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Performance study of membranes for suspended solid separation in activated sludge process

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This work describes performance study of membranes for suspended solid separation in ASP effluent. Two membranes, namely nylon membrane (NM) of 50 µm pore size and stainless steel membrane (SSM) of 30 µm pore size were used in this study. The performance was evaluated in terms of flux, permeate quality and fouling characteristics. The gravity filtration technique has been utilized for solid-liquid separation. Transmembrane pressure has been developed using water head. The SSM membrane was found to be superior and consistent in terms of fouling resistance and removal efficiency. The comparative study suggests that stainless steel membrane reactor has better removal efficiency and gives permeate with dischargeable effluent quality in terms of MLSS concentration.

Keywords: Membrane bioreactor, activated sludge process, solid-liquid separation, stainless steel membrane, nylon membrane.

Introduction

The purpose of biological treatment of wastewater is to convert the dissolved organic substances into suspended solid like biomass. In both attached growth and suspended growth processes the biomass needs to be separated to achieve lesser oxygen demand in the effluent. The conventional way to remove the biomass from the mixed liquor is the process of phase separation with the help of gravity in a secondary settling tank. In recent years membrane separation technique has been used to serve the purpose of secondary settling tank. The micro-filtration or ultra-filtration process can render the effluent quality fit for discharge[1]. Membrane solid-liquid separation technique has been emerged as an alternative for secondary settling tank as it requires lesser space and has high removal efficiency[1]. In this work the membrane separation has been performed in gravitational flow where the water head is used to build the transmembrane pressure.

The objective of this work is to find the performance of the membrane of two materials for solid-liquid separation in ASP under gravitational flow. Thus membrane reactors can be used as an integrated part of the ASP as next development in this study. In this study it has been observed that the performance of the SSM membrane was superior and consistent in terms of fouling resistance and removal efficiency. The flux depends on the concentration of MLSS of the ASP and the turbulence created by coarse bubble aeration. The MLSS removal efficiency of the NM for both single layer and double layered membrane module with aeration was found to be in a range of 66% to 87% whereas in case of the SSM it ranged from 89% to 97%. When the separation process was done without the coarse bubble aeration the flux became lesser and the fouling was prominent. When the aeration was not used to create turbulence, all of the liquid could not be collected due to chocking of the SSM membrane for higher MLSS concentrations.

Materials and methods

(A) Membranes:

Nylon membrane (pore size 50 µm) and stainless steel membrane (pore size 30 µm) were obtained commercially. The pore size of the membranes was chosen keeping in mind that more than 70% of suspended solids in the MLSS are more than 30 µm and more than 50% of suspended solids are more than 50 µm[2]. The membranes are chemically stable in contact with the ASP mixed liquor (checked for more than four month of contact period). The fouling resistance properties of the membranes are good and cleaning is also simple.

The nylon membrane (NM) cannot bear low pH unlike the stainless steel membrane (SSM) which would not be damaged in contact with acids. The cost of membrane is a major concern of the membrane reactor so in this study the membranes are chosen of nominal cost to minimize the overall cost of the process.

(B) Reactor set-up:

The ASP was simulated in a plastic container. The inoculums for the biological growth were collected from a municipal wastewater treatment plant. The membrane reactors were made by cutting a Plexiglas or acrylic pile in pieces of 30 cm in length. The diameter of the reactors are 5 cm. Reactors were used as an external module for solid-liquid separation. Two reactors were made using one layer of membrane of each material and another two reactors were also made using two layers of membranes.

(C) Aeration pumps:

Air pumps (SOBO air pump) with 1.33 L/min of air flow were used. These were used mainly, to supply oxygen into the aeration tank for biomass growth and in the membrane module to create turbulence inside the reactor for resisting fouling.

(D) Analytical method:

MLSS, COD and sludge volume index were determined according to Standard Methods[5]. Dissolved oxygen was measured using DO meter (Thermo Scientific Orion Star A123). The turbidity was measured by turbidity meter (Eutech Instruments) in NTU.

(E) Experimental studies:

Fig. 1 shows the schematic diagram of the membrane reactor setup for solid-liquid separation. The reactors were used under batch mode. The working capacity of each reactor is 500 ml. The aeration tank consisted of a container with working volume of 10 L. The aeration system was fed with glucose and crucial nutrients for bacterial growth. The composition of the feed is shown in Table 1. The feed was varied with the growth of the biomass stating from 100 mg/L of glucose feed on alterative day to 350 mg/L of glucose feed every day. The oxygen up take rate of the reactor was 1.55 mg/L/min. The inoculums of activated sludge were obtained from the sludge of a municipal wastewater treatment plant. The preliminary MLSS was 500 mg/L and it was allowed to grow up to 2500–3000 mg/L. The reactor was kept in room temperature. The aeration tank effluent was put to solid-liquid separation in the external membrane module prepared by assembling the membrane and the Plexiglas pipe. The membrane module was placed vertically with the membrane fitted end being at the bottom and the other end being open to atmosphere.

Table 1. Composition of feed

Compounds	Amount (mg/L)
$C_6H_{12}O_6$	10000
$(NH_4)_2SO_2$	3770
KH_2PO_4	175
K_2HPO_4	200
$FeCl_3$	20
$CaCl_2$	200
$MgSO_4$	220

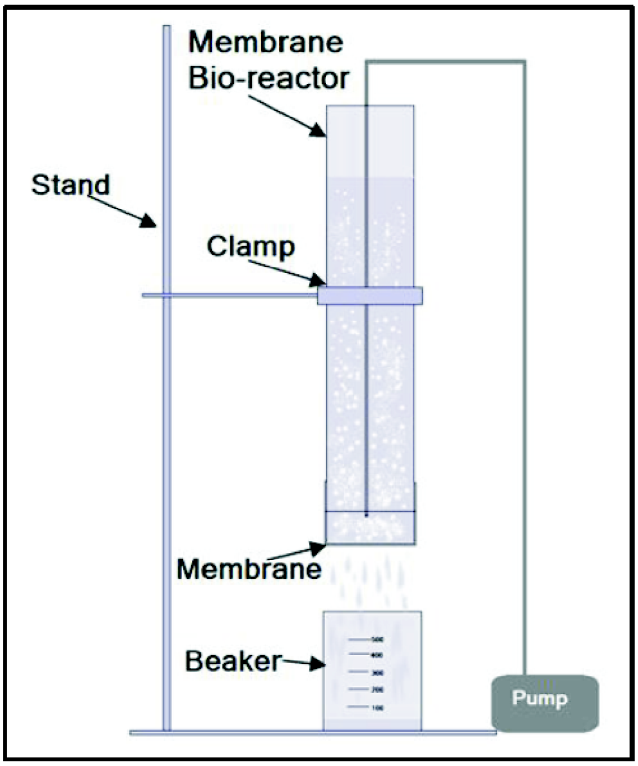

Fig. 1. Membrane bioreactor setup.

Results and discussion

The COD removal of the aeration tank was measured and it was found that it could reduce the COD by 85% in 24 h. The SVI was measured and it was found to be fluctuating in the range between 24 ml/g and 32 ml/g. The MLSS of the effluent of the aeration tank and that of the membrane modules was measured. The turbidity of the effluent of the membrane module was observed to be as less as 1.8 NTU. The efficiency was measured in terms of what portion of aeration tank MLSS could be retained by the membrane inside the module. The time for treatment and the effluent collected after the membrane treatment was measured as it indicates the variation of flux through the membranes. The data collected during the work period are shown in Table 2 through Table 9 followed by their respective plots from Fig. 2 through Fig. 5.

The data for similar process configuration in terms of number of membrane layers, presence of aeration, MLSS concentration for NM and SSM are plotted on the same graph to give an idea of their comparative performance for solid-liquid separation.

The removal efficiency of NM is more influenced by the characteristics of the effluent sludge of the aeration tank as it can be seen in run number 1 to 5. This is indicated by the fluctuation in percentage removal for different SVI. But in case of SSM this variation of percentage removal is less.

The settlement of the suspended particles did not occur when the aeration was provided. As a result, turbulence caused by aeration disintegrated the particles present in various layers formed on the membrane. Consequently, the particles imparting membrane fouling were gradually removed from the membrane pores. Thus the gravitational flow occurs without any hindrance other than membrane resistance.

It has been observed during this study that for the membrane separation process with aeration, higher removal took place, especially when SVI is more (32 ml/g) for NM. This might be due to the fact that the biomass flocs were bigger and less dense and hence not much flocs could pass through

Table 2. Single layer nylon membrane (with aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
1	918	4 min 20 s	≈ 450 ml	307	66.5
2	1404	16 min 11 s	≈ 450 ml	249	82.3
3	2060	10 min 30 s	≈ 450 ml	660	67.9
4	2562	17 min 20 s	≈ 450 ml	332	87.0
5	2964	12 min 46 s	≈ 450 ml	730	75.4

Table 3. Single layer stainless steel membrane (with aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
6	918	31 min 20 s	≈ 400	43	95.3
7	1404	55 min 30 s	≈ 400	151	89.2
8	2060	28 min 15 s	≈ 400	96.67	95.3
9	2562	87 min 23 s	≈ 400	105	95.9
10	2964	1 h 8 min	≈ 400	133	95.5

Table 4. Double layer nylon membrane (with aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
11	1084	7 min	≈ 450	270	75.0
12	1558	28 min 32 s	≈ 450	662	57.5
13	1942	43 min 47 s	≈ 450	650	66.5
14	2486	54 min	≈ 450	387	65.6
15	2953	56 min	≈ 450	970	67.2

Table 5. Double layer stainless steel membrane (with aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
16	1084	14 min 42 s	≈ 400	48	95.6
17	1558	47 min 30 s	≈ 400	66	95.8
18	1942	1 h 10 min	≈ 400	103	94.7
19	2486	1 h 10 min	≈ 400	114	95.4
20	2953	1 h 16 min	≈ 400	71	97.6

Table 6. Single layer nylon membrane (without aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
21	1170	3 min 16 s	≈ 450	387	66.9
22	1700	9 min 30 s	≈ 450	340	80.0
23	1996	7 min 02 s	≈ 450	351	82.4
24	2707	10 min 21 s	≈ 450	332	87.7
25	2993	21 min 17 s	≈ 450	289	90.3

Table 7. Single layer stainless steel membrane (without aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
26	1170	38 min 10 s	≈ 400	59	94.9
27	1700	50 min 12 s	≈ 400	95	94.4
28	1996	2 h	≈ 400	86	95.7
29	2707	1 h 50min	≈ 300	28	98.9
30	2993	27 min	≈ 150	179	94.0

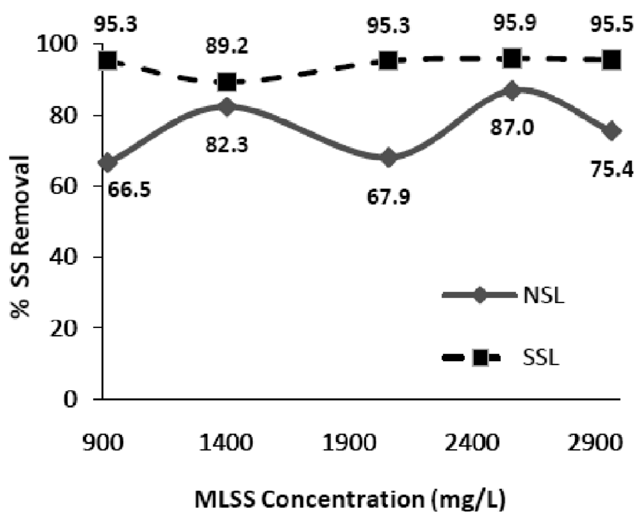

Fig. 2. Percentage removal vs MLSS concentration. NSL = Nylon single layer, SSL = Stainless steel single layer.

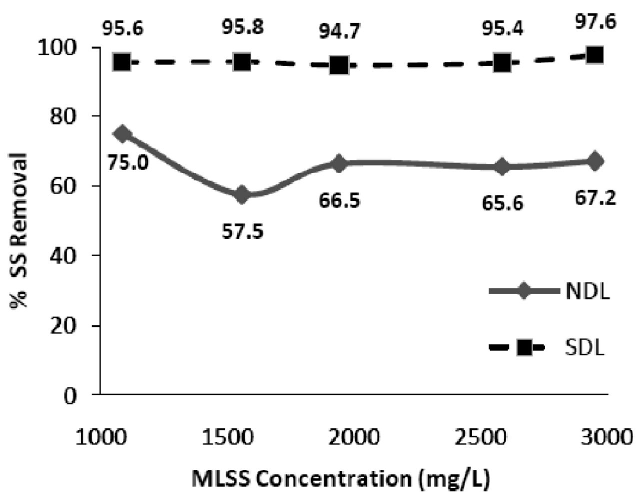

Fig. 3. Percentage removal vs MLSS concentration. NDL = Nylon double layer, SDL = Stainless steel double layer.

Table 8. Double layer nylon membrane (without aeration)

Run number	MLSS concentration of influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
31	1074	10 min 12 s	≈ 400	109	89.8
32	1700	22 min 32 s	≈ 400	156	90.8
33	2054	17 min 45 s	≈ 400	163	92.0
34	2479	19 min 45 s	≈ 400	126	94.9
35	3046	27 min 42 s	≈ 400	182	94.0

Table 9. Double layer stainless steel membrane (without aeration)

Run number	MLSS concentration of Influent (mg/L)	Time of significant separation	Amount of recovered water (ml)	MLSS concentration of effluent (mg/L)	Percentage removal of suspended solids
36	1074	52 min	≈ 300	25	97.7
37	1700	48 min 20 s	≈ 250	99	94.8
38	2054	35 min	≈ 150	86	95.8
39	2479	32 min	≈ 140	68	97.2
40	3046	30 min	≈ 120	61	97.9

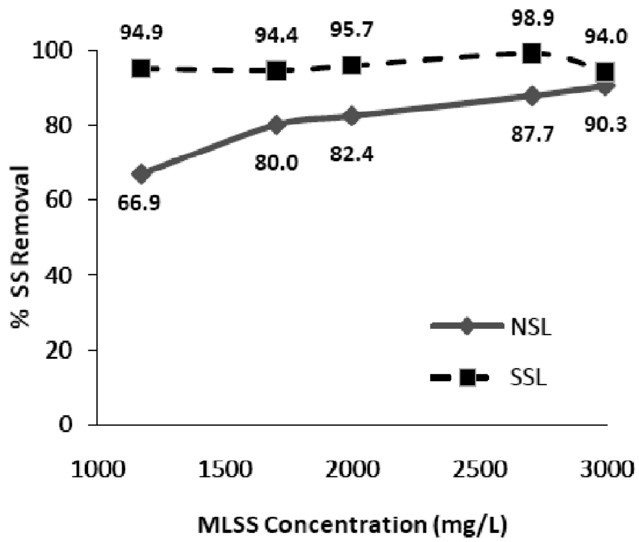

Fig. 4. Percentage removal vs MLSS concentration. NSL = Nylon single layer, SSL = Stainless steel single layer.

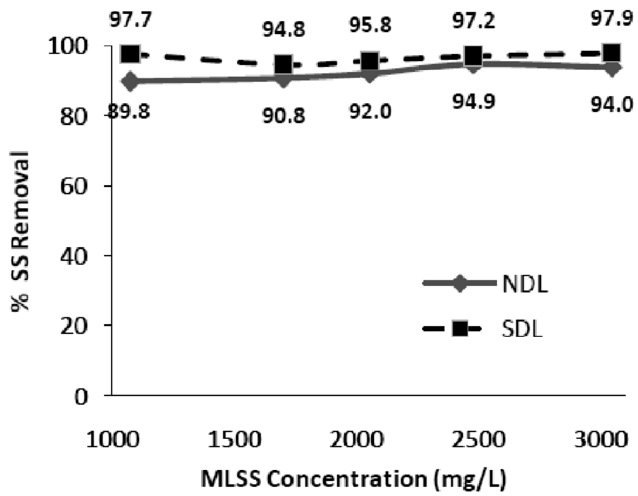

Fig. 5. Percentage removal vs MLSS concentration. NDL = Nylon double layer, SDL = Stainless steel double layer.

the pores of the membrane while the liquid passed through it.

The position of the aeration outlet inside the membrane module plays an important role in resisting fouling on the membrane. As the air outlet was placed far from the membrane the turbulence near the membrane was reduced and the membrane fouling increased causing decrease in flux. But, the removal efficiency increased as the effective pore size of the membrane reduced, for the particle layer formation on the membrane (observed in run number 11). But, when the air outlet placed close to the membrane the turbulence became more in near vicinity of the membrane which resisted pore clogging of the membrane. Though, the air pressure onto the membrane helped the particles to pass through the membrane (observed in run number 12). So the air outlet was kept inside the membrane module at an optimum height (about 25 mm).

The particles start to settle to the bottom on the membrane forming a layer of particles when aeration was not provided in the membrane module. It reduced the effective pore size of the membrane and so more removal of suspended solid took place. But, consequently the pores of the membrane got blocked by the settled particles. As the pore size of the SSM is lesser this phenomena affected the SSM severely as observed in run number 29, 30 and 36 to 40.

In contrast to the case when aeration was provided inside the membrane reactor, better removal took place especially when SVI was considerably less (25 ml/g). This is because the dense flocs settle readily on the membrane and reduce the effective pore size of the membrane by forming a layer of floc particles, which leads to fouling.

The fouling of the membrane was indicated by the increased time for collection of the effluent from the membrane module i.e. reduction in flux and chocking of the membrane itself as seen in run number 29, 30 and 36 to 40. The membranes were cleaned when fouling became severe (after run number 9, 25, and 28 and after each run from run number 36 to 40). The membranes were cleaned by 0.5 *N* of NaOH and tap water for NM[2] and 20% H_2SO_4 was used for SSM.

The membrane was chocked very fast when turbulence was not provided by aeration. Therefore, in case of SSM (from run number 36 to 40) it was indicated by lesser volume of effluent collected. The rate of flow was further decreased as the MLSS concentration of the influent increased.

In most of the previous studies the TMP was controlled by using a pump. Therefore chocking of membrane was not frequently encountered. The biomass retention percentage was observed to be in the range of 80% to 100%[2–4], A high MLSS retention was achieved by using a membrane with lower pore size (in the range of 1 μm to 20 μm) and higher TMP (in the range of 6 KPa to 10 KPa). In this study maximum of 2.3 KPa TMP was applied using water head inside the reactor. The MLSS retention was achieved by stainless steel membrane up to 97.6% in case of turbulence provided by means of aeration and 98.9% when turbulence was not provided.

Conclusion

This present study illustrated an idea of MBR operation under gravity flow process. The effectiveness of the stainless steel membrane to retain the biomass and its resistance against fouling has been established using biomass of activated sludge process. The biomass was recovered after the membrane separation and was recycled to the aeration tank. Thus, high SRT can be maintained in the aeration tank, equipped with a membrane module. Apart from that the operational cost can be reduced too by omitting the usage of suction pumps, which are used for effluent collection from the membrane module.

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