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Performance of simultaneous organic and nutrient removal in a pilot scale anaerobic–anoxic–oxic membrane bioreactor system treating municipal wastewater with a high nutrient mass ratio

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ABSTRACT

A pilot-scale anaerobic–anoxic–oxic membrane bioreactor (A2O-MBR) was applied to treat Shiraz municipal wastewater with high ratio of total phosphorous (TP): total nitrogen (TN): chemical oxygen demand (COD) (3.4: 21.4: 100) and remarkable nitrate concentration. Various operating conditions were tested to investigate nutrient and organic matter removal as well as membrane capacity and biomass development. The pilot system was operated at a constant sludge retention time of 60 d. During different runs, the biomass concentration increased with a reduction of HRT while the F/M ratio was stable around an average of 0.087 gCOD g^{-1}MLSS d^{-1}. Results also showed that the treatment performance of A2O-MBR system was extremely stable and was not affected by aerobic hydraulic retention time (HRT) changes (12, 10, 8, 6 h). COD reduction reached over 95% and nitrification was completed. The maximum efficiency of TN and TP removal was 86.2% and 55.9%, respectively, which occurred with an overall HRT of 12 h, external and internal mixed liquor recycle rate of 200%. Membrane capacity measurements showed an average flux of 5.5 L m^{-2} h^{-1} with a mean transmembrane pressure of 30 kPa under periodical air backwashing without any chemical cleaning over three months.

1. Introduction

In recent years, there has been increasing demand for better quality of effluents from wastewater treatment plants (Kimura et al., 2008). Eutrophication, mainly caused by nitrogen and phosphorus, has become a challenge worldwide. In addition, with the increasing pressure on water resources globally, recycling and reuse of wastewater effluent is a necessity (Chae and Shin, 2007; Kimura et al., 2008). In this context, upgrading wastewater treatment processes is very important.

Membrane bioreactors (MBRs) are rapidly gaining in popularity and are a promising technology for future wastewater treatment (Stephenson et al., 2000). In particular, microfiltration MBRs (MF MBRs) with low transmembrane pressure have received significant attention for wastewater treatment to remove particulate and colloidal matters. This technology usually produces permeate water free of turbidity and bacteria (Chae and Shin, 2007). In addition, the use of submerged membrane has reduced the power consumption of MBR significantly and hence increased the potential for the application of membrane in wastewater treatment (Rosenberger et al., 2002).

MBR generally has several advantages over well-known activated sludge processes (ASP) including stable and high effluent quality, ease of operation, small footprint, high loading rate capability, upkeep of high mixed liquor suspended solids (MLSS) in the reactor, low/zero sludge production, rapid start-up, lower energy consumption, complete removal of bacteria, and preventing collapse of biological systems due to biomass loss and/or bulking (Davies et al., 1998; Rosenberger et al., 2002; Wen et al., 2004; Kimura et al., 2005; Zhang et al., 2009).

Although MBRs have shown improved organic matter and total Kjeldahl nitrogen (TKN) removal, total nitrogen (TN) and total phosphorous (TP) were not removed in significant amounts (Wen et al., 2004; Han et al., 2005; Li et al., 2005; Pollice et al., 2008; Liu et al., 2010; Gao et al., 2012; Khan and Ilyas, 2013). Focussing on this concern, more than a few of biological processes configurations, which are combined with MBR technology, have been developed for the simultaneous organic and nutrient removal, recently.

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Many of these studies have been performed over synthetic/actual wastewaters with low nutrient mass ratio (TP: chemical oxygen demand (COD) less than 1.4: 100 and/or TN: COD less than 11: 100) (Chae and Shin, 2007; Fu et al., 2009a, 2009b; Monclús et al., 2010; Yang et al., 2010; Brown et al., 2011; Di Trapani et al., 2011; Hasan et al., 2014). Taking into consideration a minimum nutrient requirement for microbial cell synthesis and growth in biological process, extra nutrient removal is a more significant and difficult task. Therefore, there is a necessity for research on actual wastewater with high ratio of TP: TN: COD to determine the performance of these integrated systems, especially amount of enhanced biological nutrient removal (EBNR). Keeping this fact in mind, in the present study, a pilot scale of anaerobic–anoxic–oxic membrane bioreactor (A2O-MBR) system was employed to treat Shiraz municipal wastewater with high ratio of TP: TN: COD (3.4: 21.4: 100) and remarkable nitrate concentration. The experimental data were then statistically analysed to evaluate the performance of this system.

2. Materials and method

2.1. A2O-MBR pilot plant

The A2O-MBR pilot plant with a capacity of at least 19.1 L h^{-1} was constructed and installed at Shiraz municipal wastewater treatment plant (WWTP), Shiraz, Iran. A schematic representation of the used pilot plant is shown in Fig. 1. The pilot plant consisted of four reactors: anaerobic, anoxic, aerobic, and a membrane compartment containing one submerged hollow fibre membrane module. The characteristics of the membrane module are shown in Table 1.

As shown in Fig. 1, the influent was introduced to the anaerobic tank continuously. The aerobic zone was equipped with diffusers to provide air bubbles for carbonaceous BOD (cBOD) removal and nitrification as well as complete mix condition. In the anaerobic and anoxic reactors, a complete-mix condition was achieved with a low speed mixer.

The pilot plant was equipped with two internal and external mixed liquor recycle (MLR) lines to enhance nutrient removal efficiency. The internal MLR (IMLR) line connects the aerobic and anoxic reactors and the external MLR (EMLR) line connects the aerobic and anaerobic reactors. In the anaerobic reactor, phosphorous release occurs under anaerobic condition, and phosphorous uptake occurs in the aerobic and anoxic reactor. In the anoxic reactor, denitrification is carried out under anoxic condition using the nitrates of the MLR and the organic matter of the influent. In the aerobic reactor, nitrification and phosphorous uptake occur (Song et al., 2009).

As demonstrated in Fig. 1, one solenoid valve was located on the filtration line, and another on the backwash line. Two timers were then linked to these solenoid valves to adjust the periodical filtration and air backwash. The time interval for each cycle of filtration and air backwash was 10 min, with 9 min and 42 s of filtration and 18 s of air backwash.

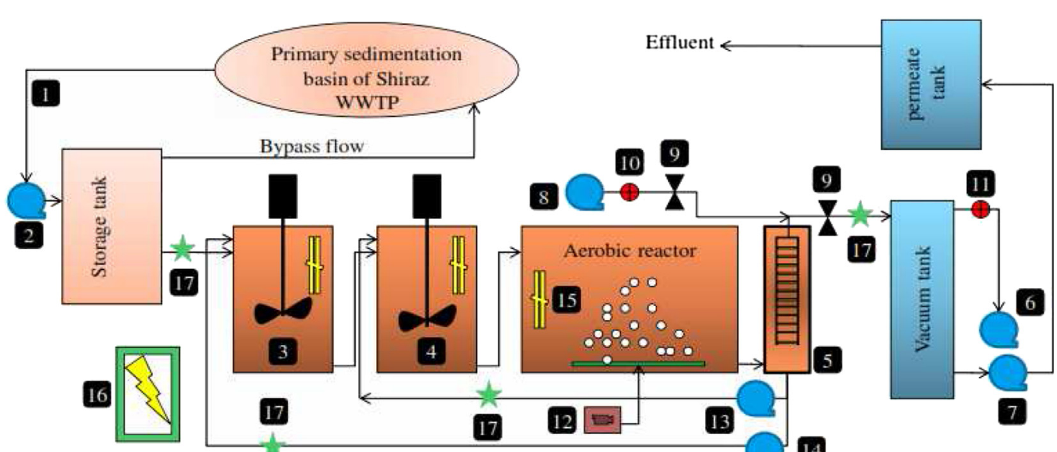
The air backwash pressure was maintained at 150 kPa by the air regulator to reduce the filtration resistance during each cycle. In order to avoid considerable membrane flux decline, the transmembrane pressure was maintained at around 30 kPa by the pressure gauge.

2.2. Feed wastewater

In this study, actual wastewater with high ratio of TP/TN/COD from primarily sedimentation basin effluent of Shiraz municipal WWTP was used to evaluate the performance of the pilot scale A2O-MBR system. The actual wastewater was selected to investigate the quality variability of Shiraz municipal wastewater on the EBNR. The main influent wastewater characteristics are reported in Table 2. The mean TP: TN: COD ratio of this wastewater was found to be about 3.4: 21.4: 100 indicating very low level of carbon for effective nutrient removal (Chae and Shin, 2007).

2.3. Operating conditions

At the beginning of start-up of the pilot plant, biomass from the waste recycle line of Shiraz municipal WWTP with concentration of 4937 mg L^{-1} was added to the system to provide a MLSS concentration of 2760 mg L^{-1}. Under stable operating condition, the sludge retention time (SRT) was calculated considering the amount of biomass present in the pilot plant. The desired SRT (60 d) was maintained by wasting the excess sludge daily from the system. To study the process performance of the pilot scale A2O-MBR system especially on the nutrient removal, four different modes of the



1: Feed, 2: Influent Pump, 3: Anaerobic reactor, 4: Anoxic reactor, 5: Membrane tank, 6: Vacuum Pump, 7: Discharge pump, 8: Air backwash pump, 9: Solenoid valve, 10: Pressure gage, 11: Vacuum gage, 12: Blower pump, 13: Internal mixed liquor recycle pump, 14: External mixed liquor recycle pump, 15: Heating element, 16: Electrical board, 17: Flow meter

Fig. 1. Scheme of the A2O-MBR pilot plant showing the different compartments, flow directions and main instruments and equipments.