

# EVALUATION OF MEMBRANE BIOREACTOR TECHNOLOGY FOR TREATING MUNICIPAL WASTEWATER

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**Abstract:** With variation in Mixed Liquor Suspended Solids (MLSS) and Hydraulic Retention Time (HRT) a pilot-scale membrane bioreactor of capacity 100L/day was operated for a period of more than 6 months to determine the biokinetic coefficients. On the basis of MLSS variation experiments were divided into 4 phases. In this paper last two phases that is MLSS concentrations 8000-9000 mg/L and 9000 mg/L and above are discussed for biochemical parameters. The results showed a mean COD removal efficiency of 95.36% and 91.41% and BOD removal efficiency of 96.08% and 90.24% for MLSS 8000-9000 mg/L and MLSS 9000 mg/L and above respectively.

**Keywords:** Membrane bioreactor, MLSS, HRT, removal efficiency, COD & BOD

## Introduction:

A membrane bioreactor (MBR) is a type of an activated sludge process in which the biomass is retained in the bioreactor by microporous semipermeable pressure-driven rejection membranes. Membrane-coupled bioreactors (MBRs) can resolve the problem of biomass separation by using a microfiltration or ultrafiltration membrane to retain up to 100% of the biomass in the aeration basin. (*Chen et al, 2006*)

MLSS concentrations in submerged MBR systems can be in the range of 5-25 g/L. (*Melin et al, 2006*). In a trade-off between capital expenditures (CAPEX) associated with reactor's volume and operational expenditures (OPEX) associated with process aeration costs, mixing costs and fouling control, the maximum allowed MLSS in Conventional Activated Sludge Process is in practice around just 4,500 mg/L due to the existence of the, maximum permissible solids flux as explained in the Kynch's theory of sedimentation (*Tomasz Janus, 2013*)

The design basis and operational conditions of MBR processes have an influence on membrane fouling. The factors included are feed and biomass characteristics, operating conditions such as hydraulic retention time (HRT), solids retention time (SRT) and the type of membranes.

Thus the present study aims at determination of MBR performance at varying MLSS and HRT conditions. In continuation to the MLSS and HRT combination at Phase I and Phase II; current study includes Phase III at MLSS 8000-9000 mg/L and Phase IV MLSS 9000 mg/L and above.

## Materials and methods:

The pilot plant of capacity 100L/day was studied in the laboratory of Effwa Infra and Resarsch Pvt. Ltd., Thane, Maharashtra. The compact MBR pilot/demo plant was designed by ShenZhen KaiHong Membrane Environmental Technology co. Ltd China.

The dimensions of the reactor are 510mm\*370mm\*420mm. MBR consists of two compartments, one Aeration tank in which sewage/ waste water shall be added which consist of a blower of capacity 85 L/min@ 0.04 MPa and the other compartment is MBR part which consists of 6 nos. Hollow fiber membranes of area 0.2 m<sup>2</sup> and type reinforced PVDF material and as seen in fig 1.the aeration tank was supplied with additional blower at intermittent time intervals for additional supply of oxygen as aeration flow is also one of the main factors that affect the biochemical process of BOD and COD removals (*Radjenovic et al, 2008*).

Table 1. Concentration for preparing synthetic sewage

Ingredient	mg/L
Peptone	160
Meat	110
Urea	30
K <sub>2</sub> HPO <sub>4</sub>	28
NaCl	7
CaCl <sub>2</sub>	4
MgSO <sub>4</sub>	2

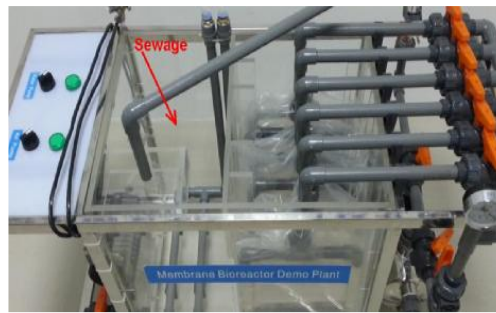


Fig 1. Membrane bioreactor demo plant

The operation of pilot scale MBR unit is same as traditional active sludge treatment, the organics in raw wastewater is degraded by microorganisms in first compartment. Membrane play a role of separating water and sludge after biochemical process in the second compartment. The tank is equipped with water pump and Air Pump, once tank is filled Air pump is started. Water pump is provided to pump permeate flow from membranes. Once waste is added in first zone it is biologically degraded based on the principle of Activated Sludge process, after that filtration by means of membranes takes place providing clearer permeate. It is also called as membrane separation activated sludge treatment. Permeate collected from all the membranes is pumped and is transferred via permeate pipe.

Sufficient mixed liquor suspended solids were developed by adding continuously fresh synthetic wastewater. The cycle of wasting and feeding was continued till steady state condition was achieved. During this period, the pH was monitored throughout the study. The steady state condition is indicated by development of required MLSS. The MLSS was developed by addition of jaggery and synthetic sewage to aerated water in increasing concentration day by day. Synthetic sewage of concentration 500-600 ppm was prepared referring OECD (Organization for Economic Co-operation and Development) guidelines for testing of chemicals simulation test Aerobic Sewage Treatment:303 A: Activated Sludge as shown in table 1. The raw sewage characteristics were referred from CPHEEO manual on Sewerage and Sewerage treatment systems PART A Chapter 5. Table 2 represents concentration of various parameters for municipal waste water/sewerage.

The plant was run in following phases:

Phase III : MLSS 8000-9000 ; HRT 4 hrs, 6 hrs, 8 hrs and 10 hrs  
Phase IV : MLSS 9000 & above; HRT 4 hrs, 6 hrs, 8 hrs and 10 hrs

Table 2: Concentration of various parameters in the absence of drain or outfall

Illustration  $BOD = 27 * 1000 (mg) / 135 X 0.8 (litres) = 250 mg/L$

Parameter	Per capita contribution (g/c/d)	Water supply (L/C/d)	Sewage generation 80% of (3)	Concentration (mg/L)
(1)	(2)	(3)	(4)	(5)
BOD	27.0	135	108	250.0
COD	45.9	135	108	425.0
TSS	40.5	135	108	375.0
Total Nitrogen	5.4	135	108	50.0
Organic Nitrogen	1.4	135	108	12.5
Ammonia Nitrogen	3.5	135	108	32.5
Nitrate Nitrogen	0.5	135	108	5.0
Total Phosphorous	0.8	135	108	7.1
Ortho Phosphorous	0.5	135	108	5.0

After attaining steady state, inlet and outlet samples that is permeate/effluent from reactor were analyzed. Inlet and effluent were checked mainly for pH, BOD, COD, (APHA 2005).

The activated sludge was examined often for pH and DO as both of the parameters play crucial role in proper running of reactor. pH was neutralized using alkali or acid as per requirement, as during the course of MLSS development pH used to decline. DO was maintained in the range of 0.5-1.5 mg/L using aeration. The aeration tank was run with additional blower for intermittent cycles of excessive aeration and normal aeration designed

in the reactor. MLSS and SVI for sludge were determined on daily basis. The parameters analyzed, methods and instruments used are summarized in table 3.

Table 3. List of parameters analyzed along with adopted methods and instruments.

Sr No.	Parameter	Method [Ref. Standard Methods for the examination of water and wastewater 21 <sup>st</sup> edition (2005)]	Instruments used [Make: Spectralabs]
1.	pH	pH meter	MULTIPARA (Model MP-8)
2.	BOD	BOD 5210 C Winkler's method	Make :Spectralabs
3.	COD	COD 5220 B Open reflux method	Model – COD 2015M
4.	MLSS	Weighing method	Analytical Balance Model: PA214
5.	DO	DO meter	MULTIPARA(Model MP-8)

## Results and discussion:

### Phase III: MLSS 8000-9000

#### pH

At phase III pH was observed in the range of 6.2-7.64. pH was kept in the range 6.5-7.5 with occasional addition of alkali during start of experiment. Table 4 shows that mean pH was 7.0 during experimental run.

#### MLSS:

As shown in table 4, the MLSS concentration range was between 8004-9057 mg/L and mean was found to be 8600.05 mg/L. It was kept in the range of 8000-9000 by continuous monitoring addition of food or by removing excess solids as required.

#### COD:

COD in inlet was found in the range of 517-652 mg/L for synthetically prepared municipal wastewater whereas it was found to be reduced upto 98.01 % during experimental run at different HRT's. The outlet COD at HRT's 8 hrs and 10 hrs was found to be 19.4 and 19.0 mg/l respectively which is lower than the expected value of 30 mg/L. Hence it can be observed that permissible COD values can be attained at HRT of 8-10 hrs and MLSS 8000-9000mg/L. Figure 2 shows COD profile at phase III indicating huge difference between inlet COD and outlet COD. Fig 3 shows COD reduction efficiency at different HRT's. The reduction efficiency was found to be increasing with increase in HRT. Highest reduction was observed at HRT of 10 hrs, though the reduction efficiency is slightly greater at 10 hrs; it can be observed that similar reduction can be achieved at 8 hrs retention time with saving time and energy.

#### BOD:

As similar to reduction in COD values, higher reduction was observed in case of BOD also. In contrast to inlet BOD in the range of 331-412 mg/l, outlet BOD in the range of 8-23 mg/L was observed. Higher reduction was seen at HRT 10 hrs. Figure 5 shows BOD reduction efficiency at different HRT's. The reduction efficiency was found to be increasing with increase in HRT. Highest reduction was observed at HRT of 10 hrs, but it can also be seen that there is no much difference in reduction efficiency at 8 hrs and at 10 hrs. So 8 hrs can be considered ideal for BOD reduction as retention time and energy can be saved attaining higher reduction.

#### Statistical analysis

Table 4: Descriptive statistics for pH, MLSS, HRT, COD & BOD at MLSS 8000-9000 mg/L

Parameters	pH	MLSS (mg/L)	HRT (hrs)	COD inlet (mg/L)	COD outlet (mg/L)	Efficiency (%)	BOD inlet (mg/L)	BOD outlet (mg/L)	Efficiency (%)
Mean	7.06	8600.05	7.00	581.95	26.70	95.36	367.70	14.40	96.08
Median	7.10	8723.50	7.00	578.50	26.00	95.60	360.50	13.50	96.26
Mode	#N/A	#N/A	4.00	562.00	26.00	92.59	404.00	12.00	#N/A
Std. Deviation	0.34	407.18	2.29	39.22	9.30	1.71	23.46	4.16	1.08
Range	1.44	1053.00	6.00	135.00	33.00	5.76	81.00	15.00	3.47
Minimum	6.20	8004.00	4.00	517.00	13.00	92.25	331.00	8.00	94.31
Maximum	7.64	9057.00	10.00	652.00	46.00	98.01	412.00	23.00	97.78
Count	20	20	20	20	20	20	20	20	20

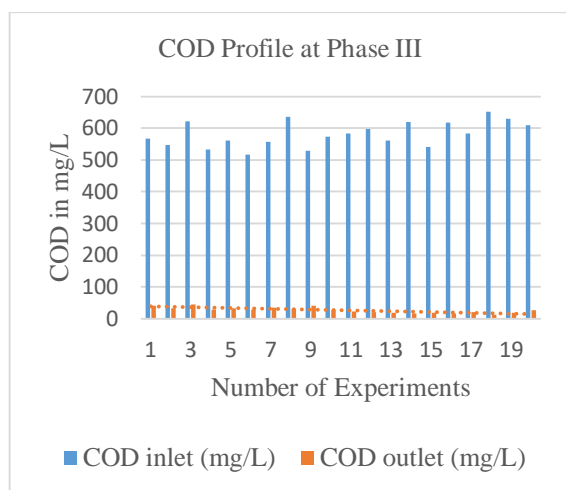


Fig 2 COD at Phase III MLSS 8000-9000mg/L

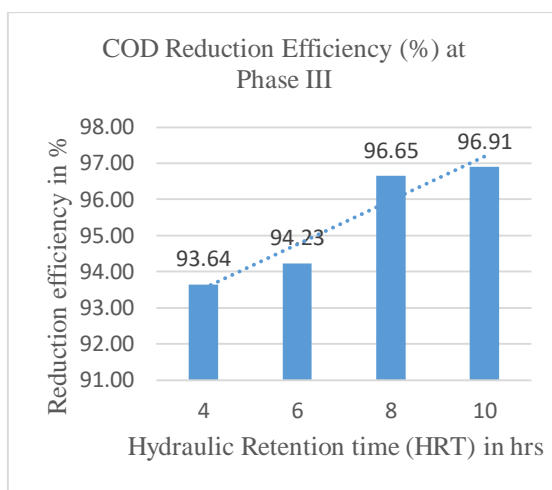


Fig 3 COD reduction efficiency at Phase III

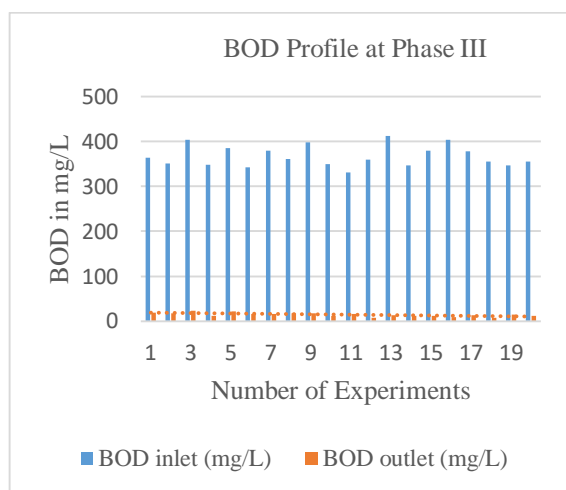


Fig 4 BOD at Phase III MLSS 8000-9000 mg/L

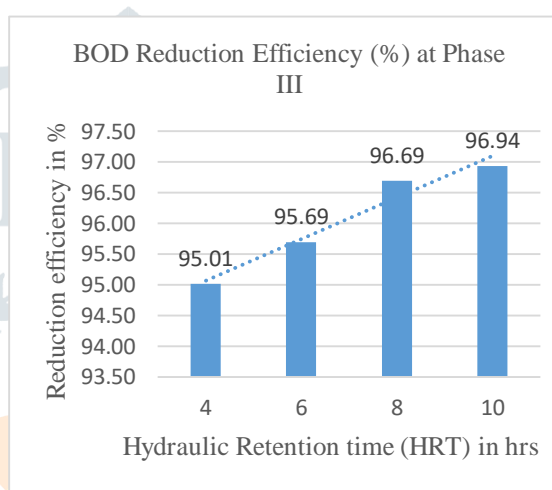


Fig 5 BOD reduction efficiency at Phase III

### Phase IV: MLSS 9000 and above

During Phase IV, MLSS was kept above 9000 mg/L varying HRT's i.e. 4 hrs, 6 hrs, 8 hrs and 10 hrs and also varying SRT's. For each set of HRT 5 experimental runs were carried out. During this phase pH, MLSS, SVI, COD, BOD were determined.

### pH

pH was found in the range of 6.31-7.7.8; pH was kept in the neutral range during the start of each set of experiment. It was monitored throughout the experimental run and maintained in neutral range for proper results.

Table 5: Descriptive statistics for pH, MLSS, HRT, COD & BOD at MLSS 9000 mg/L and above

Parameters	pH	MLSS (mg/L)	HRT (hrs)	COD inlet (mg/L)	COD outlet (mg/L)	Efficiency (%)	BOD inlet (mg/L)	BOD outlet (mg/L)	Efficiency (%)
Mean	6.97	11045.10	7.00	557.95	47.29	91.41	339.05	33.75	90.24
Median	6.95	10612.00	7.00	560.00	20.00	95.96	334.00	19.50	93.81
Mode	6.82	#N/A	4.00	582.00	19.00	#N/A	378.00	13.00	#N/A
Std. Deviation	0.38	1316.22	2.29	42.81	40.13	7.38	25.90	29.06	8.07
Range	1.47	3566.00	6.00	164.00	107.70	19.83	91.00	90.00	24.48
Minimum	6.31	9330.00	4.00	467.00	12.00	77.86	287.00	8.00	73.00
Maximum	7.78	12896.00	10.00	631.00	119.70	97.69	378.00	98.00	97.48
Count	20	20	20	20	20	20	20	20	20

**MLSS**

MLSS was found between 9330 mg/L to 12896 mg/L. In this set of experiment, MLSS was started from 9000 mg/L and was outlined to set higher upto 12000 mg/L or above but with increase in MLSS concentration membrane clogging was observed and its implications on other parameters were also seen. Hence further increase in MLSS was stopped.

**COD**

The COD was observed in the range 467-631 mg/L for inlet and at outlet it was found in the range 12-119.70 mg/L. Figure 6 represents COD profile at Phase IV and it can be observed that outlet COD levels are increasing with increase in MLSS and HRT for first two sets of experiments and decrease in reduction efficiency i.e. increase in the outlet COD values was observed during last 2 sets of experiments of phase IV. Also as shown in figure 7 the reduction efficiency was also found to be reduced with increase in HRT and MLSS unlike other set of experiments. This might be due to clogging of membranes with increasing MLSS as Membrane could not withstand the solid content in tank; it has implicated on reduction efficiency of parameters like COD and BOD.

**BOD:**

Table 5 shows statistical analysis for BOD at inlet, at Outlet and reduction efficiency of BOD. Figure 8 represents BOD profile at Phase IV, BOD at inlet was found in the range of 287-378 mg/L where as it is in the range of 8-98 mg/L at outlet. Figure 9 shows BOD reduction efficiency at different HRT's. The reduction efficiency was found to be decreasing with increase in HRT and MLSS in last 2 sets of experiments. Though initially higher reduction i.e. around 97.12 % was observed with increase in MLSS it was found to be decreasing later.

Figure 10 gives comparative account of removal efficiency at Phase III and IV for COD and BOD, which shows COD & BOD reduction was more in phase III, it was found to be highest in all phases. Upto phase III reduction efficiency has found to be following increasing trend with increase in MLSS and HRT. But at Phase IV with increase in MLSS, membrane clogging resulting in reduced reduction efficiency was observed. So out of all the combinations; MLSS 8000 mg/L and HRT 8 hrs can be considered most suitable and efficient and energy saving combination. Because with increase in MLSS and residence time the consumption of energy for aeration and pumping, food supply etc. increases.

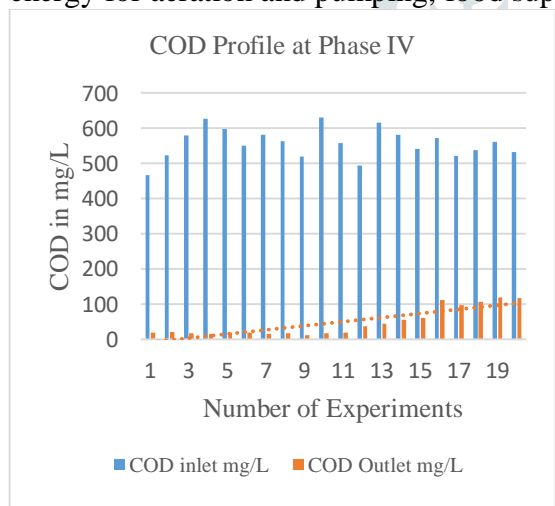


Fig 6 COD at Phase IV MLSS 9000 mg/L & above

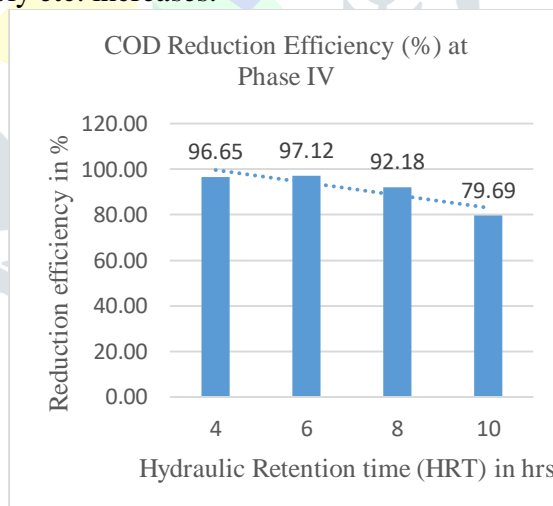


Fig 7 COD reduction efficiency at Phase IV

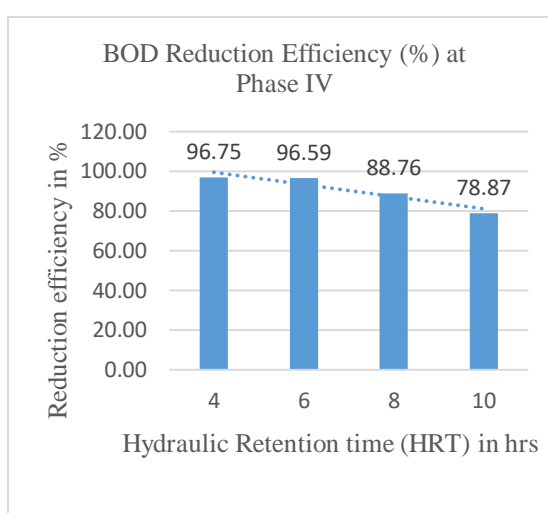
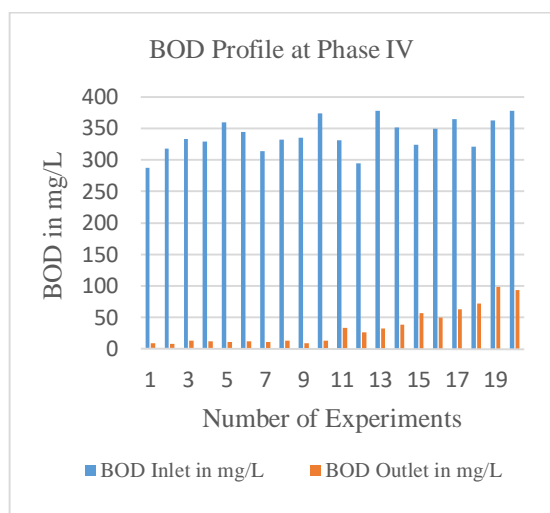


Fig 8 BOD at Phase IV MLSS 9000 mg/L & above

Fig 9 BOD reduction at Phase IV

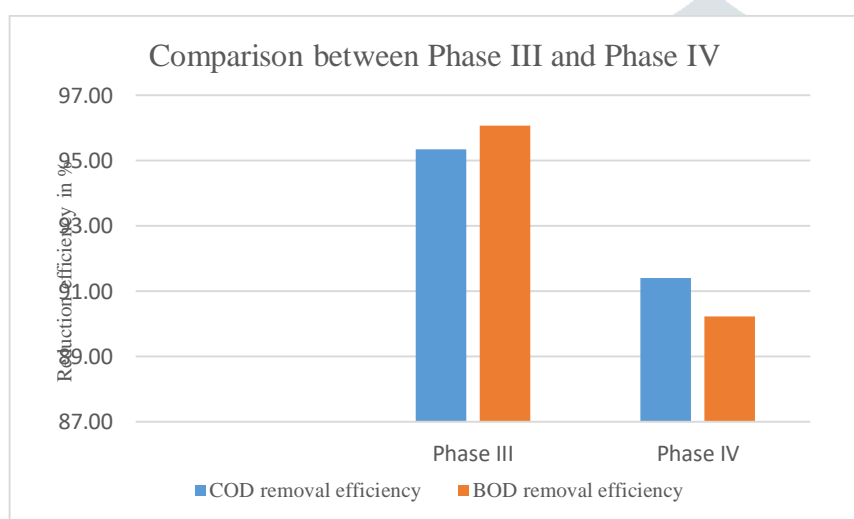


Fig 10 Comparison of COD and BOD removal efficiency at Phase III and Phase IV

At Phase IV similar trend might be possible with change in membrane characteristics and reactor volume. But in this study it was found to be decreasing with increase in MLSS.

Though the MBR technology is known for providing benefits over conventional Activated Sludge Process (ASP) such as Higher-quality effluent and volumetric loading rates, shorter hydraulic retention times (HRT), longer solid retention times (SRT), less sludge production, (Iorhemen *et al*, 2016, Brindle *et al*, 1996); Higher MLSS concentration may reduce aeration efficiency which is possibly the most significant problem with maintenance of high MLSS concentration (Radjenovic *et al*, 2008).

Treatment plants are designed and operated according to F/M ratio i.e. food to microorganism ratio. A low F/M ratio in reactor means that less substrate is available per unit of biomass. Using this technique very low sludge production in pilot MBR operations are reported (Rosenberger *et al*, 2002). But it is impractical for full-scale operations to keep much low F/M. The design of such plants would include very high MLSS concentrations that can promote membrane clogging, or large bioreactors, which contributes to the initial capital cost. Thus maintaining suitable or ideal MLSS concentration as per membrane capability is best solution to get required results.

**Conclusion:**

From the above mentioned results it can be concluded that MBR technology can be employed to treat municipal wastewater to achieve higher reduction in COD and BOD. The mean reduction was observed to be above 98% for both COD and BOD. Thus it can be concluded that MBR are highly efficient for organic pollutant removal. The factors like MLSS concentration, material and type of membrane used and wastewater to be treated should be considered to gain best possible results from MBR technology. Also the retention time can be reduced keeping MLSS concentration higher. Using membranes of different types and configuration the same set of experiments can be performed to determine most suitable combination.

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