# Significant Study of Effect of Aeration Intensities on Membrane Bioreactor Performance

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***Abstract-*** The performance of a tailor-made design of membrane module was studied at different aeration intensities (120, 240 and 480 L/h) to comprehend the concept of membrane fouling control using aeration. The effect of aeration on membrane fouling control is evaluated by observing the structure of cake layer, the quality of effluent and the flux of filtrate obtained.

Aeration rate was found to be a significant factor in cake removal rate and improving the filtration performance. Then, the aeration rate has to be optimized. High air flow rate would add higher operating cost and can affect the biomass characteristics. Low air flow rate results in inappropriate membrane scouring and lower oxygen supply to the biomass. Aeration intensity has a positive influence on the cake removal but as the aeration intensity increases beyond its optimum range, severe breakage of sludge occurs which further results in severe blockage of membrane pores and enhances the membrane fouling, reducing the flux.

During the aeration, efficient membrane scouring can be achieved by optimal design of membrane module. Flat sheet membrane elements which are arranged vertically on a primary manifold for the support are comprised of gaps between the membrane elements through which the gas bubbles pass, when the air is introduced. The gap between the membrane elements and the volumetric air flow rate and superficial air velocity play a vital role to facilitate an efficient scouring of the membrane elements due to the passage of the bubbles.

The current study has been carried out to study the membrane fouling control by optimizing aeration intensity and channeling of air passage through the system with appropriate membrane module design. The major components of organic matters in the membrane foulants are identified as proteins, polysaccharides and lipids by the Fourier transform infrared spectroscopy (FTIR) of the collected cake.

***Index Terms***- Membrane bioreactor (MBR), Aeration intensity, Flat sheet Membrane Module and membrane Fouling.

## I. Introduction

Membrane bioreactor (MBR) is a biological wastewater treatment process where biomass is been separated by membrane and gives better permeate quality. This process has advantages like high biomass concentration, less footprint, low sludge production and higher permeate rates and standards.[2]

To avoid the high energy consumption (2-12KWh/m3) resulting from the recirculation of the effluent through the side stream MBR, submerged MBR has been developed, which needs less energy consumption (0.19-0.70 KWh/m3) (Judd 2011). In submerged MBR, aeration not only provides the oxygen to biomass but also provides scouring of the membrane surface which further reduces membrane fouling.

Membrane allows sludge retention to optimum level. The MBR can be operated with higher sludge concentration (10-30 gm/lit) (Judd 2011). High sludge concentration indicates high biomass which will degrade or decompose the organic matter present in the system at higher rate and loading. High quantity of biomass demands high oxygen requirement. The purpose of aeration is significant in the membrane bioreactor systems. MBR should be with sufficient aeration which can efficiently transfer the oxygen to the water medium for the ideal performance of the systems.

A major disadvantage of MBR is the decline in the permeation flux due to substantial membrane fouling.[3] Aeration has a significant effect on the membrane filtration performance and cake removal efficiency. The cake-removal efficiency due to aeration does not increase linearly with an increase in the air flow rate. A high aeration rate certainly can reduce sludge adherence to the membrane, but it also significantly influence the biomass characteristics and membrane fouling and defouling.

## II. MATERIALS

Flat sheet membrane plates were fabricated by gluing membranes on both the sides of PVC frame by an epoxy resin, supplied by Tech INC, Chennai, India. Wastewater which was used throughout the study was obtained from Dombivali Common Effluent treatment plant, Mumbai, India. Bioreactor was fabricated and operated at ICT, Mumbai, India.

Table 1 shows a schematic details of the system.

| | |
|---|---|
| Material of Membrane: | PVDF |
| Effective membrane surface: | 10 x10 cm |

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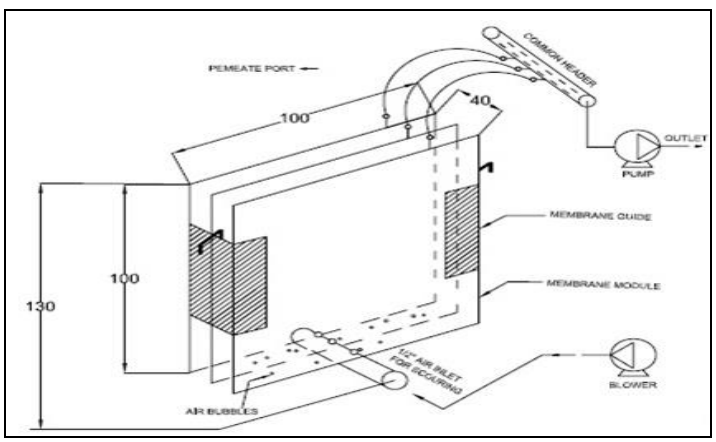
| | |
|---|---|
| Pore size of membrane: | 0.1- 0.2 µm |
| Nominal cut-off: | 20 kDa |
| No. of membranes: | 3 |
| Total Membrane surface area per reactor: | 0.06 $m^2$ |
| Material of Module: | Stainless steel |
| Size of Module: | 100mm x 130mm x 55mm |
| Material of reactor: | Stainless steel |
| Size of reactor: | 7 lit |
| Aeration intensity: | 120L/hr<br>240L/hr<br>480L/hr |
| Specific Aeration Demand (SADm): | 2m/s<br>4m/s<br>8m/s |
| Superficial Gas Velocity: | 1.7mm/s<br>3.3mm/s<br>6.7mm/s |
| Characteristics of wastewater: | |
| COD: | 1100 ppm |
| DO: | 3-4.5 ppm |
| pH: | 7-7.5 |
| MLSS: | 4000 ppm |

**Fig. 1: Flat sheet membrane module with air diffuser tube**

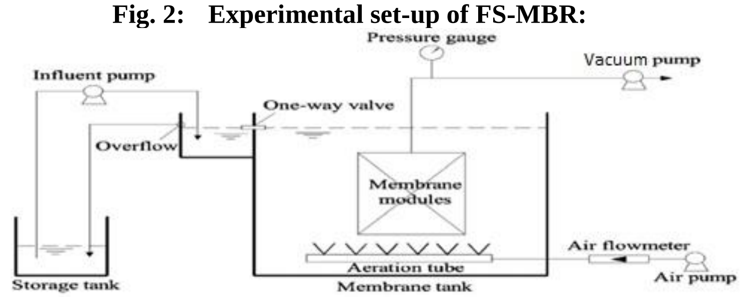



III. PROCESS:

In this work, submerged MBR under three different aeration intensities were operated for about 30 days to investigate the influence of aeration intensity on membrane fouling mechanism.
Throughout the tests, the membrane permeate flux was measured to study the extent of membrane fouling under different aeration intensities. The accumulated membrane foulant after 10-12 hrs of operation was collected and analyzed for the particle size distributions, FTIR analysis and the COD test to characterize the effect of aeration intensities on wastewater and biomass characteristics.

The fouling layer formation mechanism was examined to describe the deposition/ adsorption mechanism of membrane foulants. To study the foulant that accumulated on the membrane surface, membrane module was taken out from the bioreactor after 10-12hrs of operation and flushed with pure water.
The current study is performed in a pilot scale Flat Sheet MBR (FS-MBR) system. Wastewater is fed into the reactor for observation after primary treatment. Wastewater sample is firstly screened with sieve size of 2-3µm and then treated with 30mg/lit concentration of chemical coagulant i.e. Ferric Chloride and Polyaluminum Chloride (Rutuja 2019). Coagulation pretreatment on wastewater (pH 7) with the combination of FC and PAC (30 mg/lit) is able to reduce COD and TOC efficiently by 50-60% from 1100 ppm COD to 500 ppm COD. Primary treatment not only reduces the load on MBR but also enhances the life of the membrane. The primary treated wastewater having COD of 500 ppm is fed to the bioreactor. To achieve an aerobic condition for the normal growth of the activated sludge, a diffuser aerator is employed in bioreactor which also produces stirring within the reactor and scouring of the membrane due to the passage of the gas bubbles through the gaps of the membrane modules. A suction pump is used to extract the filtrate water from the membrane.

**Fig. 2: Experimental set-up of FS-MBR:**




**DESIGN OF FS-MBR MODULE:**

Membrane module is comprised of 3 flat sheet membranes mounted vertically. Membrane elements are held vertically with spacers to maintain a distance of 5mm between them and for a sturdy support. Air inlet tube is just welded below the membrane module, serves the purpose of air bubble scouring as well as aeration. Air inlet tube is ½" in diameter and has perforations of 5 mm which provides coarse bubbles through the membrane elements.
All three membrane elements are connected to the main header through individual tubes. Main header is further connected to the vacuum pump for suction. This system extracts filtrate through membrane elements which are mounted vertically on the membrane module. Larger bubbles (5mm in diameter) are effective for providing the scrubbing action in the Membrane system. Bubble scrubbing occurs as bubbles rise in the upward direction through the space created by the spacers mounted between the membranes. So it is important to have same or small space between the membranes to have effective scrubbing. The space between the membrane elements also plays a vital role in terms of scouring, which further relates to the membrane fouling control. As rising bubbles create sufficient shear force on the sides of membrane and it helps to remove fouling from the membrane surfaces.

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Aeration for microbial survibility is also of prime concern in the design of bioreactor, so fine bubble (0.5 mm in diameter) diffusers are also planted near the bottom of the membrane module. This serves the main purpose of supplying oxygen to the microbes in the wastewater. When fine bubbles pass through the spaces between the membranes they would combine and form large bubbles and helps in controlling the membrane fouling.

## IV. OPERATIONAL DEVELOPMENTS OF FS-MBR SYSTEM:

Aerobic biological suspensions mainly comprise of pollutants to be degraded, microorganisms, decay products and influent solids forming microbial aggregates which are held together by high molecular weight polymers secreted by the bacteria.

It has been reported that the structure, morphology and surface properties of such suspensions can be altered by changes in the operational parameters of bioreactor such as Sludge retention time (SRT) and the concentration of the mixed liquor suspended solids (MLSS) (Liao et al. 2001). For study purpose, these operation parameters were kept constant throughout this set of experiments.

MLSS is the concentration of microorganisms and non-biodegradable suspended solids, in an aeration tank during the activated sludge process, which occurs during the wastewater treatment. The MLSS concentration is controlled and maintained by sludge wasting at frequent intervals from the MBR. The MLSS concentration of the activated sludge suspension was maintained at 4000 mg/L for MBR to ensure the best treated effluent quality and the highest BOD/COD removal efficiency.

F/M ratio (Food to microorganisms in aeration) results from two main operating parameters i.e. COD of influent (the influent biodegradable substrate) and MLSS. Common range of F/M ratio for activated sludge process should be in the range of 0.15 to 0.5 (Judd 2011). In this study F/M in the wastewater system is about 0.12 (COD = 500 ppm), marginally lower than the suggested range.

Prior to MBR operation, sludge was acclimatized with MBR system. The pH was maintained at 7-7.5 throughout the experiment. The temperature of the mixed liquor was maintained at 25 °C. The hydraulic retention time (HRT) ranged from 10 to 12 h and SRT was set at 25 days. The effect of aeration intensities on MBR system were studied at 120, 240 and 480 L/h of air flow rate. The average DO concentration for MBR system at three different aeration intensities were 2.9, 3.6 and 4.5 mg/L for study purpose as measured.

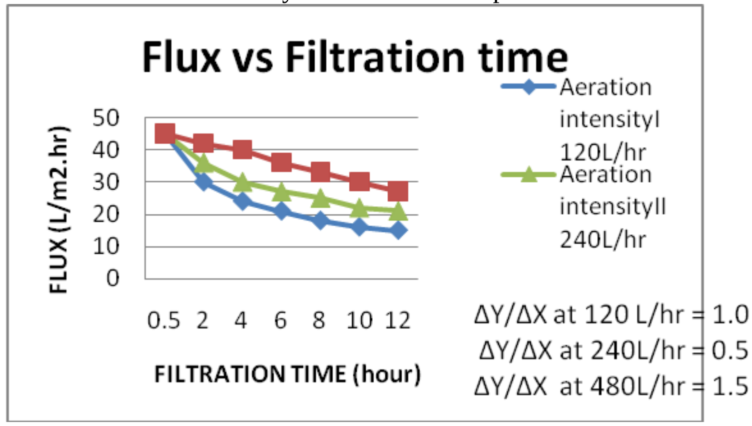
## V. RESULTS AND DISCUSSION:

### a) Permeation Flux:

The MBR can be operated in two modes: constant flux and constant transmembrane pressure (TMP). The mode of constant TMP is suitable for the study of membrane fouling because it can provide more information about the variation in flux due to membrane fouling over a predefined period.

Throughout the operation of the MBR, the membrane module was driven continuously with a constant low-pressure, TMP= 196 mm Hg (261 mbar). In constant TMP mode, the membrane flux will decline during membrane filtration as a result of membrane fouling. Every 10-12 hrs of operation, the membrane modules were taken out and cleaned by flushing with deionized water to remove the fouling cake from the membrane surface.

Fig. 3: Comparison between permeate flux of MBR at different Aeration intensity over 0-12 hrs of operation




In the 10-12 hrs of filtration operation, the membrane permeation flux was influenced by the Shear force induced by aeration intensity. Fig. 3 illustrates that, higher aeration intensity induces higher shear force by generating air bubbles that dislodges the cake layer from membrane surface. It has been observed that, Permeate flux of MBR at 480L/hr aeration intensity decreases abruptly than permeate flux of MBR at 120 L/hr and 240 L/hr aeration intensity, which shows a much gradual decrease.

According to Carman-Kozeny equation, specific resistance to membrane filtration is significantly influenced by sludge particle size and cake porosity. High aeration intensity affects the biomass characteristics and may lead to higher release of Extracellular Polymeric Substances (EPS) and breakage of sludge flocs. High aeration intensity forms non porous cake layer on membrane surface, resulted from pore blocking of membrane by small solutes [Judd, 2001], resulting into higher rate of the fouling. The observed higher slope ($\Delta Y/\Delta X = 1.5$) of the flux verses filtration time graph at air flow rate of 480 L/hr (Fig. 3) clearly supports the above hypothesis.

It has been observed that, at 240 L/hr aeration intensity permeation flux decreases linearly and gradually with the constant slope ($\Delta Y/\Delta X = 0.5$) throughout the 10-12 hrs of the filtration operation. At optimum aeration intensity, fouling layer acts as a dynamic membrane whose permeability is less than the actual membrane. Dynamic membrane composed of living microbes, so it biodegrades the soluble organic and colloidal particles. So at 240 L/hr aeration intensity less irreversible fouling has been observed compared to 480 L/hr aeration intensity.

At 120 L/hr aeration intensity, permeation flux kept on reducing at slightly higher rate (marginally higher slope ($\Delta Y/\Delta X = 1.0$)) due to low shear created to dislodge the cake layer formed due to filtration and it resulted in thick cake layer on the membrane surface which increases membrane resistance significantly.

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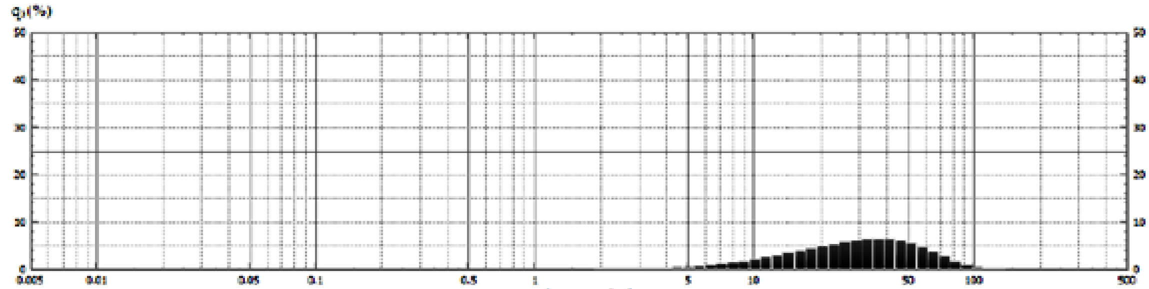
### b) Particle Size Distribution of Sludge Suspension:

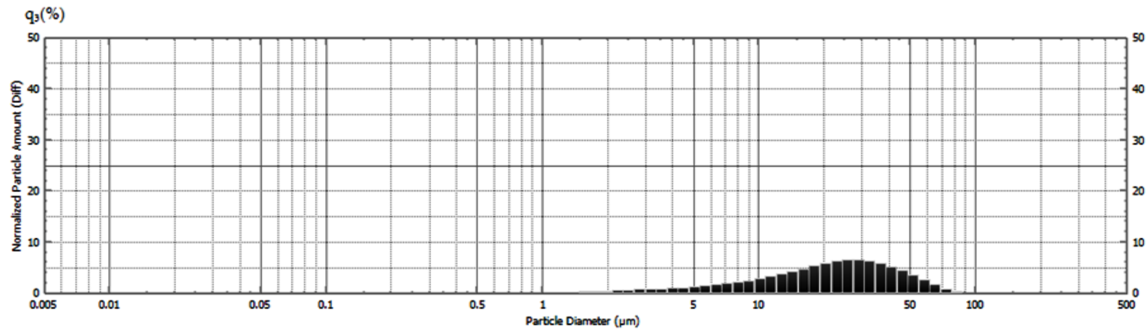
The particle size distribution was measured by Nano particle size analyzer (Shimadzu, Japan) to study the sludge suspension particles distribution in MBR at different aeration intensity. A sample of the suspension from the MBR was collected and analyzed for the Particle Size Distribution. The peak points demonstrate the largest particle size within the distribution and mean particle size calculated on the basis of number of particles. It has been studied that the size of the suspension particles varied in a range of 3-450 µm and more than 70% of the sludge suspension particles are in the range of 10-100 µm. It has been reported that particle size less than 50 µm would affect the membrane permeation significantly. [Judd, 2011]

At 120 L/hr aeration intensity, 20% of suspension particles have size smaller than 50 µm; at 240 L/hr aeration intensity, 48% of suspension particles have size smaller than 50 µm; at 480 L/hr aeration intensity, 66% of suspension particles have size smaller than 50 µm.

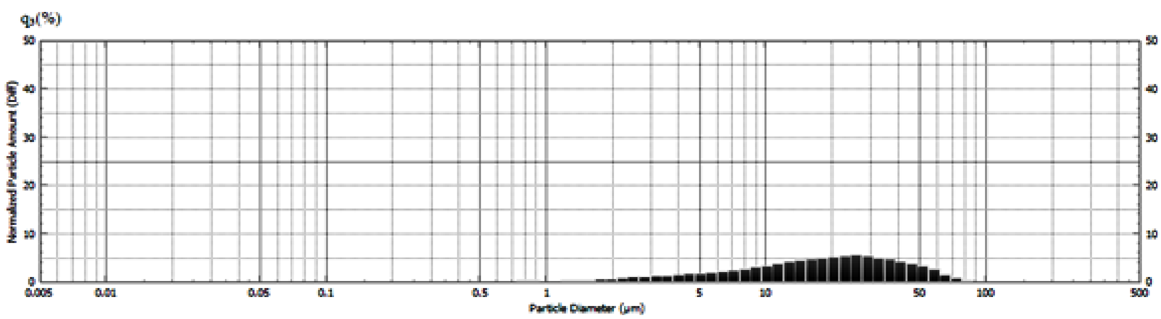
Fig.4: Particle size distribution of the sludge suspension in the MBR (a) MBR with aeration intensity 120L/hr, (b) MBR with aeration intensity 240L/hr, (c) MBR with aeration intensity 480L/hr.




**(a)**




**(b)**




**(c)**

Fig. 4 illustrates that, MBR at aeration intensity 120L/hr has 15-20% of the particles distributed in the range from 0 to 50 µm, which shows that at low shear force induced by aeration doesn't affect much the particle size in the suspension.

MBR at aeration intensity 240L/hr has 35-40% of the particles distributed in the range from 0 to 50 µm. At moderate aeration intensity rate of particle convection towards the membrane surface is balanced by the rate of reverse transport, therefore at 240L/hr aeration intensity shows significant effect on particle size reduction.

MBR at 480L/hr aeration intensity generates more small particles which are less than 50µm due to high shear force generated by high gas flow rate. The smaller particle in the suspension causes severe deposition resulting high fouling of the membrane than the moderate aeration intensity. The breakage of the sludge floc releases polysaccharides and colloids in the suspension which changes the microbial characteristics and affects the filtration mechanism of the system and affects the filtration rate significantly.

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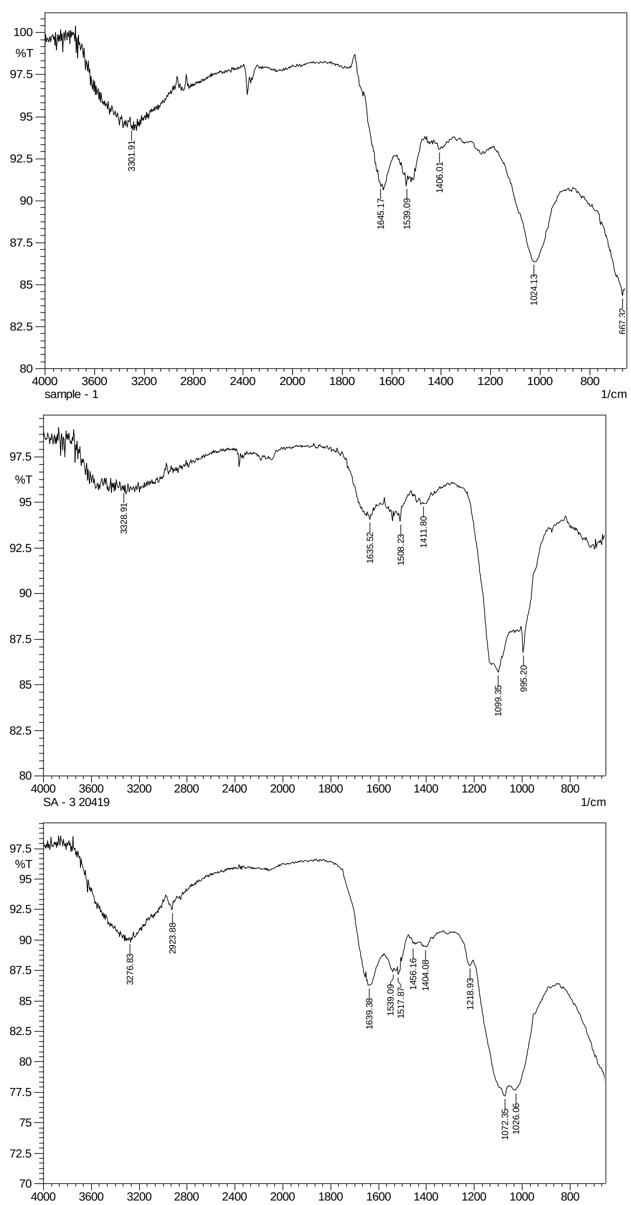
### c) Fourier Transform Infrared Spectroscopy (FTIR) study:

The FTIR spectrometer (Shimadzu, Japan) is used for the analysis of biopolymers deposited on the membrane. The fouled membrane module was taken out and washed with deionized water. About 200ml of washed water was dried at $105^0$C for 24 hrs to obtain dry foulants. The spectrum was studied from the average of 256 scans over the wave number ranging from 4000 to 400 $cm^{-1}$ at a resolution of 4 $cm^{-1}$. This technique provides more elaborate information about the nature of the deposit of biopolymers on the membrane surface.

Fig. 5: FTIR analysis of the membrane at aeration intensity 120 L/h, 240L/hr and 480L/hr




The FTIR analysis of the membrane at three different aeration conditions shows the peak at 1100 $cm^{-1}$ which is due to the stretching of C-O bonds and is associated with alcohols, ethers and polysaccharides. The amide I is the stretching of C=O group and the amide II is due to the stretching of C-N-H group. This indicates that the presence of the proteins in the membrane fouling. FTIR analysis indicates two broader peaks at 1650 cm-1 and 1520 cm-1 in the spectrum are unique to the protein secondary structure, called amides I and amides II. The peak 1400 cm-1 shows membrane foulants contained a medium amount of lipids.

The presence of proteins, lipids and polysaccharides in the membrane foulants suggests a significant organic fouling which is mainly resulted from extracellular polymeric substances (EPS) secreted by microorganisms into the wastewater and may be also due to the partial cell disruption as a result of the intense shearing action.

FTIR analyses of all three operating conditions show similar profile but considerably dissimilar absorption intensities. Absorption intensity indicates relative amount of biopolymers in the membrane fouling. FTIR spectrum of the MBR system at 480L/hr aeration intensity has highest absorption intensity compared to the MBR system operated at 120L/hr and 240L/hr aeration intensities.

Thus above mentioned result indicates that amount of biopolymers or EPS in the membrane fouling of the MBR system at 480L/hr aeration intensity is comparatively more than MBR operated at 120L/hr and 240L/hr aeration intensity. This analysis is consistent with the results of the particle size distribution.

### d) Analysis of Membrane foulants :

It has been observed that colloidal particles in the sludge suspension have an impact on membrane fouling and great contribution towards the cake layer formation. It was essential to measure COD of membrane foulant to understand the main cause of membrane flux reduction and to interpret the deposition structure of the foulant.

To quatify the foulant that were accumulated on the membrane surface, membrane modules were taken out from the MBR after a 10-12hrs of operation and flushed with pure water. Same washed liquid with sludge was used for the evaluation of COD of membrane foulant and to quantify the weight of the accumulated foulant.

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**Table 2: Analytical outcome of the membrane foulants**

| **MBR at different aeration intensities** (SRT=25 days HRT=10-12hrs) | **COD** of sludge suspension ppm | **COD** of membrane foulant ppm | **Amount of foulant** on membrane element(g/m2) |
|---|---|---|---|
| MBR at 120L/hr | 206 | 194 | 13.5 |
| MBR at 240L/hr | 240 | 142 | 9 |
| MBR at 480L/hr | 310 | 85 | 7.5 |

As the aeration intensity increases from 120L/hr to 240L/hr, amount of foulant accumulated on membrane decreased by 33.3% and COD of membrane foulant decreased by 27%. With further increase in the aeration intensity from 240L/hr to 480L/hr, amount of foulant accumulated on membrane surface reduced by 16.7% and COD of membrane foulant decreased by 40%.

This shows that high aeration shear stress condition resulted in a thinner but denser bio-fouling layer with high EPS content (proteins and polysaccharides) which was confirmed through FTIR study (Fig.5). The average thickness of the fouling layer under high aeration shear stress condition is lower than at low shear stress condition. Shear stress caused by air bubble scouring continuously removes the part of bio-fouling from the membrane surface which was loosely bound, while the tightly bound fouling (resulting from higher shear stress condition) adhered to the membrane surface. This results in a continuous accumulation of tightly bound material on the membrane, and forms compact sticky biofouling layer on membrane surface, which does not get removed easily and results in higher rate of the flux reduction.

It has been observed that as aeration intensity increases from120 L/hr to 240 L/hr, COD of sludge suspension increases by 17% and as aeration intensity increases from 240Lhr to 480L/hr, COD of sludge suspension increases by 30%. This illustrates that at high air flow rate exerts high shear stress on the membrane module, which results into dislodging of the biofouling from the membrane surface. So at high aeration intensity, sludge breakage is significant which is been confirmed through Particle size analysis (Fig.4).

## VI. CONCLUSION:

This paper comprises a study of flat sheet membrane filtration performance to observe the effect of aeration intensities. Aerations intensity has a significant impact on membrane fouling and membrane filtration. Optimization of aeration intensity gives optimum performance of the membrane system.

Sludge forms a primary layer on membrane which protect membrane to get fouled from fine particle blockage. At high aeration intensity (480 L/hr), we observed severe breakage of sludge flocs which has been confirmed by particle size distribution analysis. This fine and colloidal blockage of the membrane, causes irreversible fouling of the membrane and reduces the life of the membrane. Inertial lift and shear induced diffusion are the dominant mechanisms in reverse transport of large particles. This indicates that high aeration intensity stimulates non porous cake layer formation consisting of soluble and colloidal particles. This is the main cause of reduction of permeate flux in MBR at 480L/hr more rapidly than MBR at 120L/hr and 240L/hr. Low aeration intensity induces inadequate shear stress which is unable to remove the foulant accumulated on the membrane surface during the operation. Brownian diffusion is the dominant mechanism in reverse transport of small particles from the membrane.

The above study indicates that, optimum aeration intensity protects the membrane from severe irreversible blockage and fouling. Feasibility of optimum aeration intensity appears to be a key factor to study to reduce the operating cost and membrane performance.

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