Use of Membrane Bioreactor Process for Wastewater Treatment: Case Study

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Abstract

Paulding County in the State of Georgia has experienced approximately a 96% population increase in the last decade [1]. As a result of this population growth the need for increasing wastewater treatment capacity and improving effluent quality have become one of the main priorities for the Public Works Department (PWD). In an effort to improve the existing capacity of one of the existing wastewater treatment plants, the PWD approached the Civil Engineering Technology (CET) program at Southern Polytechnic State University to conduct a pilot-scale evaluation of an immerse membrane system (or membrane bioreactor) for municipal wastewater treatment.

A three-month study was conducted to evaluate the efficiency of a membrane bioreactor. This work was conducted on a 918 L/h pilot plant comprised of an anoxic tank, an aeration tank and four membrane modules. This pilot system was operated in parallel with the full-size wastewater treatment plant to determine and compare removal efficiencies for BOD, COD, TSS, TKN, NH_3, NO_3, PO_4 and fecal coliforms. With the exception of nitrates, phosphates and fecal coliforms, all the analyses were performed at the CET environmental laboratory. The pilot system produced an effluent containing BOD concentrations less than 1.0 mg/L and turbidity readings below 1.0 NTU.

Introduction

Trussell [2] and Adham [3] have reported that membrane bioreactor systems can produce high quality effluent with respect to BOD, TSS and fecal coliform count. The objective of this study was to evaluate the efficiency of the membrane system under two different mixed liquor conditions and determine the best operating conditions; while comparing the performance of the pilot system with the existing treatment facility.

The pilot system designed by US Filter and used in this study, consisted of a 3028-L (800 gal) anoxic tank, a 6814-L (1800 gal) aeration tank, and four membrane modules with a surface area of approximately 9 m^2/module, for a total area of 36 m^2. This system was operated at a rate of 25.5 L/m^2-h, corresponding to a flow rate of 918 L/h. The average hydraulic retention time in the anoxic system was 3.3 hours, and the retention time in the aeration time was 7.42, for a total of 10.72 hours.

The Pumkinvine wastewater treatment plant has a capacity of 0.5 million gallons per day. The plant consists of three sequencing batch reactors (SBRs), two sand filters, an aerobic digester and a UV disinfection system. The treated effluent is currently used for irrigation of a golf course.

The hydraulic conditions were constant throughout the duration of the pilot test. The only parameter changed in the tests was the concentration of solids in the biological system. The first phase of the study was conducted with an average mixed liquor suspended solids (MLSS) of 9370 mg/L for a period of 60 days. The second phase of the study was conducted with an average MLSS of 6470 mg/L for approximately 30 days.

Waste Characterization

The students participating in this project were instructed on the operation of the pilot system and sampling of the influent and effluent, as well as the type of samples required for this study. Grab samples were considered appropriate, since the raw wastewater is pumped to an equalization tank with an average retention time of approximately 18 hours. A profile of the raw wastewater was produced as a result of the analyses conducted on influent samples to the pilot system. Table 1 summarizes the influent characteristics to the wastewater treatment system during the testing period.

Table 1. Characteristics of the Influent to the Pumpkinvine Wastewater Treatment Plant

Parameter	Minimum	Average	Maximum
Total BOD	121	240	376
Soluble BOD	56	92	186
Total COD	176	517	1607
Soluble COD	43	201	383
Total Suspended Solids	64	330	683
Volatile Suspended Solids	55	220	475
Total Kjeldahl Nitrogen (TKN)	32	43.8	56.8
Ammonia	17.5	34	50.5
Phosphates	10.2	12.4	15.1

This characterization effort shows that the soluble organic matter, expressed as soluble BOD_5 (or soluble COD), represents approximately 38 to 39% of the total organic content. The total BOD_5 to total COD ratio for this waste stream is approximately 2.15:1. As expected for sanitary sewage, the volatile suspended solids represent a high percentage of the total suspended solids, 69%. Therefore, the removal of suspended solids will improve the treatment capacity of the biological system by reducing the organic load. The average TKN and ammonia concentrations correspond to reported medium strength untreated domestic wastewater [4].

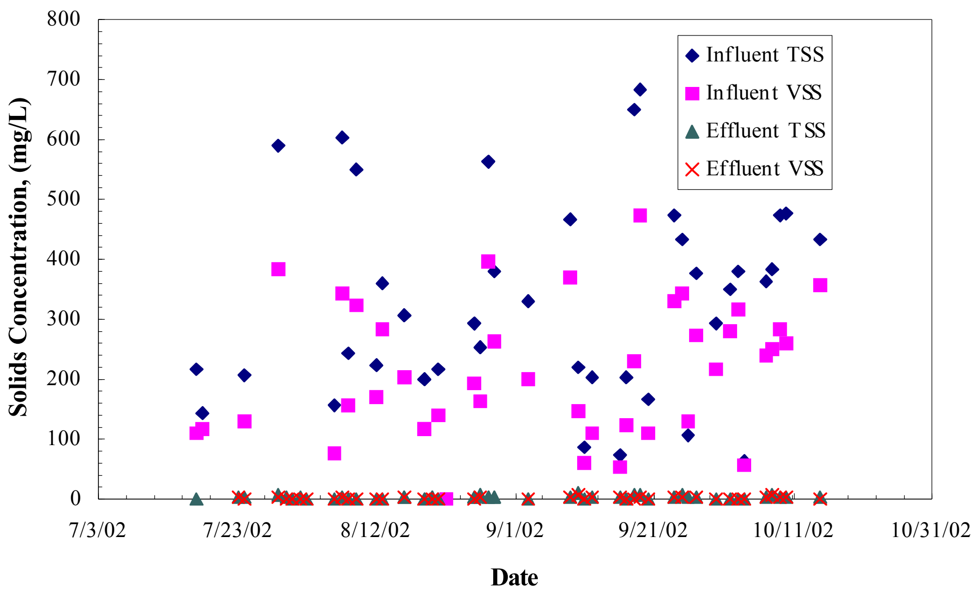
Performance of Pilot System

The pilot system operated almost continuously since the start-up, with the exception of four major incidents that took the system completely out of operation. The first incident was the presence of surfactants in the influent water; which produced large amount of foam in the aeration tank and the membrane unit. From conversations with the supervisor of the wastewater treatment plant, we concluded that surfactants might have been discharge during the weekend prior to the incident. The other incidents included sustained power failures and the rupture of a pipe inside the membrane system. The pipe failure required a complete shut down of the pilot system. During this incident the biological system lost part of the mixed liquor, forcing the team to conclude all sample collection activities.

The control system proved to be extremely sensitive to power surges, which turned off the system completely. Fortunately most of these power surges or failures occurred during the day, when the operator of the wastewater treatment plant or a student was present to reset the control panel and restart the pilot system.

Analysis of effluent and influent data shows that the bio-membrane system is extremely efficient in solids removal (Figure 1). This system achieved an average TSS removal efficiency of approximately 99%. The average turbidity of the effluent, 0.28 NTU is below the turbidity levels found in natural waters and below the required turbidity for drinking water in the State of Georgia [5]. Therefore, based on turbidity alone, the effluent of the pilot system could be discharged to any surface water without adverse effects.

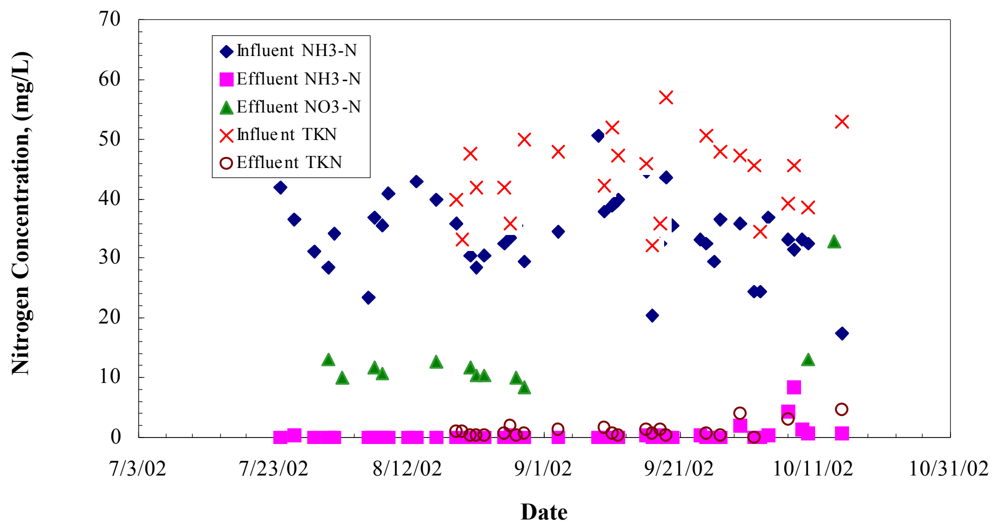
Figure 1. Pumpkinvine Pilot Plant Suspended Solids Concentrations



The organic matter removal attained with the pilot plant was greater than 99%, with BOD_5 effluent concentrations less than 1 mg/L. This removal efficiency is directly related to high solids retention times. Although wasting of activated sludge was difficult to control, the volume of waste activated sludge was estimated based on a theoretical solids retention time of 12 days.

Based on the hydraulic and solid retention times, the biological system should have been capable to nitrify and denitrify; however, denitrification did not take place in the pilot system. The failure of the system to denitrify is clearly identified by the high nitrate concentrations detected in the effluent (average concentration, 12.9 mg/L). Ammonia and organic nitrogen conversion to nitrates was successful (Figure 2). The nitrification efficiency attained during the testing period exceeded 97%. Although the pilot unit contained an anoxic tank, compressed air was provided to satisfy mixing requirements, thus affecting the overall nitrogen removal process. We believe that the presence of dissolved oxygen at regular intervals, in the anoxic tank, affected the overall nitrogen removal by hindering denitrification.

Figure 2. Pumpkinvine Pilot Plant Nitrogen Levels



Aluminum sulfate for phosphorous removal was initially added based on stoichiometric requirements for an average concentration of 10 mg/L PO_4-P. Due to the demand exerted by the suspended solids in the influent and mixing deficiencies in the addition point, the stoichiometric dose proved to be insufficient. Jar test conducted on influent samples showed that a dose of approximately 200 mg/L alum would remove the suspended solids and would produce a treated effluent with phosphorous concentrations below 0.4 mg/L PO_4-P (Table 2). The alum dose has to be adjusted so sufficient phosphorous was left in solution to satisfy the biological requirements. Based on theoretical macronutrient requirements (BOD: N: P = 100:5:1) for aerobic processes, the amount of phosphorus required to sustain biological growth should be approximately 1.9 mg/L, for a maximum soluble BOD_5 of 186 mg/L.

An average effluent fecal coliform count of 58 colonies per 100 mL was obtained from readable samples. It is the opinion of the authors that the sampling port influenced the results of the fecal coliform analysis. The effluent had to travel through transparent tubing before it was collected. Exposure of the effluent, in the tubing, to light stimulated algae growth; making it impossible to maintain a clean and unobstructed sampling port. The biological mass in the tubing may have retained bacteria and enhanced their growth. Despite that interference, the coliform levels are much lower than those in the effluent of the sand filters of the SBRs system [6].

Table 2. Phosphorus Precipitation Tests, Pumpkinvine Wastewater Treatment Plant

Sample No.	Alum Dose (mg/L)	PO_4-P (mg/L)
1	200	0.31
2	250	0.65
3	300	1.21
4	400	0.39
5	500	0.54
6	600	0.37
7	750	0.66
8	1250	1.63

Experimental Conditions: 5% alum solution, fast mix: 1 minute @ 100rpm, slow mix: 5 min @ 20 rpm, settling time: 15 minutes.

Comparison of Pilot System and Existing SBR Reactors

Operating data of the SBRs reported to the Georgia Environmental Protection Division by the wastewater management, for the testing period, are presented in Figure 3. These data show that the full-size treatment system consistently removed 99% of the influent BOD_5 and TSS, respectively. The effluent BOD_5 concentrations were less or equal to 2 mg/L. Although the effluent concentrations of the pilot system were consistently less than 1 mg/L, the BOD removal efficiencies of both systems were comparable, and both were greater than 99%.

The suspended solids removal efficiencies for the SBRs and the bio-membrane system were similar. Both systems achieve removals greater than or equal to 99%. However, the SBR system produced a more consistent effluent than the pilot system. One of the reasons for variations in the effluent of the pilot system was the presence of algae in the sampling port and the effluent storage tank. Even after changing the clear tubing for black tubing, the TSS concentration in the effluent of the pilot system never reached a consistent value. Although the variations were not extreme, the presence of algae in the effluent storage tank could affect the overall effluent quality.

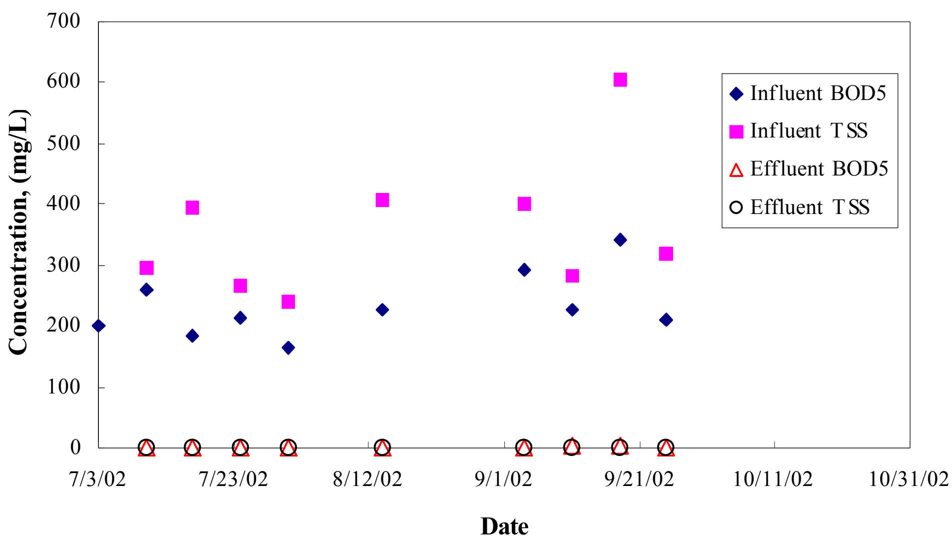
Conclusions

After evaluating the analytical data for the pilot and full-scale treatment systems, we conclude:

- The biomembrane system can produce a treated effluent with BOD_5 concentrations of less than 1 mg/L.
- The removal efficiency of the SBR system during the testing period was similar to that of the biomembrane system

- Suspended solids removal efficiencies of 98 percent or more are achievable with either the biomembrane system or the conventional treatment system.
- Approximately 61% of the influent BOD_5 is particulate matter, which could be removed by physical processes.
- The treatment capacity of the existing wastewater treatment can be increased with the implementation of preliminary and primary treatment systems, which reduce the organic loading to the biological system.
- The control system of the biomembrane reactor is extremely sensitive to power fluctuations, thus requiring constant supervision to establish normal operation after a power surge or failure.

Figure 3. Performance of Pumpkinvine Wastewater Treatment Plant



Lessons Learned

The experience gained during this study can be evaluated from the academic point of view and from the student perspective. From the academic point of view we believe that we gained a better understanding of the membrane process as a secondary treatment component, and its control requirements. This project also improved our laboratory capabilities allowing us to include the microkjeldahl digestion and distillation systems as additional components of the academic material. These pieces of equipment will help the implementation of new laboratory experiences, and their integration in the required environmental course for CET students, as well as in elective courses. This project also exposed the demands of research on faculty in academic programs dedicated almost exclusively to teaching, and without the support of graduate programs in engineering technology. Despite time and resource limitations, it is important to continue implementing engineering application projects to motivate faculty and students to search for better solutions to engineering problems.

This experience broadened the students understanding on testing and evaluation projects. The students learned about the preliminary steps that must be taken to start a project, from the initial survey of the site to preparation of all required equipment. Discussions on type of samples and sample collection, made the students understand the impact of sampling collection on analytical results. Perhaps for the first time, students were faced with real world applications regarding the operation of biological treatment systems, and the complexities of their control systems. It was also evident for the team that the performance of the pilot system and its overall evaluation, depended heavily on the reliability of the control system, which affected the operation of the physical and biological process.

The students participating in this project consider that they increased their knowledge on analytical testing and data collection, interpretation and application to practical solutions. The students participating in this project felt that this type of projects also enhanced communication between faculty and students. Finally, they considered that this project helped them reinforce the material learned in the courses, and understand how that knowledge applies to everyday practice, while stimulating their interest in the environmental engineering field.

References

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[3] Adham, S., et. al., "Overview of the Membrane Bioreactor Process for Wastewater Treatment and Water Purification", WEFTEC 1999 Conference Proceedings, New Orleans, Louisiana, October 9-13, 1999.

[4] Metcalf & Eddy, Inc., "Wastewater engineering: treatment and reuse", 4th. Edition, McGraw-Hill, 2003, (186-187).

[5] Georgia Department of Natural Resources, Rules for Safe Drinking Water, Section 391-3-5.20(4), 1993 (www.dnr.state.ga.us/dnr/environ/).

[6] Conversation with Mr. Tom Brill, Supervisor of the Pumpkinvine Wastewater Treatment Plant.

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