ORIGINAL ARTICLE

Food industrial wastewater reuse by membrane bio-reactor

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Abstract

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The objective of this investigation was to study the possibility and performance of treating food industrial wastewater by Membrane BioReactor (MBR). In addition, the effluent of MBR was treated by Reverse Osmosis system (RO) to reuse in boiler or cooling tower. The membranes of hollow fiber type were filled in the aerobic tank with aerobe bacteria. The total area of membrane 6 units was 630 m^2 so the flux of the operation was 0.25 m/d or 150 m^3/d. The spiral wound RO was operated at 100 m^3/d of influent and received 72 m^3/d of permeate. The sludge volume (MLSS) of MBR was maintained at 8,000-10,000 mg/l. The average COD and SS of MBR influent were 600 mg/l and 300 mg/l respectively. After treating by MBR, COD and SS of effluent were maintained at less than 100 mg/l and less than 10 mg/l respectively. In the same way, COD and SS of RO permeate were less than 10 mg/l and less than 5 mg/l respectively.

Key words : hollow fiber type, Membrane Bio-Reactor, MBR, Reverse Osmosis, RO

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บทคัดย่อ

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การนำน้ำเสียอุตสาหกรรมอาหารกลับมาใช้ใหม่โดยระบบบำบัดน้ำเสียแบบตะกอนเร่งร่วมกับเมมเบรน

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งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาความเป็นไปได้ และศักยภาพในการบำบัดน้ำเสียโรงงานอาหาร โดยใช้ระบบตะกอนเร่งร่วมกับเมมเบรน ซึ่งน้ำเสียที่ผ่านการบำบัดจากระบบเมมเบรนแล้วจะนำไปบำบัดต่อด้วยระบบรีเวิร์สออสโมซิส เพื่อนำกลับมาใช้ในระบบหม้อไอน้ำหรือระบบหล่อเย็น ลักษณะของเมมเบรนที่ใช้เป็นชนิดแบบ hollow fiber ซึ่งบรรจุลงในถังเติมอากาศที่มีเชื้อจุลินทรีย์ที่ใช้ออกซิเจน พื้นที่รวมของเมมเบรนที่ใช้ประมาณ 630 ตร.เมตร จำนวน 6 หน่วย เดินระบบที่อัตราการสูบน้ำเสีย 0.25 เมตร/วัน หรือ 150 ลบ.เมตร/วัน ลักษณะของระบบรีเวิร์สออสโมซิส เป็นแบบ spiral wound ที่อัตราสูบน้ำเสีย 100 ลบ.เมตร/วัน สามารถกรองน้ำได้ 72 ลบ.เมตร/วัน โดยมีปริมาณของเชื้อจุลินทรีย์ในระบบเมมเบรนในช่วง 8,000-10,000 มก./ลิตร ปริมาณซีโอดี และของแข็งแขวนลอยของน้ำเสียก่อนบำบัดเป็น 600 และ 300 มก./ลิตร ตามลำดับ หลังการบำบัดด้วยระบบเมมเบรน ปริมาณซีโอดีและของแข็งแขวนลอยที่ได้น้อยกว่า 100 และ 10 มก./ลิตร ตามลำดับ ในทำนองเดียวกันปริมาณซีโอดี และของแข็งแขวนลอยที่ได้หลังการผ่านระบบรีเวิร์สออสโมซิส น้อยกว่า 10 และ 5 มก./ลิตร ตามลำดับ

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The membrane bioreactor (MBR) is an advance biological treatment system. The characteristics of the system are like an activated sludge (AS) system (Chang and Judd, 2003). However, it differs from AS in that MBR uses membranes to separate solid and liquid, replacing the gravity sedimentation (Liu, 1999). The MBR processes can be divided into 2 phases. First, microorganism as an aerobe bacterium decomposes organic substance with excess oxygen. Second, treated water is passed through the membrane micro filter to reduce SS (Lubello and Gori, 2004).

The MBR permits the maintenance of high sludge concentration in the bioreactor so the system can treat the high strength wastewater and may leave a compact foot print (Chang and Judd, 2003; Lubello and Gori, 2004). In addition, the hydraulic retention time may be short. The treated water can be reused effectively because it has a good quality, especially COD and SS, so the maintenance and management of the system are easier than for AS.

The high strength wastewater comes from starch production from rice. The wastewater contains high COD and SS, of 6,000 mg/l and 2,000 mg/l respectively. Normally, the wastewater is treated by an anaerobic process as upflow anaerobic sludge blanket (UASB) and followed by the activated sludge (AS). The effluent COD and SS of UASB is maintained at 1,000 mg/l and 900 mg/l respectively and the effluent COD and SS of AS is maintained at less than 100 mg/l and 50 mg/l respectively. The disadvantage of AS is that the treated water cannot be reused directly because COD and SS are so high that the water may have to be treated with sand filter and membrane micro filter before reuse. In the objective of this research was to study the possibility and performance of MBR to treat wastewater replacing existing AS. Because of the advantage of MBR, COD and SS of the effluent are such lower less than 100 and 10 mg/l respectively, therefore the effluent can be used for cleaning or flushing directly or be treated by RO before reuse in a boiler or cooling tower (Liu, 1999).

Materials and Methods

The experiments were conducted at Choheng Rice Vermicelli Factory Co.,Ltd., Nakhonpathom in a pilot plant MBR and RO at 150 m^3/d and 100 m^3/d respectively. The treated wastewater from UASB was the MBR influent and it maintained an average of COD and SS as 600 mg/l and 300 mg/l respectively. The apparatus of the pilot plant consisted of a membrane tank, 6 membrane units of hollow fiber type, a vacuum pump and a spiral wound RO unit. The MBR was operated at a flux of 0.25 m/d (5.25 m^3/hr) for 8 months. Not only was the MLSS concentration maintained at 8,000-10,000 mg/l but also the DO was maintained at 1 mg/l. The flow rate of the air blower was 180 m^3/hr to clean the sludge clogging the membrane surface and to keep the DO steady. In the same way, the operating parameters of the RO were permeate flow rate 3 m^3/hr, brine flow rate 2 m^3/hr, recycle rate 6 m^3/hr, recovery rate 60% and rejection rate 90%.

Table 1. Specification and operating condition of MBR.

Membrane specifications	Type : HDPE Pore size: 0.4 µm Dimension: 540 µm (outer diameter) x 360 µm (inner diameter) Surface area: 210 m^2 x 3 unit = 630 m^2
Operating conditions	Suction pump: 12 min ON, 3 min OFF Designed flux: 0.25 m/d Designed capacity: 157.5 m^3/d

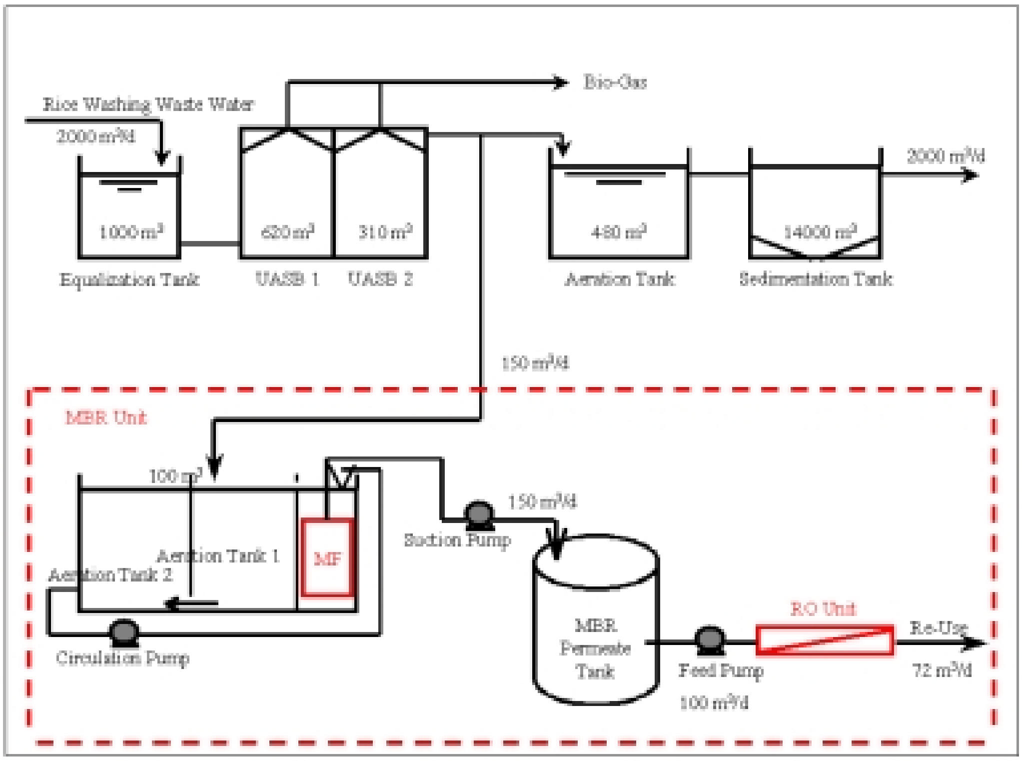

Figure 1. Flow chart of replacing MBR and RO system.

Table 2. Specification and operating condition of RO.

RO membrane specifications	Type: LFC1-Membrane Element: 8 inch, 3 vessels, 6 elements
Operating conditions	Permeate: 3 m^3/hr Brine: 2 m^3/hr Recycle: 6 m^3/hr

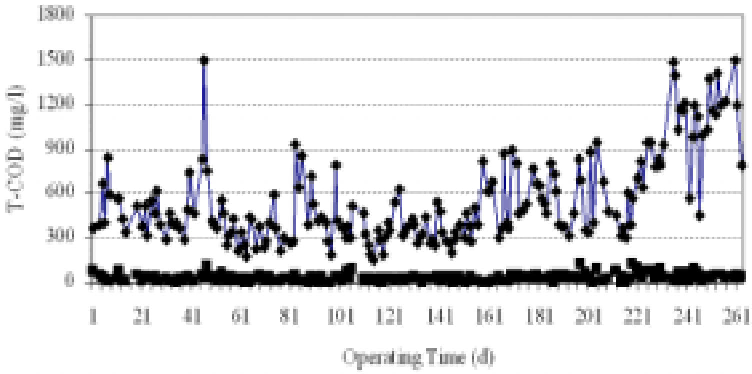

Figure 2. The COD of influent (◆) and effluent (■) of MBR

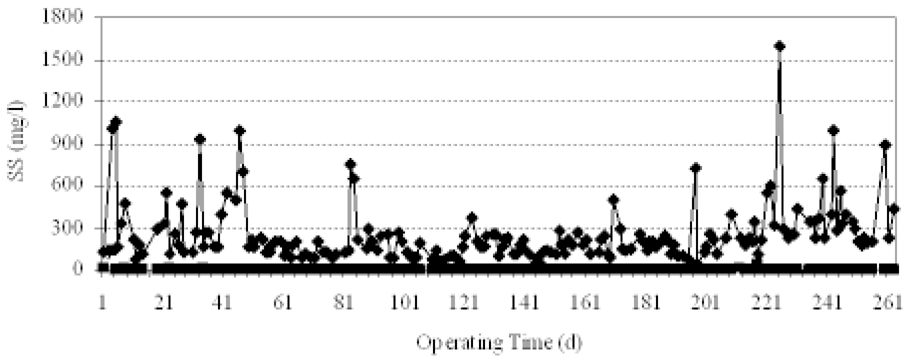

Figure 3. The SS of influent (◆) and effluent (■) of MBR.

Result and Discussion

Normally, aerobe bacteria decompose organic substances so that the COD is reduced in the aeration tank. The result of COD removal efficiency of MBR is shown in Figure 2 as the COD of influent and effluent of MBR. The average COD of influent and effluent were 600 mg/l and less than 100 mg/l respectively and the efficiency of COD removal was more than 95%. Thus, the MBR has a high efficiency to reduce COD.

After treatment in the aeration tank, the wastewater was pumped through the membrane micro filter to separate SS. Not only SS of waste-water but also sludge in the aeration tank was separated from wastewater by the membrane filter. Therefore, the SS of MBR effluent was less than 10 mg/l. The result of the influent and effluent SS of MBR is shown in Figure 3.

For the operating conditions in MBR, it was necessary to control the MLSS. Normally, the MLSS of the activated sludge was 3,000-4,000

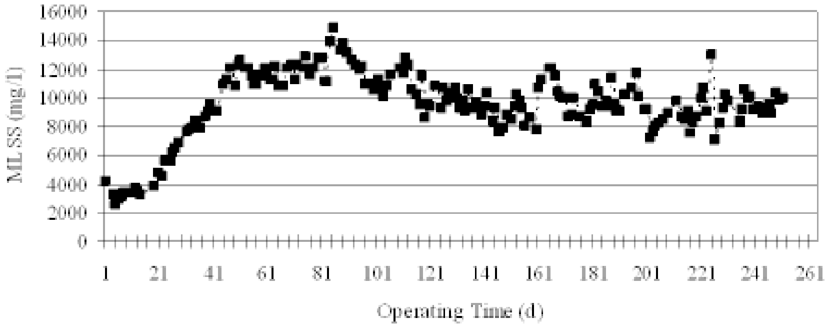

Figure 4. The MLSS (■) of MBR.

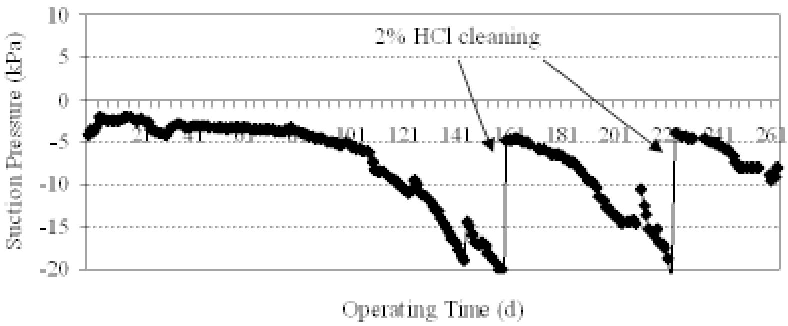

Figure 5. The Suction Pressure (■) of MBR.

mg/l but the MLSS of MBR was higher. In this experiment, the MLSS was maintained at 8,000-10,000 mg/l in order to treat high strength wastewater. When the MLSS was higher than 10,000 mg/l, the operating conditions of MBR were changed is that not only was DO decreased to less than 1 mg/l but also the suction pressure was decreased from -5 kPa to -20 kPa and membrane fouling occurred. However, sludge draining was conducted twice a week to maintain the concentration. It is possible to maintain a constant DO and extend the fouling time. In addition, high COD influent caused a decreased DO of less than 1 mg/l. The result of the MLSS in MBR is shown in Figure 4.

The specifications of the membrane micro filter were: an operating flux of 0.25 m/d (5.25 m^3/hr) and the range of suction pressure from -5 to -20 kPa. At the start, the suction pressure was -5 kPa and was constant for 3 months; after that it decreased from -5 to -20 kPa. This seems to indicate the time to clean the membrane or reduce the flux. The increasing MLSS also caused decreasing flux. When starting the experiment, the MLSS was 3,000 mg/l, and the suction pressure was constant at -5 kPa. After MLSS increased to 10,000 mg/l, the suction pressure was decreased continuously to -20 kPa. Then, the suction pressure was increased back to -5 kPa after cleaning the membrane. Cleaning of the membrane was conducted with 3,000 ppm NaOCl soaking for 2 hrs and 2% HCl soaking for 2 hrs depending on the type of clogging. Normally, NaOCl is used for sludge cleaning and HCl is used for inorganic cleaning (Lubello and Gori, 2004; Okabe, 2002; Smith and Bentley, 2001). The period of cleaning was 2-3 months for each. The result of suction pressure of MBR is shown in Figure 5.

The effluent of MBR had a good quality with COD and SS were less than 100 mg/l and 10 mg/l respectively. The effluent can be used directly for cleaning or flushing as well as for a boiler or cool-

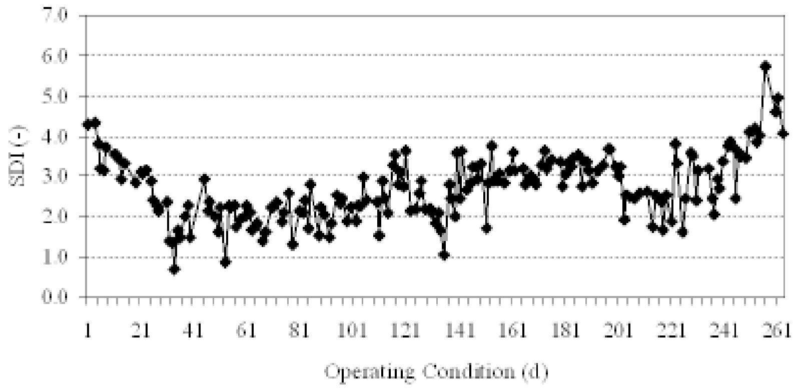

Figure 6. The SDI Permeate (■) of MBR.

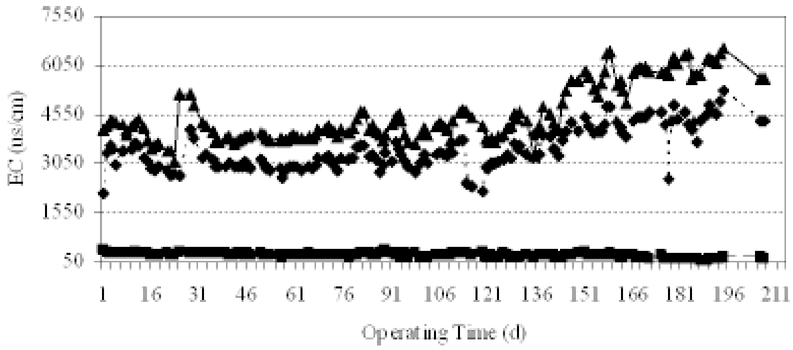

Figure 7. The EC of feed (◆), permeate (■) and brine (▲) of RO.

Table 3. The water quality of MBR effluent and RO permeate.

Item	MBR effluent	RO permeate
pH(-)	8.1	6.0
EC(µS/cm)	2,180	331
Cl^-(mg/L)	74.3	18.9
SO_4^{-2}(mg/L)	39.4	0.08
T-Hardness(mg/L as $CaCO_3$)	138	1
SiO_2	26.5	3.11
Color(Pt-Co scale)	17	<1
BOD(mg/L)	<1.0	<1.0
Ca (mg/L)	10.6	0.14
TDS(mg/L)	1,610	200

ing tower after treating by RO (Lubello and Gori, 2004). Ordinarily, the Silt Density Index (SDI) value demonstrated the possibility of fouling in RO. If SDI was higher than 4, clogging will usually occur (Smith and Bentley, 2001). The SDI of MBR effluent is shown in Figure 6. The average of SDI of MBR was usually less than 4 so the effluent could be treated by RO to reduce electro-conductivity (EC) and total dissolved solid (TDS) (Liu, 1999). The EC and of MBR effluent was usually

Table 4. Guidelines for water quality in boiler. (CIBO Energy Efficiency Handbook))

Drum operating pressure	0-300 psig	301-450 psig	451-600 psig	301-750 psig	751-900 psig	301-1000 psig	1001-1500 psig	1501-2000 psig
Boiler Feed Water								
pH @ 25°C	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.8-9.6	8.8-9.6	8.8-9.6
DO (mg/l)	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Total Fe (mg/l)	≤0.1	≤0.5	≤0.3	≤0.25	≤0.2	≤0.2	≤0.1	≤0.1
Total Cu (mg/l)	≤0.05	≤0.025	≤0.02	≤0.02	≤0.15	≤0.01	≤0.01	≤0.31
Total Hardness (mg/l as $CaCO_3$)	≤0.3	≤0.3	≤0.2	≤0.2	≤0.1	≤0.05	ND	ND
Non volatile TOC (mg/l)	<1	<1	<0.5	<0.5	<0.5	<0.2	<0.1	<0.2
Oily matter (mg/l)	<1	<1	<0.5	<0.5	<0.5	<0.2	<0.1	<0.2
Boiler Water								
Silica (mg/l as SiO_2)	150	≤90	≤40	≤30	≤20	≤8	≤2	≤1
Total alkalinity (mg/l as $CaCO_3$)	<350	<300	<250	<200	<150	<100	NS	NS
Specific conductivity without neutralization (µS/cm)	1100-5400	900-4600	800-3800	300-1500	200-1200	200-1000	5150	580
TDS (mg/l)	1.0-2.0	1.0-2.0	1.0-2.0	0.1-0.5	0.1-0.5	0.1-0.5	0.1	0.1

Remark : ND = Not Detected, NS = Not Specified

more than 3,000 µS/cm and 1,500 mg/l respectively.

RO was operated at 3 m^3/hr of permeate. The percentage of rejection was 90% and the recovery rate was 60%. The permeate of RO has a good quality with COD and SS less than 10 mg/l and 5 mg/l and EC less than 400 µS/cm, as shown in Figure 7. Therefore, it can be used for a boiler or cooling tower. The water quality of MBR and RO permeate is shown in Table 3 and the guidelines for water quality in boiler of CIBO is shown in Table 4.

Conclusion

It is concluded that MBR can replace AS. The effluent of MBR has a good quality more than AS effectively especially SS because only treated water can pass through the membrane. The membrane has the best separation of solid and liquid so the clear effluent of MBR can be used directly for cleaning or flushing. The EC and TDS of MBR effluent are so high that it should be treated by RO for reducing EC and TDS before use in a boiler or cooling tower.

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