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Treatment of Tapioca Starch Wastewater By Anaerobic Digestion Coupled With Membrane Separation Process

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혐기성 소화 및 막분리에 의한 Tapioca 전분의 폐수처리

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ABSTRACT

This study thus looks into two treatment processess:

i) Anaerobic digester coupled with hollow fibre membrane unit. Treatment of starch waste with anaerobic digester-membrane system was studied. 0.17 ㎡ area of hollow fibre membrane unit of known pore size was immersed into laboratory-scale anaerobic digestion system. The pore size of membrane was varied from 0.03 to 0.15㎛. The hydraulic retention time of anaerobic digester was varied from 1.5 to 10 days. The effect of hydraulic retention time on treatment efficiency was significant while effect of membrane size was not significant. The gas production was about 0.74㎥/kg COD treated. The COD removal efficient was about 80−95% depending on the hydraulic retention time.

ii) Crossflow ultrafiltration as post treatment to anaerobic filter. The effluent from anaerobic filter, which had a total COD in the range of 4,500−5,200 mg/L was treated by crossflow ultrafiltration units. The study conducted with different membrane pore size indicated that membrane with 1,000,000 molecular weight cut-off size gave a higher COD removal efficiency in the range of 83−87% while giving a study flux of 120−130 L/㎡ · h. A study was conducted to see the long term clogging effect of membrane also.

INTRODUCTION

Tapioca, also known as cassava(1), is grown throughout the tropical world and is one of the most important starchy root crops in the tropics. Among the Asian countries, Thailand is one of the largest producers and exporters of tapioca. The main products of tapioca roots are pellets, chips and starch. Only the tapioca starch industry has water pollution problem from its wet processing operation(2). During the processing of tapioca root to produce tapioca starch, wastewater originates from both the root washing stage and the separators. The combined wastewater from these two sources amounts to an average of 20㎥/ton of starch produced. As the tapioca starch is one of the major export products with a promising future, means to alleviate its wastewater problems have to be developed.

Anaerobic digestion was popular in the years immediately following World War Ⅱ and there has been a resurgence of interest in this application of the process in recent years (3–5). However, this form of the once-through completely-mixed anaerobic digester, in which the solids retention time(SRT) equals the hydraulic retention time (HRT), is of limited value in the treatment of liquid industrial effluent. In a digester with SRT/HRT ratio of 1.0, "wash out" of anaerobic microorganisms will pose a serious problem if high loading rates are applied and short hydraulic retention time results. Hence, developments in anaerobic biological processes for industrial waste treatment have concentrated on ways of achieving higher SRT/HRT ratios, thus allowing high loading rates to be applied to small digester volumes. The membrane anaerobic digester system is one of the processes which adopts a suspended growth digester in conjunction with an external ultra/micro filtration membrane unit for solid/liquid separation(6–9).

Wastewater from the tapioca starch factories released directly into the surrounding areas before proper treatment has been a source of pollution and has caused environmental problems to the nearby population. Laboratory-scale anaerobic digester coupled with hollow fiber ultrafiltration experiments were conducted using different operating parameters such as membrane pore size, organic loading rate, and detention time to study the role of ultrafiltration in the improvement of treatment efficiency and biogas production. The study also looked into the possibility of using membrane as post treatment for the effluent of tapioca starch wastewater from an anaerobic filter(AF).

MATERIALS AND METHODS

The experimental set-up for an anaerobic digester coupled with hollow fiber ultrafiltration is shown in Fig. 1. The volume of the digester is 1 liter and the synthetic tapioca starch wastewater was fed by using peristaltic pump twice per day or at every 12 hrs. Feeding time for each digester was about 30 minutes. During this 30 minutes,

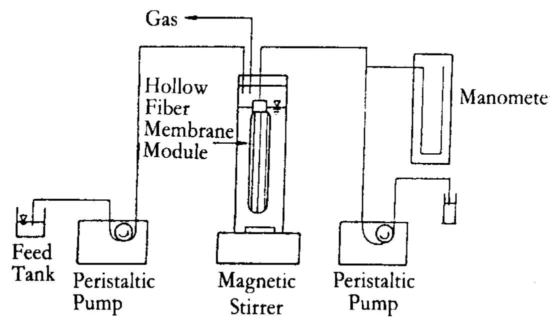

Fig. 1. Experimental Set-up for Anaerobic Digester Coupled with Hollow Fiber Ultrafiltration Membrane.

Table 1. Composition of Synthetic Starch Wastewater

Starch	20,000 mg/L
$(NH_4)_2SO_4$	250 mg/L
$MgSO_4$ $7H_2O$	50 mg/L
$FeCl_3$ $6H_2O$	0.25 mg/L
$CaCl_2$	3.75 mg/L
KH_2PO_4	263.5 mg/L
K_2HPO_4	535 mg/L
$MnSO_4$ H_2O	5 mg/L
$NaHCO_3$	2,000 mg/L

filtrate was withdrawn at a constant rate. After each feed, synthetic starch wastewater was kept in 5℃ room temperature. The digesters were installed in a room where the temperature was maintained at 30℃. Composition of synthetic starch wastewater(10–11) is shown in Table 1.

The experimental runs conducted with the anaerobic digester coupled with the hollow fiber module are shown in Table 2. In the experimental study, temperature, pH, alkalinity, volatile acids, COD removal, and gas production were determined. After the start-up of these experiments, HRT for all units was decreased (i. e., organic loading rate was increased). When the units reached the steady state after a number of days of operation, again the organic loading rate was increased and so on.

The treatment of tapioca starch wastewater by using the anaerobic filter alone is not sufficient. The effluent

Table 2. Experimental Runs with the Arrangement of Anaerobic Digester Coupled with Hollow Fiber UF Module

Run No.	Membrane pore size (μm)	Detention Time (days)	Organic Loading Rate (kg COD / m³·d)
1	0.03	10	1.76
2	0.03	2	8.83
3	0.05	10	1.76
4	0.05	3	5.88
5	0.10	10	1.76
6	0.10	5	3.53
7	0.15	10	1.76
8	0.15	7	2.51
9	0.15	1.5	11.77

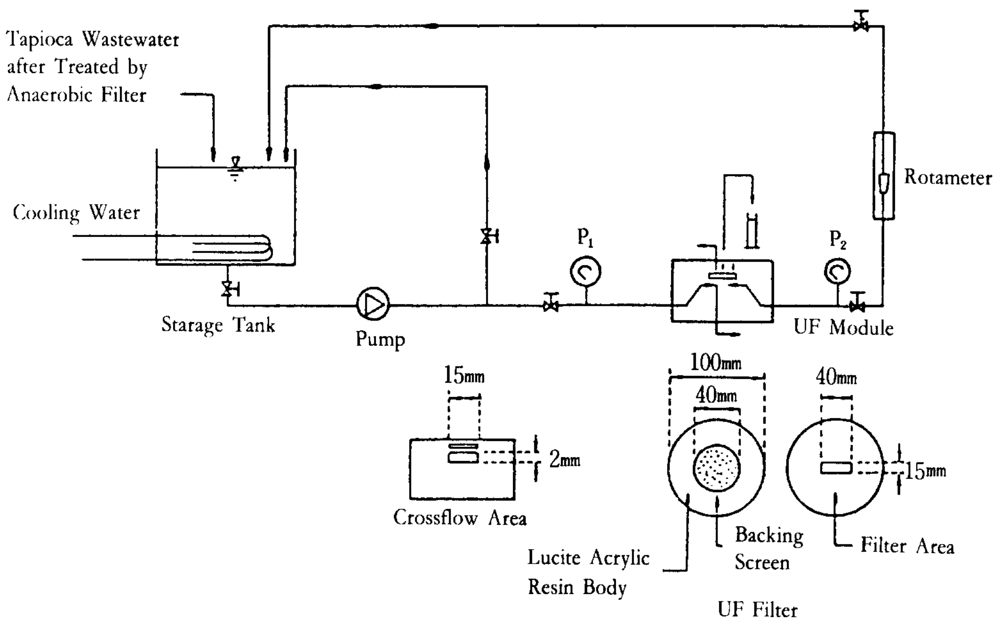

Fig. 2. Experimental Set-up of Laboratory-scale Crossflow Ultrafiltration Module.

still had higher BOD_5 and COD. In this study, the treated effluent of tapioca wastewater by anaerobic filter was treated by using the laboratory-scale crossflow ultrafiltration module. The schematic diagram of the laboratory-scale ultrafiltration unit is shown in Fig. 2. The ultrafiltration in this case (flat geometry), was used as post-treatment after anaerobic filter. The effluent from the anaerobic filter was pumped from the base of the stock tank and fed into the membrane filter. A small portion of the feed was filtered out as filtrate while most of the feed was recycled back to the stock tank. The by-pass system was necessary for controlling the operating condition at different pressure and crossflow velocity. The cooling system was necessary for keeping the temperature constant.

These experiments were conducted to observe the filtration performance at different membrane pore sizes. Furthermore, a long term membrane filtration study was also conducted to investigate the degree of recovery of flux in the membranes as shown in Table 3. The temperature, crossflow velocity, and applied pressure were fixed at 30℃, 3m / s and 138 kpa respectively.

RESULTS AND DISCUSSION

Anaerobic digester coupled with hollow fibre membrane unit

For the start-up of the digesters, four laboratory-scale anaerobic digesters coupled with hollow fiber UF membranes were seeded with active digester sludge taken from the Huay Kwang Treatment Plant in Bangkok. All of the digesters were fed with synthetic starch wastewater at the rate of .044 L / d (HRT=20 days). The influent concentration had an average COD of 20,150 mg / L. Thus the average organic loading rate for the start-up was 0.88kg COD / m³·d. The acclimatization was completed after 4 weeks of operation. After the start-up stage, HRT was decreased from 20 days to 10 days.

COD Removal Efficiency

COD removal efficiency increased with an increase in HRT and decreased with an increased in the organic loading rate. The results obtained are summarized in Table 4. HRT of 10 days was conducted with four different pore sizes of membrane and COD removal from these digesters was nearly the same. Fig. 3 shows the average COD removal efficiency at the steady-state which was about 92.2 percent at HRT of 10 days (organic loading rate of 1.76kg COD / m³·d) and reduced with a decrease in HRT.

An empirical relationship between the average COD removal efficiency and the organic loading rate was developed(12) as given by equation 1.

$$Y=92.63\times(-0.059) \qquad (1)$$

(R−squared= .8455)

where

Y=COD removal efficiency (%)

X= organic loading rate (kg COD / m³·d), 1.76〈X〈11.77

Note: R−squared obtained from the value of logarithm of organic loading rate and COD removal

Table 3. Experimental Runs with Laboratory-scale Crossflow Ultrafiltration Module

Run No.	P (kPa)	Velocity (m / s)	Membrane Pore Size (Molecular Weight Cut-off)
1	138	3	10,000
2	138	3	50,000
3	138	3	100,000
4	138	3	1,000,000
5	138	3	1,000,000

Note *long term study

Table 4. Average COD Removal with Organic Loading Rate

HRT (days)	Membrane Pore Size (μm)	Organic Loading Rate (kg COD / m³·d)	average COD Removal at Steady State (%)
10	.03, .05, .10, .15	1.76	92.2
7	.15	2.51	86.0
5	.10	3.53	84.9
3	.05	5.88	82.5
2	.03	8.83	82.0
1.5	.15	11.77	81.1

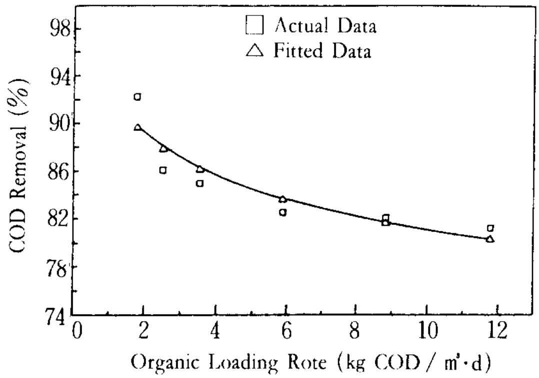

Fig. 3. Average COD Removal Efficiency at Steady-state with Organic Loading Rate (Influent COD=20, 150㎎ / L).

Biogas Production

Table 5 shows average biogas and methane gas production at the steady-state. Fig. 4 also shows the plot of biogas and methane gas production at different organic loading rates. The maximum gas production rate was equal to 0.74㎥ / kg COD utilized at 92.2 percent COD removal.

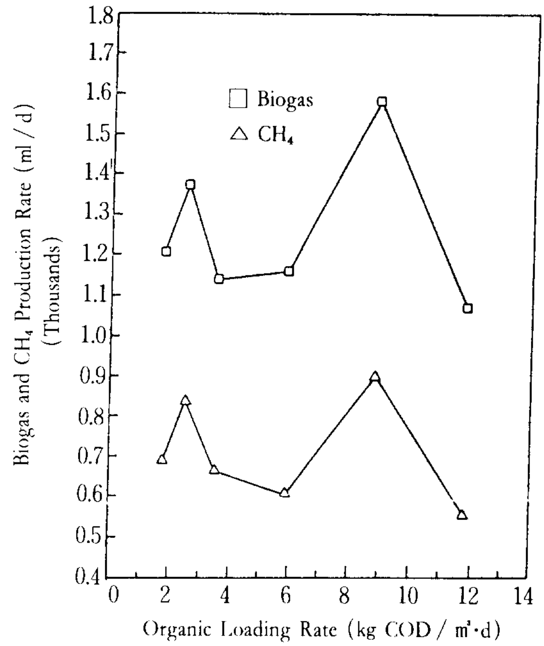

Fig. 4. Biogas and Methane Gas Production with Organic Loading Rate.

Crossflow ultrafiltration as post treatment to anaerobic filter

The effluent from anaerobic filter, which had a total COD in the range of 4,500−5,200㎎ / L was treated by crossflow ultrafiltration units. These results led us to look for the alternative of using an ultrafiltration membrane as post-treatment to treat this wastewater (after biological process). The long term membrane filtration study was also conducted to investigate the degree of recovery of the flux of the membrane.

Effect of Membrane Pore Size

The effect of membrane pore size was studied by performing series of experiments using different pore size of flat geometry membranes. The membrane pore sizes used were 10,000, 50,000, 100,000 and 1,000,000. Fig. 5 shows that an increase in membrane pore sizes results in a higher filtrate rate. A microscopical investigation revealed that most of the fibers in tapioca starch wastewater are decomposed by biological and physical processes in an anerobic filter (AF). COD removal at the steady state is also high,

Table 5. Average Biogas and CH_4 Production

HRT (days)	Organic Loading Rate (kg COD / ㎥·d)	Biogas Production (mL / d)	CH_4 Production (mL / d)	CH_4 Content (%)
10	1.76	1,210	686	56.67
7	2.51	1,370	839	61.24
5	3.53	1,140	663	58.20
3	5.88	1,160	603	52.02
2	8.83	1,580	897	56.76
1.5	11.77	1,070	552	51.59

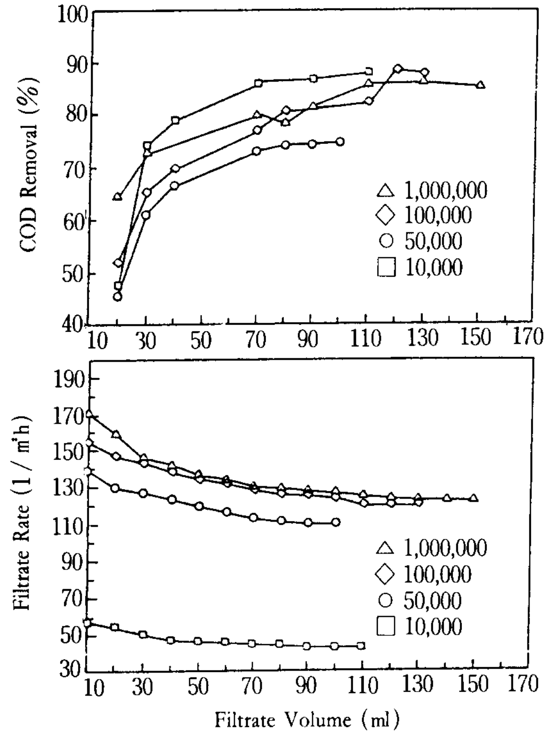

Fig. 5. Effect of Pore Size of Membrane: Effluent of Tapioca Starch Wastewater from AF, Velocity=3m / s, Pressure=138kPa, Temperature=30℃.

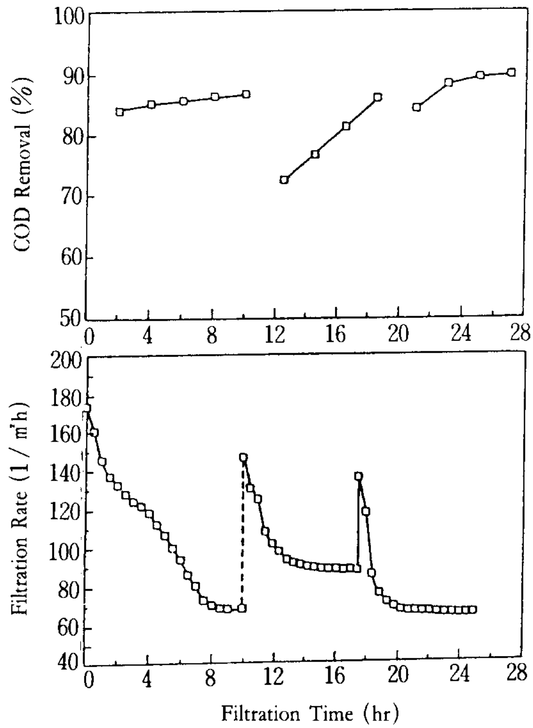

Fig. 6. Long Term Filtration Study: Effluent of Tapioca Starch Wastewater from AF, Molecular Weight Cut-off Size=1,000, 000, Velocity=3 m / s, Pressure=138 kPa, Temperature=30℃. Note* after backwash, let the membrane submerged in distilled water overnight.

about 85 percent at a steady state flux of 120−130 L / m²·h.

Long Term Filtration Study

The long term membrane filtration study was also conducted to investigate the degree of the recovery of the filtrate rate in the membrane. The temperature, cross-flow velocity, and applied pressure were fixed at 30℃, 3m / s, and 138 kPa respectively. Fig. 6 shows the performance of membrane filtration in terms of filtrate rate recovery and COD removal. After each steady state, the membrane was backwashed by using a gooch crucible apparatus and distiled water. The recovery filtrate rate is about 80 percent of the previous one. It was also noticed that the steady state filtrate rate after the first backwash was higher than that of the new membrane. This may be due to the reason that, at the beginning of this experiment, the filtration mechanism is an intermediate blocking. For the second backwash, the filtrate rate recovery at the steady state was lower than after the first backwash. This may have been due to the progressive standard blocking that occurred. COD removal was high, approximately 80 percent and it increased with time. This may have been due to the gel formation and standard blocking mechanism that occurred on the surface of the membrane.

CONCLUSION

This study clearly showed satisfactory performance of the four digesters indicating that the treatment of tapioca starch wastewater using an anaerobic digester coupled with hollow fiber UF membrane is possible (over 80 percent COD removal). The effect of hydraulic retention time on treatment efficiency was significant while effect of membrane size within the range used was not significant. The COD removal efficiency was about 80−95% depending on the hydraulic retention time. The performance of the digester at the organic loading rate of 1.76kg COD / $m^3 \cdot d$ was the best among the four digesters in terms of daily gas production. Maximum gas yield was 0.74m^3 / kg COD utilized at 92.2 percent COD removal. CH_4 gas composition was about 55 percent. Theoretical methane gas production was about 0.35m^3 / kg COD utilized. The stable operation was kept over an operational period of 3 months at an average net flux of $1.85 \times 10^{-7} m^3 / (m^2 \cdot s)$. Intermittent operation was necessary to reduce the clogging of membrane. Post-treatment of the effluent of tapioca starch wastewater from an anaerobic filter by UF membrane filtration was possible. The COD removal was about 85 percent (from about 5,000mg / L to 600 mg / L).

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