic retention time (HRT) = 6.0 hr.
- Mixed Liquor Suspended Solids (MLSS) = 10000 mg/l.
- Temperature = 20 C^o.
- Membrane pore size = 1.0 µm.
- Total membrane surface area = 4000 m^2.
- Transmembrane pressure = 0.1 bar.
- Cross air flow = 19000 m^3/d.
- Frequency of backwash = 15 min, duration of backwash = 30 sec, backwash flow = 2000 m^3/d.
- Frequency of chemical cleaning = 6.0 months.

2.2. Influent wastewater and model scenarios

The MBR plant model was run by using three scenarios. First scenario was the normal operation; second scenario was the hydraulic shock load operation whereas the third scenario was the organic shock load operation. During the normal operation scenario the biochemical oxygen demand BOD_5 and the average flowrate for the influent wastewater were constant along the running time for the MBR plant model. All scenarios run for 80 days of operation. Influent wastewater characteristics for the MBR plant showed on table 1.

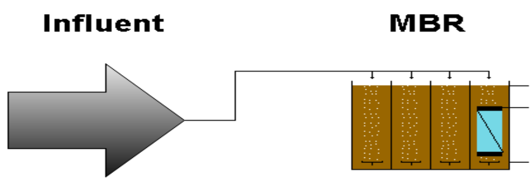

Fig. 1. MBR plant layout.

Table 1

Influent wastewater characteristics

Parameter	Concentration (mg/l)
BOD_5	200
COD	451
Total SS	250
Volatile SS	150
TKN	18
Ammonia nitrogen	11.7

3. Results and discussion

3.1 Normal operation

The GPS-X model for the normal operation mode of the MBR plant run for 80 days of operation with average daily flow and BOD_5 2000 m^3/d and 200 mg/l respectively. Figure 2 shows relation between the effluent BOD_5 concentrations with time of operation during normal case of operation of the MBR plant. Fig. 3 shows the relation between effluent TKN with time of operation during the normal case of operation.

Table 2 shows the summary of results for the MBR model for the normal operation scenario. It is clear from these results that, the 90.0 % of the BOD removal can be achieved after 30 days of operation (no external sludge were seeded to the MBR system). So it can be concluded the start up period for the MBR plant is 30 days. After that period, the efficiency of the MBR plant for the BOD removal ranged form 90.0 up to 96.0 %. The average of the TKN removal for the MBR model were 85.0 %.

3.2. Hydraulic shock loads

The GPS-X model for the hydraulic shock loads operation mode of the MBR plant run for 80 days of operation with average daily flow and BOD_5 2000 m^3/d and 200 mg/l respectively. The suddenly hydraulic shock loads on the MBR plant model was conducted by duplication of the average influent flow rate in the middle of the time of operation period. The average influent flow rate during the hydraulic shock loads was 4000 m^3/d. Figure 4 shows the relation between the average influent flow rate with the time of operation during the hydraulic shock load case of operation.

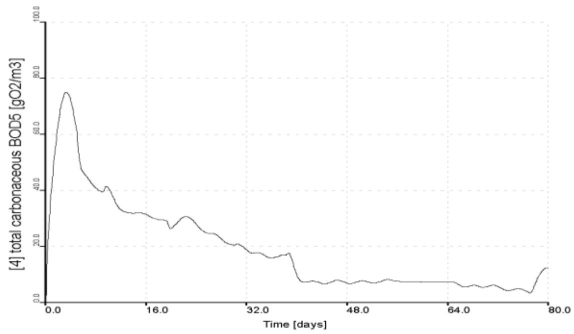

Fig. 2. Relation between effluent BOD_5 with time (normal operation).

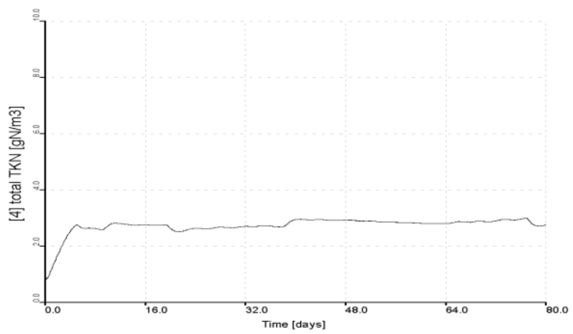

Fig. 3. Relation between effluent TKN with time (normal operation).

Table 2
Summary of results for the MBR model for normal operation

Time of operation (days)	Effluent BOD concentration (mg/l)	BOD removal %	Effluent TKN concentration (mg/l)	TKN removal %	Notes
8	40	80.0	2.63	85.4	Start up period
17	30	85.0	2.75	84.7	
30	20	90.0	2.66	85.2	
40	10	95.0	2.95	83.6	Steady state
50 up to 80	8 up to 12	94.0 up to 96.0	3.0 up to 2.7	83.3 up to 85.0	

Fig. 5 shows the relation between the effluent BOD_5 concentrations with time of operation. Fig. 6 shows the relation between effluent TKN with time of operation during the hydraulic shock loads of operation.

Table 3 shows the summary of results for the MBR model for the hydraulic shock loads scenario. Similar to the normal case of operation, the start up period to achieve 90 % of BOD removal for the MBR plant was 30 days of operation. After that, the steady state operation started and the efficiency of the MBR plant during the steady state period for the BOD removal and TKN removal were about 95.0% and 85.0 % respectively. The treatment efficiency was suddenly decreased due to the hydraulic shock load period (from day 39 up to 40). After that, as shown in the table 3, an interruption period of operation was continued for about 9 days of operation (from day 40 up to 49). The efficiency of the MBR plant during the interruption period of operation for the BOD removal and TKN removal decreased up to 49.0% and 33.3 % respectively. After that, a new steady state of operation started and the treatment efficiency returned back to the same values as the normal case of operation. It can be concluded from these results the MBR is very sensitive due to hydraulic shock load of operation and the treatment efficiency for the MBR plant decreased up to 49.0 % of BOD removal. Also, a significant interruption period occurred due to the suddenly hydraulic shock loads on the MBR plant.

3.3. Organic shock load

Similar to the hydraulic shock load case, the GPS-X model for the organic shock loads operation mode of the MBR plant was run for 80 days of operation with average daily flow and BOD_5 2000 m^3/d and 200 mg/l respectively. The suddenly organic shock loads on the MBR plant model was conducted by duplication of the influent BOD_5 in the middle of the time of operation period. The influent BOD_5 during the organic shock loads was 400 mg/l. Fig. 7 shows the relation between the influent BOD_5 with the time of operation during the hydraulic shock load case of operation. Fig. 8 shows the relation between the effluent BOD_5 concentrations with time of operation whereas, Figure 9 shows the relation between effluent TKN with time of operation during the organic shock loads of operation.

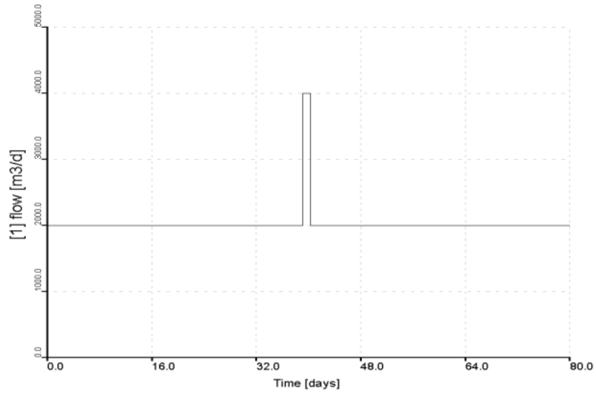

Fig. 4. Relation between influent flow with time (hydraulic shock load).

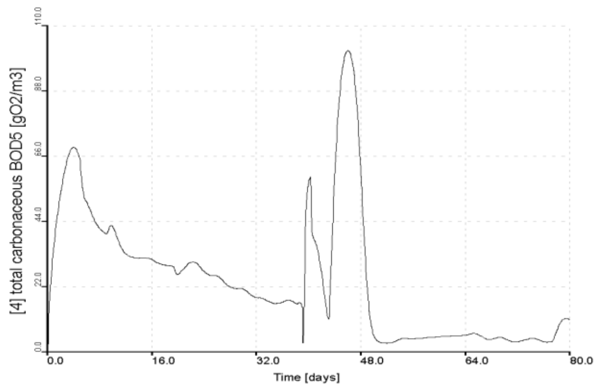

Fig. 5 Relation between effluent BOD_5 with time (hydraulic shock load).

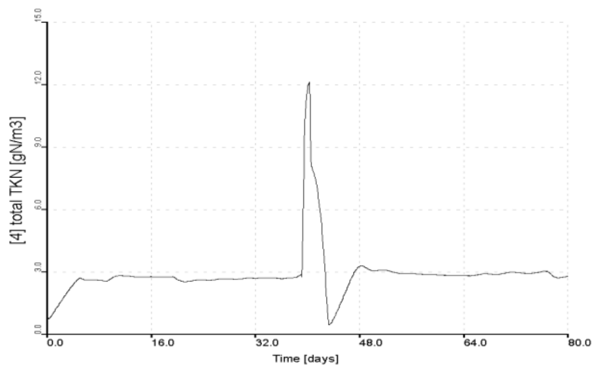

Fig. 6. Relation between effluent TKN with time (hydraulic shock load).

Table 3
Summary of results for the MBR model for hydraulic shock load operation

Time of operation (days)	Effluent BOD concentration (mg/l)	BOD removal %	Effluent TKN concentration (mg/l)	TKN removal %	Notes
8	40	80.0	2.63	85.4	Start up period
17	30	85.0	2.75	84.7	
30	20	90.0	2.66	85.2	
30 up to 39	20 up to 10	90.0 up to 95.0	2.66 up to 2.95	85.2 up to 83.6	Steady state
39 up to 40	10 up to 59	95.0 up to 70.5	2.95 up to 12.0	83.6 up to 33.3	Hydraulic shock load period
40 up to 43	59 up to 11	70.5 up to 94.5	12.0 up to 0.5	33.3 up to 97.2	Interruption period
43 up to 46	11 up to 102	94.5 up to 49.0	0.5 up to 3.2	97.2 up to 82.2	
46 up to 49	102 up to 10	49.0 up to 95.0			
49 up to 80	10 up to 3	95.0 up to 98.5	3.2 up to 2.8	82.2 up to 84.4	Steady state

Table 4 shows the summary of results for the MBR model for the organic shock loads scenario. Similar to the normal case of operation, the start up period was 30 days of operation to achieve 90 % of BOD removal for the MBR plant. After that, the steady state operation started and the efficiency of the MBR plant during the steady state period for the BOD removal and TKN removal were about 95.0% and 85.0 % respectively. The treatment efficiency was slightly decreased due to the organic shock load period (from day 40 up to 41). After that, as shown in the table 3, a short interruption period of operation was continued for only one day of operation (from day 41 up to 42). The efficiency of the MBR plant during the interruption period of operation for the BOD removal and TKN removal slightly decreased up to 84.0% and 72.8% respectively. After that, a new steady state of operation started and the treatment efficiency returned back to the same values as the normal case of operation.

It can be concluded from these results that the MBR has a good ability to receive the organic shock loads of operation without a significant reduction in the treatment efficiency. And also, the organic shock load caused a short interruption period of operation (only one day) with a slightly reduction in the treatment efficiency.

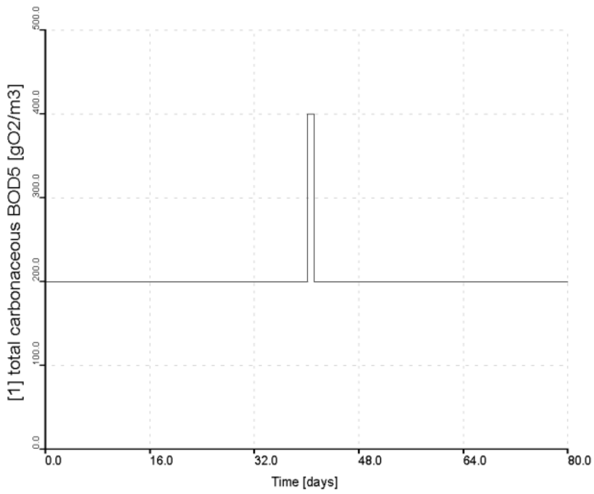

Fig. 7. Relation between influent BOD_5 with time (organic shock load).

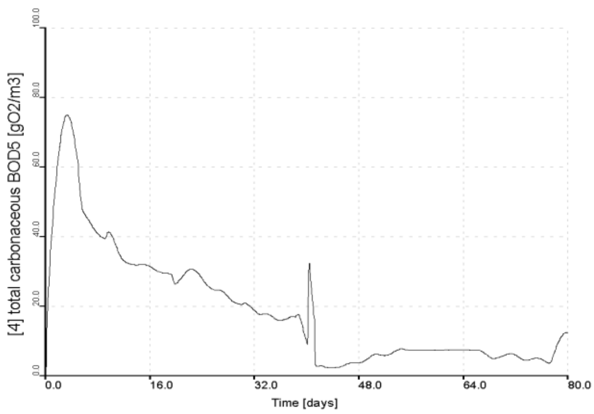

Fig. 8. Relation between effluent BOD_5 with time (organic shock load).

Table 4
Summary of results for the MBR model for organic shock load operation

Time of operation (days)	Effluent BOD concentration (mg/l)	BOD removal %	Effluent TKN concentration (mg/l)	TKN removal %	Notes
8	40	80.0	2.63	85.4	Start up period
17	30	85.0	2.75	84.7	
30	20	90.0	2.66	85.2	
30 up to 40	20 up to 10	90.0 up to 95.0	2.66 up to 2.95	85.2 up to 83.6	Steady state
40 up to 40.5	10 up to 32	95.0 up to 84.0	2.95 up to 4.9	83.6 up to 72.8	Organic shock load period
40.5 up to 41	32 up to 17	84.0 up to 91.5			
41 up to 42	17 up to 3	91.5 up to 98.5	4.9 up to 3.5	72.8 up to 78.9	Interruption period
42 up to 80	3 up to 10	98.5 up to 95.0	3.5 up to 2.75	78.9 up to 84.7	Steady state

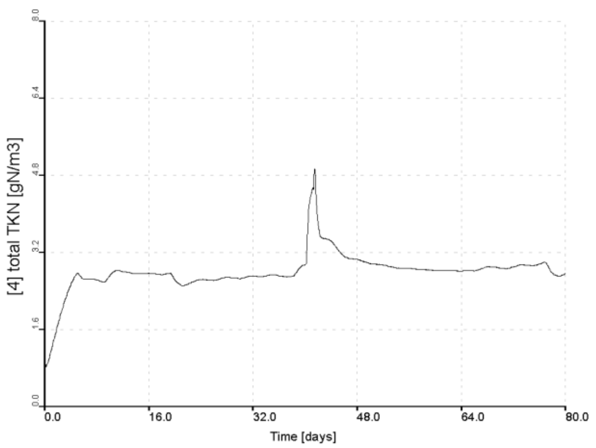

Fig. 9. Relation between effluent TKN with time (organic shock load).

4. Conclusions

Based on the observation and results obtained from this study, the following points are concluded:

- The treatment efficiency of the MBR system for the BOD removal was about 95 % during the steady state of operation whereas the TKN removal (without denitrification operation phase) for the MBR system was about 85.0 %.

- The MBR system has a sensitive ability due to suddenly hydraulic shock load of operation. Also, the hydraulic shock loads caused a significant interruption period of operation for the MBR system. The treatment efficiency for the MBR plant due to this shock loads based on BOD removal and TKN removal decreased up to 49.0 % and 33.3 % respectively.

- The MBR system has a good ability to receive suddenly organic shock load of operation without high loss of the treatment efficiency. Also, the organic shock loads were caused a short interruption period of operation for the MBR system. The treatment efficiency for the MBR plant due to this shock loads based on BOD removal and TKN removal were slightly decreased up to 84.0% and 72.8% respectively.

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