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A study on the performance of a pilot scale A2/0-MBR system in treating domestic wastewater

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Abstract: *Phosphorus and nitrogen are the important eutrophication nutrients. They were removed in the anaerobic/anoxic/oxic (A2/O) system through biologically. The use of pilot scale A2/O systems with immersed membranes in removing nutrients phosphorus and nitrogen were investigated over a period of 150 days. The A2/O membrane bio reactor (MBR) was operated at a flux of 17 LMH. The designed flux was increased stepwise over a period of one week. The reactor was operated with the mixed liquid suspended solids (MLSS) concentrations in the range of 7000-8000 mg l^{-1}. The phosphorus removal was found to be in the range of 74-84%. The ammonification was completed in the aerobic zone and the ammonia concentration was almost nil. Nitrate concentration in the anoxic zone was found to be in the range of 0.3-1.6 mg l^{-1} indicating efficient denitrification. The nitrogen removal efficiency of the A2/O-MBR system was in the range of 68 to 75%. The chemical oxygen demand (COD) in the effluent was in the range of 8-5 mgl^{-1} indicating the efficiency of membrane. During the period of reactor operation transmembrane pressure (TMP) of the reactor increased slowly from 0 to 6 -cmHg over a period of 150 days.*

Key words: *A2/O - MBR, Nutrient removal, TMP*
PDF of full length paper is available online

Introduction

The discharge of nutrient nitrogen and phosphorus into natural receiving sources raises the growth of algae and results in eutrophication of lakes and streams (Mervat and Logan, 1996; Saraswathy *et al*., 2007). So it is necessary to reduce the concentration of these nutrients before discharging to prevent the algal bloom. Among the various process of nitrogen removal biological nitrogen removal is effective and inexpensive, it has been adopted widely (WPCF, 1983; Rajesh Banu *et al.,* 2007a, b). A2/O process is one such process and it has the advantage of achieving, nitrification and denitrification along with organic compound oxidation and phosphorous removal in a single sludge configuration using linked reactors in series (Metcalf and Eddy, 2003). The nitrification happens in aerobic basin of the A2/O reactor. Nitrification is the two step biological conversion of ammonia to nitrite and then nitrate under aerobic conditions. The nitrate formed during nitrification converted into nitrogen gas by denitrification process in the absence of oxygen and it happens in the anoxic basin of the A2/O reactor. The biological phosphorus removal mechanism is based upon anaerobic release of phosphorous and followed by luxury uptake of phosphorous in aerobic basin (WEF, 2005). In recent years, MBRs received increasing attention because of their advantages in water and wastewater treatment (Parco *et al.,* 2007). Submerged membrane bioreactors, which are characterized by immersing the membrane modules as separation units directly in the aerobic basin, were developed for wastewater treatment (Yamamoto *et al.,* 1989; Yamamoto and Win, 1991). Membrance bioreactor (MBR) have the advantages of complete solid removal from the effluent, effluent disinfection, high loading rate capability, low/zero sludge production, rapid start-up *etc.*, but also has a more compact size and lower energy consumption (Wen *et al.,* 2004). The objective of the present study was to summarize the long-term performance experience of A2/O-MBR system for treating domestic wastewater. During the study period particular interest was shown towards phosphorous and nitrogen removal efficiency of the reactor and membrane performance.

Materials and Methods

The schematic diagram of the pilot plant A2/O-MBR reactor is shown in Fig. 1. The working volume of the pilot scale reactor was 20 m^3. A baffle was placed inside the reactor to divide it into anaerobic (2 m^3) anoxic (6 m^3) and aerobic basin (12 m^3). The domestic wastewater from Kiheung sewage treatment plant (Yongin City, Korea) was feed into the reactor at a flow rate of 2 m^3 hr^{-1} (Q) using a feed pump. A liquid level sensor, planted in aerobic basin of A2/O-MBR controlled the flow of influent. The hydrolic retention time (HRT) of anaerobic, anoxic and aerobic basin was 1, 3 and 6 hours, respectively. In order to facilitate nutrient removal the reactor was provided with two internal recycle (IR). IR1 connects anoxic and anaerobic and IR 2 (Q=3) was between aerobic and anoxic. Anaerobic and anoxic basin was provided with low speed mixer to keep the mixed liquid suspended solids (MLSS) in suspension. In the aerobic zone, diffusers were used to provide air bubbles for oxidation of organics and ammonia. Dissolved oxygen (DO)

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Table - 1: Characteristics of wastewater

Parameter	Values*
pH	7.25 - 8.1
Chemical oxygen demand (COD)	232 - 360
Biological oxygen demad (BOD_5)	112 - 172
Suspended solids (SS)	65 - 180
Total phosphorus (TP)	4.52 - 7.30
Total nitrogen (TN)	34 - 62
NH_3	28 - 45
Alkalinity, as $CaCO_3$	215 - 255

*All in mg l^{-1}, except pH

concentration in the aerobic basin was maintained at 3.5 mg l^{-1} and was monitored continuously through online DO meter. The solid liquid separation happens in aerobic basin with the help of membrane. Flat sheet type of membrane with the pore size of 0.4 mm was used for the study. Membranes are arranged in two separate modules inside the aerobic basin and each module consists of 80-membrane unit. The area of the each membrane was 1 m^2. A common tube which interns connected to a suction pump connected the each module. A provision was made in the common tube to measure the transmembrane pressure (TMP) in the range of 0 to 50 cmHg during suction. The suction pump was operated in sequence of timing, which consists of 10 min switch on and 2 min switch off.

Wastewater and chemical analysis: The domestic wastewater used for the present was collected from Kiheung STP (sewage treatment plant), (Yongin City, Korea). Table 1 explains the physico-chemical characteristics of the wastewater used for the present study (APHA, 2005).

Chemical oxygen demand (COD), Mixed liquid suspended solids (MLSS), Mixed liquid volatile suspended solids (MLVSS), alkalinity, total phosphorus (TP), total nitrogen (TN) of the raw and treated wastewater were analysed following methods detailed in APHA (2005). The ammonia concentrations were measured using an ion-selective electrode (Thermo Orion, Model: 95-12) were analysed. Nitrate in the sample was analysed using cadmium reduction method.

Results and Discussion

Figure 2 shows variation of MLSS and MLVSS during the operations of the reactor. The reactor was seeded with activated sludge from the Kiheung, sewage treatment plant (STP). The solids concentration increases steadily and reached a value of 8100 mg l^{-1} on day 38.

From then on the MLSS concentration was maintained around 7500 mg l^{-1} to 8500 mg l^{-1} by withdrawing the excess sludge at the rate of 1.5% of Q. Although the sludge retention time (SRT) was designed to be 65 days, but was varied between 55 to 70 days. One of the advantages of MBR reactor was it can be operated in high MLSS concentration. At high MLSS concentration the yield observed was very less compared to that of conventional activated sludge reactor (Visvanathan *et al.,* 2000). As a result of that the MBR reactor generated less sludge compared to that of activated sludge process. The organic portion of the MLSS was found to be in the range of 6000 to 7000 mg l^{-1}. During the period of study the volatile

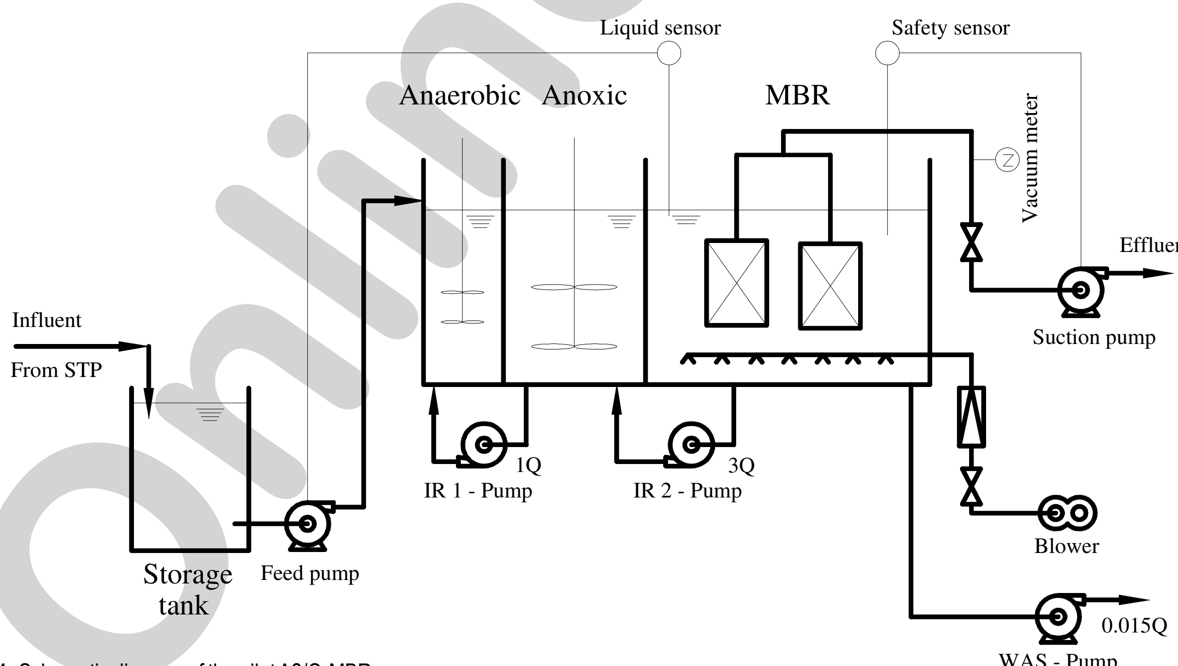

Fig. 1: Schematic diagram of the pilot A2/O-MBR

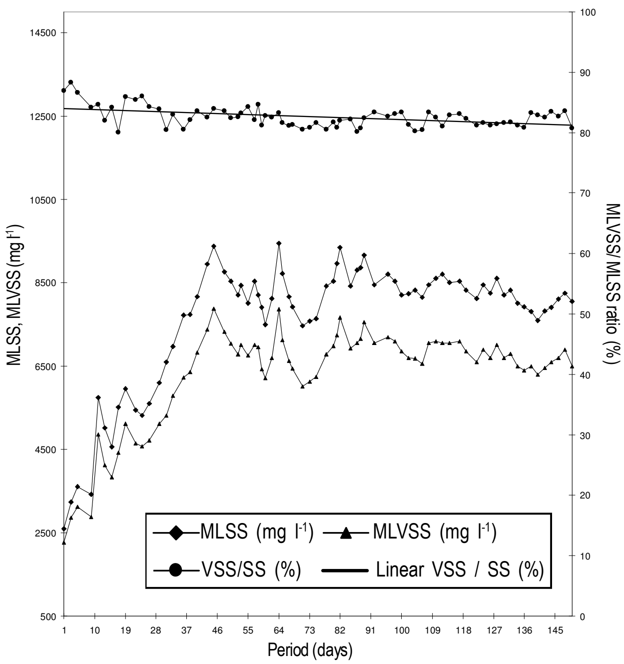

Fig. 2: MLSS and MLVSS profile during the treatment of domestic waste water

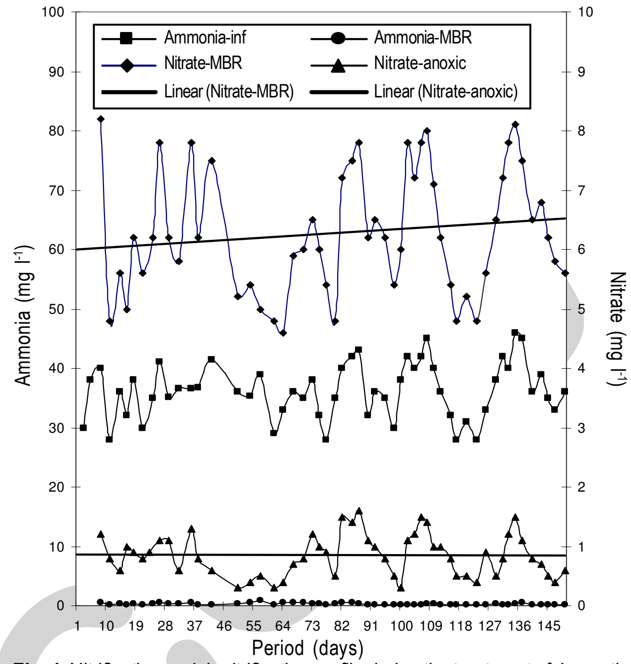

Fig. 4: Nitrification and denitrification profile during the treatment of domestic waste water

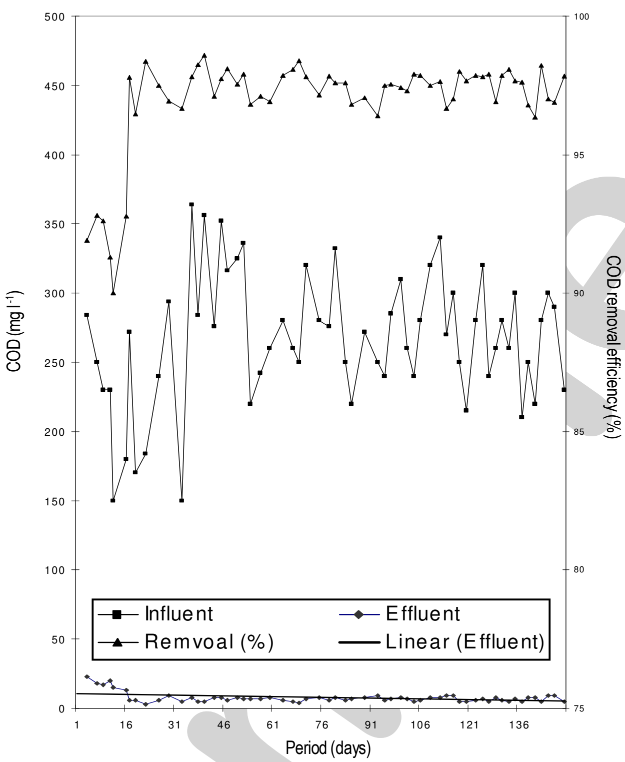

Fig. 3: COD removal profile during the treatment of domestic waste water

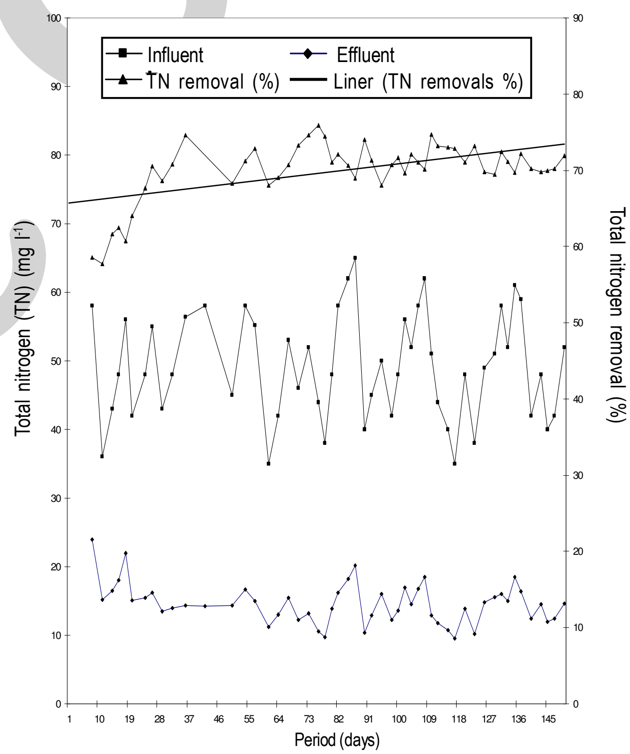

Fig. 5: Total nitrogen removal profile during the treatment of domestic wastewater

fractions of the mixed liquor solids were found to be in the range of 82 to 88%.

Fig. 3 shows variation in COD removal efficiency of A2/O-MBR reactor during the study period. It is evident from the figure that the COD removal efficiency of A2/O system remains unaffected irrespective to influent COD. The influent COD was highly fluctuating and was in the range of from 232-360 mg l^{-1} during the period. The COD removal increased with increase in time during the initial phases of reactor operation. It attains steady state on day 19. From then

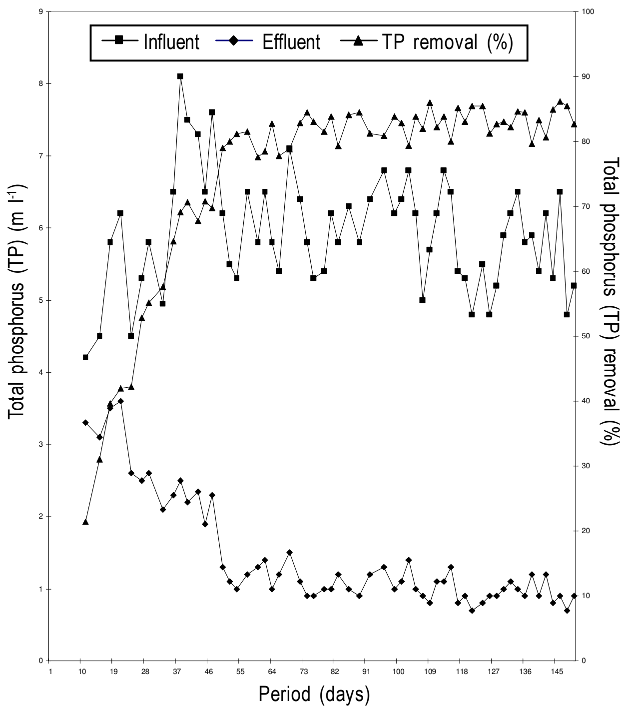

Fig. 6: Total phosphatase removal profile during the treatment of domestic wastewater

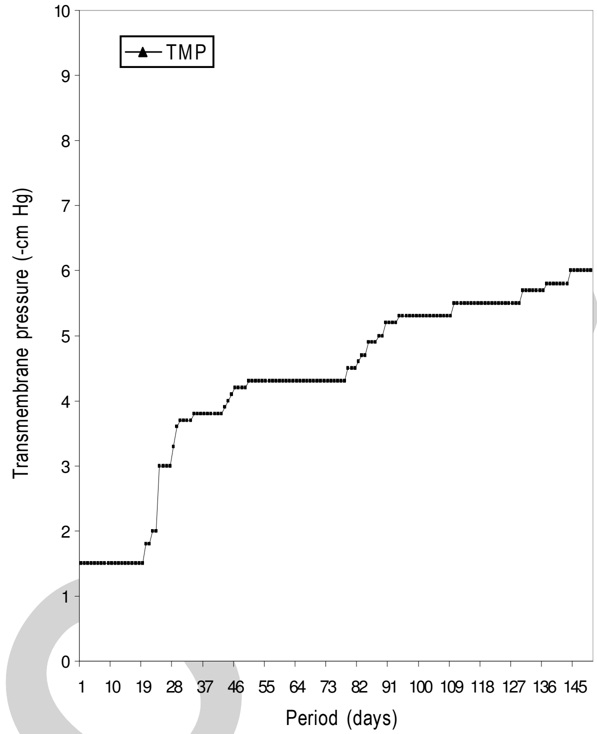

Fig. 7: TMP profile of A2/O-MBR

onwards the COD removal was in the range of 96-98%. The A2/O MBR system can provide a consistently high COD removal efficiency. The organic concentration in the effluent was varied from 8-5 mg l^{-1} and was much lower than conventional reactors. The results showed that membrane separation played an important role in providing the excellent and stable effluent quality.

Figure 4 explain nitrification and denitrification processes in the A2/O-MBR system. Nitrogen removal is a two step process (Baikun and Shannon, 2007). In the first step ammonia was converted into nitrate under aerobic conditions called nitrification and is susceptible to inhibition by variety of compounds (Andrea *et al.,* 2005).

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

Nitrification is the primary important process in removing total nitrogen from the wastewater. Incomplete nitrification resulted in decrease in TN removal efficiency of the system (Morita *et al.,* 2007). Dissolved oxygen (DO) is the principal parameter that controls nitrification. Nitrification efficiency goes down when DO decreases below 2.5 mg l^{-1} (Van Benthum *et al.,* 1998). To ensure complete nitrification the DO in the aerobic basin was maintained around 3.5 mg l^{-1}. From the Fig. 4, it can be seen that ammonia concentration in the aerobic basin was almost near invisible during all period of reactor operation. Whereas, the nitrate concentration in the aerobic basin was found to be in the range of 4.8 to 8.2 mg l^{-1}. The result indicates that the nitrification process was complete and all the influent ammonia entered in to aerobic basin was completely oxidised into nitrate.

From the Fig. 4 it is evident that there was no accumulation of nitrate in anoxic basin through out the period of A2/O-MBR operation. The nitrate concentration in the anoxic basin was in the range of from 0.3 to 1.6 mg l^{-1} indicating efficient denitrification process. All nitrate species entered into anoxic basin from aerobic basin via internal recycle (IR = 3 Q) was converted into atmospheric nitrogen. While working on nitrogen removal Meinhold *et al.* (1999) have reported that anoxic phosphorus uptake was inhibited in the presence of nitrate at critical concentrations ranging from 5 to 8 mg l^{-1}. The presently observed nitrate value in the anoxic basin was much lower than 8 mg l^{-1}, which is an indicator of reactor performance in removing TN and TP. Nitrate concentration in the anaerobic reactor was found to be nil through out the period of operation. This condition favors anaerobic release of phosphorous by phosphate accumulating organisms (PAO) because the presence of nitrates the oxidized species of nitrogen in anaerobic basin found to inhibit phosphorous release by PAO.

Fig. 5 explains total nitrogen (TN) removal efficiency of the A2/O-MBR system. It is evident from the figure that the nitrogen removal efficiency of A2/O system was remains unaffected by the varying influent TN load. The influent TN was fluctuating and was in the range of 34 to 62 mg l^{-1}. During the initial phase of operation (1-20 days) the TN removal was in the range of 58 to 65%. The lower TN removal percentage at this phase is due to the initial acclimatization period. Nitrogen removal efficiency in the effluent starts increasing with increase in operational period. It was in the range of 68 to 75% during the reaming days of reactor operation and the corresponding TN concentration in the effluent was found to be in the range of 11 to 22 mg l^{-1}.

Phosphorus is the primary nutrient responsible for algal bloom and it is necessary to reduce the concentration of phosphorus in treated wastewater to prevent the algal bloom. Fortunately its growth can be inhibited at the levels of TP well below 1 mg l^{-1}. Fig. 6 depicts TP removal efficiency of the A2/O-MBR system during the period of study. It is clear from the figure that the total phosphorus (TP) removal efficiency of A/O system was remains unaffected by the fluctuating TP concentration in the influent. The influent TP concentration varied from 4.5 to 8.1 mg l^{-1}. During the first four weeks of operation the TP removal efficiency of the system was not efficient as the TP concentration in the effluent exceeds over 3 mg l^{-1}. The lower TP removal efficiency during the initial period was due to the slow growing nature of PAO organisms and other factors such as anaerobic condition and internal recycling. After the initial period, the TP removal efficiency in the effluent starts increases with increase in period of operation. During this phase the TP removal was in the range of 74 to 82% and the corresponding TP concentration in the effluent was found below 1 mg l^{-1} for most of the operational period.

The suction pump was started after the first week of seeding and was based on the sCOD of the aerobic basin. The pump was started when sCOD in the aerobic basin was 35 mg l^{-1}. The designed flux for the membrane was 17 LMH. This was achieved by stepwise increase of flux from 25 to 100% over a period of one week. Fig. 7 shows the transmembrane pressure variation during the operational period. It indicates that transmembrane pressure increased slowly over a period of 150 days. At the time of start up the TMP was found to be nil. It increased slowly over a period of 150 days and at the end of 150 days the TMP was found to be 6 -cmHg. However, the membrane was not cleaned during the 5 months of operation. The system operated steadily for 5 months, which demonstrated that, the start-up and operation strategy for the MBR was successful.

From the results obtained it can be concluded that the pilot scale A2/O-MBR was used effectively for treating domestic wastewater. Membrane separation played an important role in ensuring excellent and stable effluent quality. Removal of COD, TN and TP was 96, 75 and 82%, respectively. The effluent quality was meeting the standards of Korean Ministry of Environment. The system had complete nitrification and very high TN removal efficiency.

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