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The Performance of a Gaslift MBR for Slaughterhouse Wastewater Treatment in 1 m^3/day Scale

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Abstract: Slaughterhouse wastewater containing high concentration of organic contaminants and nitrogen is causing severe problems to the environment in Vietnam. The concentration of COD, BOD and NH_4^+ in the slaughterhouse wastewater in Vietnam is around 2000 mg/L, 1000 mg/L and 200 mg/L respectively. Gaslift membrane bioreactor (MBR) is a promising technology which is expected to treat wastewater with the same quality and lower operation cost compared to the traditional MBR due to its potential of reducing pumping energy and extension of membrane life. A novel labscale set up of a 500 L aerobic tank plus a 500 L anoxic tank equipped with 2 tubular Ultrafiltration (UF) membrane modules connected with air compressor was constructed to test potential of gaslift MBR to reduce the organic strength and total nitrogen in slaughterhouse wastewater. Different operation parameters such as gas flow rate (Q_{gas}), cross flow velocity (CFV), transmembrane pressure (TMP), Hydraulic Retention Time (HRT), Sludge Retention Time (SRT)… will be tested to search for the optimum operation condition of the system. This study will also prove the potential of energy saving of the gaslift MBR which makes it more feasible to apply for industrial markets and developing countries.

Key words: on-site treatment, gas-lift MBR, ultrafiltration, slaughterhouse wastewater

1. Introduction

Effluent from slaughterhouse is a high strength source of waste containing large amounts of amount of protein, fat, and suspended organic matter (i.e., meat, bones, and viscera). The characteristics of slaughterhouse wastewater depend on the type and numbers of animals killed per day. Generally, slaughterhouse wastewater contains high concentrati on of COD, BOD, TN, NH_4^+, and TSS [4-5, 12]. The average concentrations of COD, BOD, TN and TSS in slaughterhouse wastewater (SHWW) could reach 4221 mg/L, 1209 mg/L, 427 mg/L and 1164 mg/L, respectively [5]. In Vietnam, with a total of 29136 slaughterhouses divided into large scale (> 100 m^3/day), medium (30-100 m^3/day) and household (5-30 m^3/day), the lack of treatment of SHWW is major sanitary concern. SHWW is commonly discharged directly into surrounding streams, which pollutes natural waters and generates environmental and health problems to riverside and downstream residents [14]. In recently, the current wastewater management infrastructure in Vietnam is outpaced by population growth. Therefore, the construction of additional sewer infrastructure for centralization of SHWW is not focused in the future. On-site treatment, however, represents a viable option SHWW management in Vietnam.

In recently, membrane bioreactor processes have been widely applied to wastewater treatment [1, 6-7]; in decentralized settings. Few studies have reported the application of MBRs for slaughterhouse wastewater treatment with high treatment effectiveness, e.g., higher than 93% removal of COD [16]; Biological processes coupled with membrane in slaughterhouse wastewater treatment were found in both aerobic and

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anaerobic applications. Both aerobic and anaerobic MBRs showed significant high removal efficiencies of COD and TN, which vary from 90-97% and 44-90%, respectively [11, 16].

The cross-flow MBR is mostly used for industrial wastewater treatment applications. The main characteristic of cross-flow is that a part of the feed is withdrawn as permeate, while the other part is forced to flow along the membrane surface [10]. The pressure pump pressurizes the feed, while the circulation pump recirculates the concentrate; part of the concentrate is purged to the bioreactor. The advantage is a better control of the cake layer build-up resulting in a long time constant flux. However, the energy consumption for the typical cross-flow MBR was still high at the level of 1.7-2.2 kW/m^3 treated water [8]. Therefore, the airlift MBR has been developed to reduce the energy consumption during operation. The principle of the gas-lift MBR is based on the same basics as used for the cross-flow principle; however, the turbulence within the tubular shaped membranes is achieved by sparging air into the vertically mounted membranes [9]. In fact, using the produced biogas in a gas-lift configuration can provide membrane scrubbing and decrease membrane fouling [13, 15]. This study evaluates the application of a gas-lift membrane bioreactor (GL-MBR) for on-site treatment of slaughterhouse wastewater for municipal area in Vietnam. The study would investigate the filtration ability of gaslift membrane and also identify the operational parameters for the gaslift membrane. Then performance of GL-MBR in 93 days for slaughterhouse wastewater would be tested. Additionally, the energy consumption of the GL-MBR system was observed and reported in this study.

2. Material and Methods

2.1 Activated Sludge

Seed activated sludge was collected from a local wastewater treatment plant (Viet Ha Beer Corporation, BacNinh). The sludge was sieved through the 3 mm mesh filter to remove any debris that could clog the membrane lumen or block the reactor tubing. The TSS, pH of the seed sludge were1.6±0.1 g/L and 7.24 ± 0.05, respectively.

2.2 Synthetic Slaughterhouse Wastewater (SSW)

Wastewater in 05 slaughterhouses in North of Vietnam were sampled and characterized as described in Table 1.

The recipe of SSW was made based on the average compositions of the 5 slaughterhouse wastewater in Hanoi. The SWW was made using 1 L of pig blood and 30L of solid waste from viscera and stomach of a pig collected twice a week and diluted by 1000 L of tap water to formulate wastewater with the similar characteristic as real slaughterhouse wastewater.

2.3 GL-MBR System

The GL-MBR system was designed (Fig. 1) and constructed. The system included: 1 m^3 feeding

Table 1 Characteristic of Slaughterhouse wastewater.

Parameters	SLW waste waster	Vietnam Discharge regulation standard
BOD (mg/L)	891±137	50
COD (mg/L)	1697±317	150
NH_4^+ (mg/L)	171±4.2	10
TN (mg/L)	246±65	40
TP (mg/L)	28±9.9	6
pH	6.83±0.04	5.5-9
TSS (mg/L)	662±286	100
NO_3^-(mg/L)	18.39±0.03	-
Coliform (MPN/100 ml)	11.80×10^9	5000

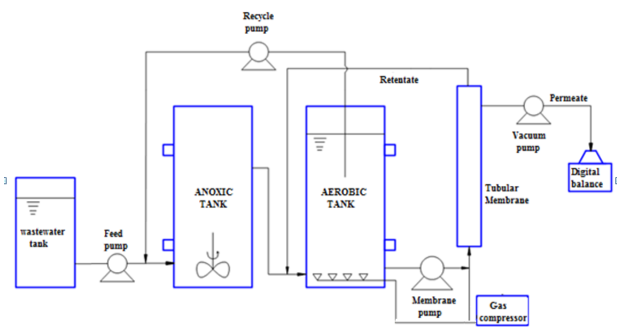


Fig. 1 Flow scheme of the gaslift MBR for slaughterhouse wastewater treatment.

wastewater tank, 420 L anoxic tank, 360 L aerobic tank, two tubular ultrafiltration (UF) membrane modules (each membrane module including 25 small tubular membrane). The small tubular membrane in module were 0.5 m × 5.2 mm (ID) polyvinylidene fluoride modules (Berhof, Germany) with mean pore size of 0.03 μm and active filtration area of 0.008 m^2 per each tube.

The SLWW was pumped from feeding wastewater tank to the anoxic tank by a centrifugal pump (Forerun MKP80-1, Italy) at pumping rate of 40 L/hour. The anoxic and aerobic tanks were operated at HRT of 10.5 hours and 9 hours, respectively.

The gas compressor (Puny Air, model: 7-36, Taiwan) was controlled at 2 bar pressure and supplied gas for the 2 membrane modules as well as oxygen to the aerobic tank. Dissolved oxygen (DO) in the aerobic tank was maintained around 4 mg/L. The recycle flow from aerobic to anoxic for nitrogen removal purpose was tested at different rates by using a centrifugal pump (Forerun MKP80-1, Italy).The system flow scheme was illustrated in Fig. 1. The sludge was circulated through the membrane modules by a centrifugal pump (Forerun MKP80-1, Italy). The crossflow velocity (CFV) and gas flow rate to the membrane modules (Q_{gas}) were determined after membrane filtration tests.

2.4 Filtrating Membrane Tests

The filtrating membrane tests were conducted before operation of gaslift MBR in 93 days in order to identify the filtration ability of the membrane modules and operational parameters such as CFV and Q_{gas}. The concentration of MLVSS for the test was managed at 6000 mg/L. The first test was implemented with a controlled rate of gas flow at 0.2 L/min and various CFVs of 0.4-1.2 m/s. The second test was operated at a constant CFV of 0.8 m/sand different values of Q_{gas} (from 0-1.6 L/min).

2.5 The GL-MBR Operation

The performance of the GL-MBR was tested and observed in more than 3 months and with different concentrations of the sludge in an aerobic bioreactor. Initially, the anoxic and aerobic reactor was seeded with sludge concentration of 4000 mg/L (Fig. 2). After 20 days, sludge concentration gradually increased and reached to 6000 mg/L in the day 30. Then the sludge concentration was keep consistently at 6000 mg/L.

2.6 Analytical Methods

Samples from the influent, mixed liquor of the aerobic and anoxic reactors, and permeate samples, were collected daily to analyze the water COD, TN, MLSS and MLVSS. The proper standard methods for the examination of wastewater by APHA [21] were used for all the monitoring analyses in this study. COD was determined by the closed reflux, colorimetric method (Method 8000). Total nitrogen (TN) was analyzed by the persulphate digestion method (Method 10071). Mixed-liquor suspended solids (MLSS) and mixed-liquor volatile suspended solids (MLVSS) were measured by using the methods 2540D and 2540E, respectively. The permeate was determined by weighing method. During operation, energy consumption were monitored by using an electric meter (EMIC Comp., Vietnam). The energy consumption includes the powers for the feed pump, the recirculation pump, internal recycle pump, and air blower. The specific energy consumption was estimated based on the flow rate of treated water and the power recorded by the electric meter.

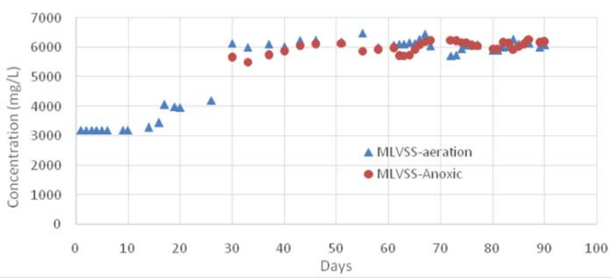


Fig. 2 Variation of sludge during operation in Aeration tank and Anoxic tank.

3. Results and Discussion

3.1 Investigation of Membrane Filtration Performance

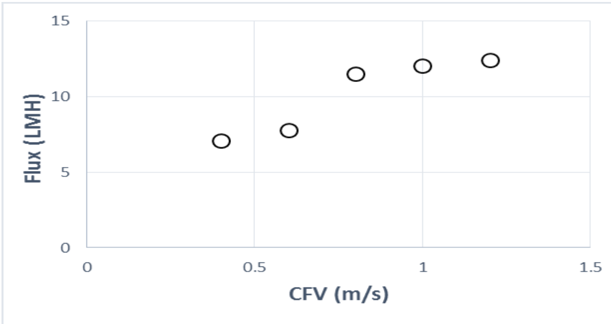
As illustrated in Fig. 3a, the increased flux from 7-12 Liter/m^2/h (LMH) was observed when increasing cross flow velocity from 0.4 m/s-0.8 m/s at a controlled gas flow rate of 0.2 L/min. The flux was stabilized at 12 LMH after CFV reached to 0.8 m/s. The result that CFV does not have any effect on flux after a certain value of CFV was also identified in Prieto's study in 2013. This result implicated that the CFV of 0.8 m/s could be the optimum operation value at a constant gas flow rate of 0.2 L/min. However, typical value of gas flow rate at 0.2 L/min could be not yet the optimum value for this GL-MBR system. The filtration of membrane was then also evaluated at a constant value of CFV of 0.8 m/s with various gas flow rate ranged from 0-1.6 L/min (Fig. 3b). In the entrance pipe before the membrane module, the mixture of three phases containing gas-solid-liquid was established. Obviously, with the gas support, the filtration of the membrane increased as the gas flow rate increased from 0-0.9 L/min. The maximum of flux was identified at value of 12 LMH at the gas flow rate of 0.2-0.9 L/min. However, beyond the value of 0.9 L/min, the filtration of the membrane could be negatively affected. Higher gas flow rate contributes to higher proportion of gas phase and lower proportion of liquid phase in the mixture. Hence, this could result in lower filtration of the membrane.

The results of the short tests for membrane filtration suggested that the optimum CFV of 0.8 m/s and Q_{gas} of 0.2 L/min could be applied for operation the gas lift in the MBR system.

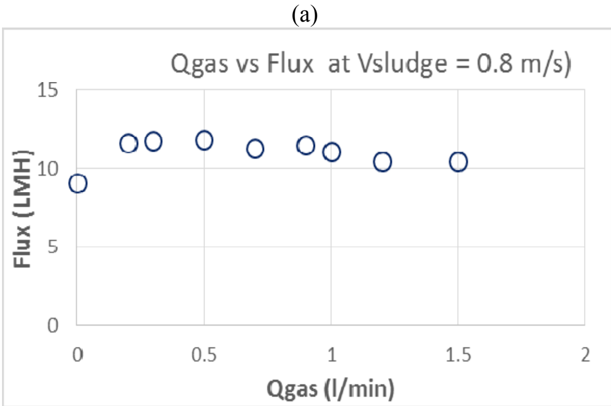
3.2 The Gaslift MBR Performance

3.2.1 Membrane Performance in the Gaslift MBR System

The maximum flux of the membrane was observed at 35 LMH/bar when starting operation of system and gradually decreased (Fig. 4). After 20 days, the flux was stable at 18 LMH/bar and doesn't depend on the concentration of the sludge. The membrane was cleaned by water for 20 minutes on the day 60th on purpose of enhancing flux. The flux was temporally increased to 25 LMH/bar but then stable at 18 LMH/bar for the rest of the experiment duration. The constant flux implicates that two phase gas-liquid helped reduce fouling of the membrane during the operation in 3 months. The gas in the two phases enters the membrane module could create turbulent flow and continuously scour the membrane surface which help



(a)



(b)

Fig. 3 Membrane filtration evaluation: (a) Gas flow rate Q_{gas}vs Flux (at CFV = 0.8 m/s); (b) Cross flow velocity (CFV) vs Flux (at Q_{gas} = 0.2 L/min).

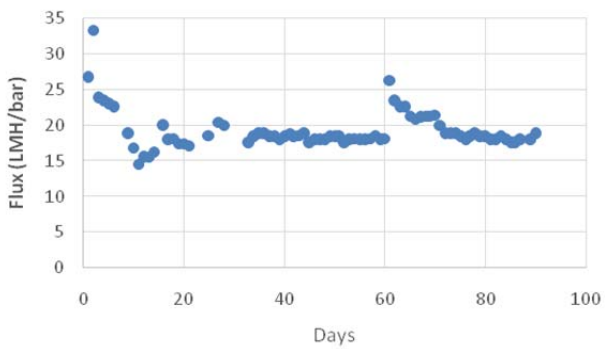


Fig. 4 Variation of flux during operation.

to take off particles attached to membrane surface. This was also proved in the study of Prieto (2013).

3.2.2 Organic Matter Reduction

The slaughterhouse wastewater contains various components such as blood, urine, fat, meat tissues, hence contain a lot of organic matters. COD in the influent was about 1915±187mg/L. The removal of organic matter by the GL-MBR during the operation was very consistent at high efficiency shown in Fig. 5. After the biological processes and the membrane process, the COD was reduced to 148±59 mg/L and 118±55 mg/L, respectively. The efficiency of COD removal by the whole system was 94±2.9%. In that the biological process removed 92±3.1% and the membrane process contributed an addition of 2±0.2%.

3.2.3 Nutrient Removal

In the influent the concentration of phosphorous is not too high approximately around 15-25 mg/L.

However the concentration of total nitrogen (TN) in the influent is quite high. The concentration of TN in the influent ranged from 170±20 mg/L (Fig. 6). After the anoxic tank, aeration tank and the membrane process, the TN was reduced to 82±14 mg/L, 60±8 mg/L and 48±9 mg/L, respectively. The efficiency of TN removal by the whole system was 71±5.3%. In that the Anoxic and Aeration process removed 52±8.2% and 26±4.7%. The membrane process contributed an addition of 7±0.5%.

3.2.4 Energy Consumption

As a result of electric meter, in 93 days we spent 135

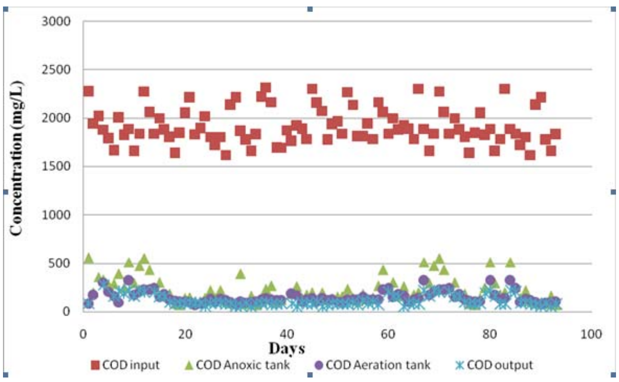


Fig. 5 Variation of COD in the influent, effluent, anoxic and aeration tanks.

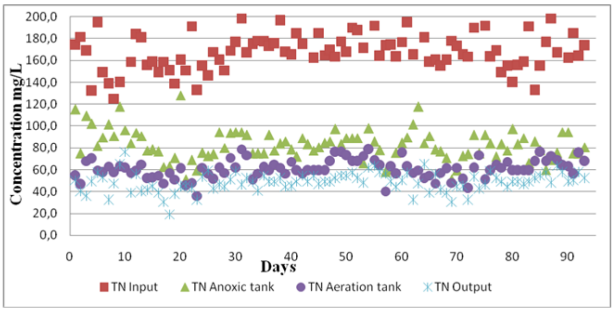


Fig. 6 Profile of TN in the gaslift MBR system.

kW equivalent about 1.45 kW/m^3 treated water was obtained in this study. Therefore, the GL-MBR could reduce about 14% of energy consumption compared to typical cross-flow MBR. During 50 years, developments in MBR technology resulted in an energy demand reduction about 5.0 kWh/m^3, in comparison with the first side-stream MBRs [2]. The energy requirement of the first tubular side-stream MBR installations was reported to be typically 6.0-8.0 kWh/m^3 [17], mainly due to energy intensive cross-flow pumping of the liquid.

4. Conclusion

The limitation of appropriate treatment for slaughterhouse wastewater has created a severe environmental problem in Vietnam. Gas lift MBRs are potential solution to treat slaughterhouse wastewater considering Vietnam's inadequate centralized treatment infrastructure. Based on the operation of the gas lift MBR during more than 93 days, the results shows that the system is capable of achieving Vietnamese discharge standards with high COD and TN removal efficiencies of 94% and 71%, respectively. The GL-MBR in this study provided a consistent flux at 18 LMH/bar at low pressures (0.8 bar) without regular membrane cleaning. The energy consumption of the system was 14% lower than an average crossflow MBR. The results of this pilot-scale system indicate that decentralized treatment of slaughterhouse wastewater can be done efficiently and with a lower than expected energy demand.

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