Study on Performance of Membrane Bioreactor (MBR) system at various temperatures for Wastewater Treatment

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***Abstract-** The study on performance of sidestream membrane bioreactor (MBR) was studied by varying temperature (30^{o}C, 33^{o}C and 40^{o}C) along with crossflow velocity (1m/s, 1.5m/s and 2 m/s).CFV and temperature had significant effect on performance of sidestream MBR. Performance was studied by analysing COD removal (%), flux declination, Transmembrane pressure, mixed liquor suspended solid concentration. Maximum COD removal was 93% is obtained at 30^{o}C with CFV 1.5 m/s. Flux declination is large at 30^{o}C as compared to flux declination at 33^{o}C and 40^{o}C temperatures for all CFVs. Sludge production in terms of MLSS, is large at 30^{o}C and minimum at 40^{o}C. This high concentration of MLSS is responsible for large COD removal as well as increased in membrane fouling which cause large flux declination. It is observed that high CFV causes less flux declination tends to large permeate flux. By visual perception it is observed that at higher temperature, bioreactor content was more turbid than at low temperature this means that, large bioflocs get segregated and cause fast scouring on membrane surface, it resultsslow down of permeate flux declination. Selection parameter (SP) was used to optimize the operational condition of MBR system. Largest value of SP was treated as optimum value for operation of sidestream MBR. Thus, condition T = 33^{o}C, CFV = 2 m/s gave highest SP value 27 lit/m^2-hr, and may be recommended for treating wastewater of COD 1092 mg/lit. Comparison of side stream MBR with submerged MBR system was carried out, and it is observed that sidestream MBR data is best suitable for waste water treatment.*

***Key words-** Membrane bioreactor (MBR); Chemical oxygen demand (COD); Cross flow velocity (CFV); Temperature, Selection Parameter (SP).*

I. INTRODUCTION

MBR technology is as an adaptation of the activated sludge process by membrane filtration as a replacement to sedimentation and has gained popularity for decentralised and reuse applications ([7], [10], [19]). The MBR process verified the improved product quality in terms of COD removal compared to the process of activated sludge process ([2], [20]). Many researchers demonstrated that technically reclaimed water by MBR system could be reused in municipal purpose or industrial purpose ([23], [26]).

One of the disadvantages coupled with the MBR are mainly cost related. High capital costs due to expensive membrane units and high energy costs due to pressure gradient requirements characterize the system. Fouling problem can be overcome by modifying MBR system like a novel aerobic granular sludge membrane bioreactor (AGMBR) [15]. Membrane fouling problems can lead to frequent cleaning of the membranes, which stops operation and requires clean water and chemicals. However, MLSS and sludge floc size were found to be the significant factors that controlled the membrane filterability while sludge viscosity have taken as the sub-factor affecting membrane fouling Kornboonraksa & Lee [22]. Several studies have been reported on comparison of sidestream and submerged MBR system. Many researchers provide an improved understanding of the effect of sidestream (SS) and submerged (Sub) MBR configurations on hydraulic and biological system performance for tubular membrane geometry. A tubular membrane MBR configured both as submerged and sidestream MBR have indicated the former to provide an inherently lower fouling propensity by virtute of the air lift. Some researcher worked on characterization of wastewater and biomass ([11], [14]).

On the other hand, different industries like pulp, paper and petroleum produced large number of high temperature wastewater. Temperature increase causes the biomass reduction, the poor sludge settleability and the supernatant turbidity caused by temperature increase [2]. Moreover, there have been very few studies are showing the effect of cross flow velocities on performance of MBR. Laitinen et al. [21] studied that when the cross-flow velocity was increased the permeate flux increased. In this study performance of sidestream MBR was investigated by varing operating temperature and cross flow velocity. Sidestream MBR process was optimized using selection parameter and comparison of performance of sidestream and submerged operation was investigated.

II. MATERIALS AND METHODS

A. Acclimatization Stage

Acclimatization was carried out for 30 days in sequencing bioreactor (10 lit). Synthetic wastewater (SWW) was used in whole experiments. Chemical composition of SWW is given in Table 1.SBR was seeded with activated sludge. Activated sludge as a source of mixed bio-culture was obtained from the effluent treatment plant of Government Dairy, Nagpur, Maharashtra, India.

TABLE 1
CHEMICAL COMPOSITION OF SWW

Chemicals	**mg/lit**
Glucose ($C_6H_{12}O_6.H_2O$)	1000
Urea ($CO(NH_2)_2$)	2.27
Magnesium Sulphate ($MgSO_4.7H_2O$)	100
Calcium chloride ($CaCl_2$)	7.5
Potassium di-hydrogen Phosphate(KH_2PO_4)	52.7
Di-Potassium hydrogen Phosphate(K_2HPO_4)	107
Ferric Chloride($FeCl_3.6H_2O$)	0.5

B. Process Description of Sidestream MBR

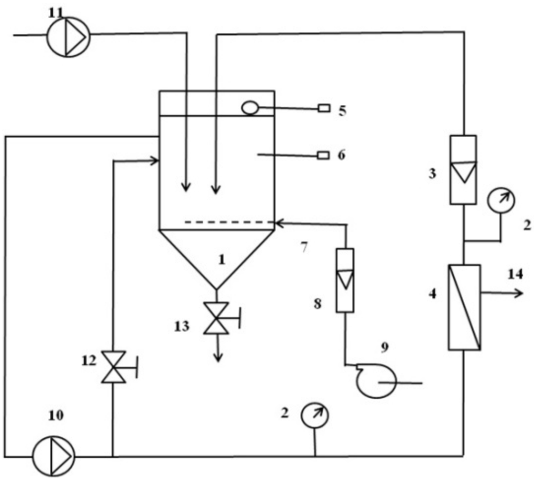


Fig. 1 Process diagram of sidestream MBR system .(1.Bioreactor, 2.Pressure guage, 3.flow meter, 4.Membrane module, 5.Level sensor, 6.Heating coil, 7.Air sparger, 8.Air flow meter, 9. Air Compressor, 10.Circulation pump, 11.Feed pump,12. Bypass valve, 13.Valve for sludge removal, 14. Permeate.)

The process diagram of MBR system for waste water treatment is described in Fig.1. It consists of bioreactor (12 lit working volume), membrane module and circulation pump. Bioreactor charged with 8 lit SWW and 4 lit activated sludge. The activated sludge was filtrated with 100 and 120 mesh network to remove impurity and large particles before to feed the bioreactor. Bioreactor receives the SWW from feed tank. Each experimental run was of 15 days, during this period no sludge was removed from the system. Level in the bioreactor was maintained constant by using a level controller and a feed pump. Bioreactor sludge was recirculated with high speed using circulation pump. Treated water was collected as a permeate through the membrane module. Recirculated stream flow was measured by flow meter to ensure the cross flow velocity. Properties of membrane used in this study in sidestream MBR is shown in Table 2.
Pressure gauges were used to measure the transmembrane pressure across the membrane module. Aerobic condition was maintained in bioreactor by supplying continuous flow of air through air sparger, placed at the bottom of the bioreactor. Microprocessor based temperature control system was installed to maintained the temperature in the bioreactor. Retentate flow was measured by flow meter installed in recycle circuit.

TABLE 2.
PROPERTIES OF MEMBRANE USED IN SIDESTREAM MBR

Manufacturer	Uniqflux
Type	Hollow fiber (inside out)
Raw Material	Polysulfone modified
MWCO (kda)	100
Effective filtration area (cm^2)	500
pore size (µm)	0.01
Length (cm)	53.5
No. of Fibers	143
Radius (cm)	0.01

C. Process description of submerged MBR

A 12 litter lab-scale MBR (Fig. 2) with a membrane pouch was continuously operated for 15 hours. The submerged membrane module had a membrane area of 0.06 m^2 per pouch. PES membrane with filtration area 0.6 m^2, pore size 0.5-3 micron was used.

The MBR was operated in a cycle of 60 min of permeation phase and 15 min of washing. It was observed that within one hour TMP reached upto acceptable limit 78 kpa therefore 60 min of permeation phase was selected. For permeation a diaphragm pump was used. The reactor was fed quasi-continuously through valve from feed tank to maintain a constant volume of 12 liters. The transmembrane pressure (TMP) was measured with vacuum gauge.

The optimum condition obtained in sidestrean MBR operation (in terms of selection parameter), same initial operating condition was opted in submerged MBR operation. Before entering the MBR, the sludge was screened through a 100 and 120 mesh successively. To achieve oxygen saturation and complete mixing in the reactor, compressed air was continuously supplied at a flow rate of 5 lit/min.

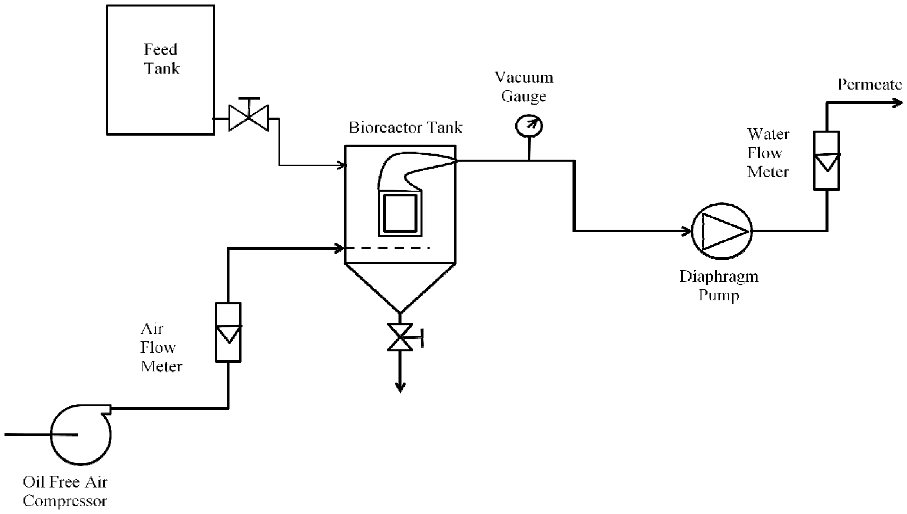


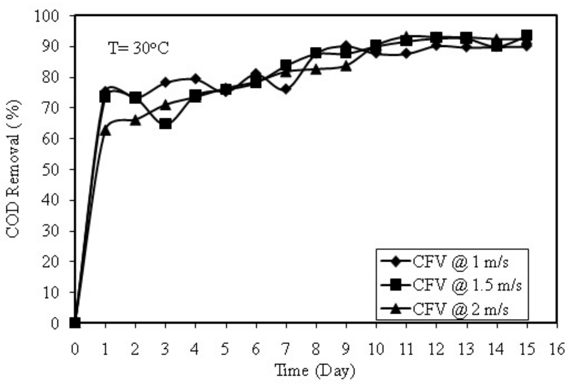
Fig. 2 Sketch of submerged MBR.

D. Analytical Methods

All analysis was carried out using standard methods prescribed by APHA, 1995. COD was measured using open reflux method. To measure the concentration of MLSS method prescribed by Dhaouadi & Marrot (2008) was adapted. The 33ml of of bioreactor content was centrifuge for 10 min at 4000 rpm (Remi R8CDX, India). The settled solide was heated in a oven at 105°C for 24 hr and cooled down to be weighed (W_1). Then same solid was ignited for 15-20 minutes in a muffle furnace maintained at 550±50°C. Final cooling was done in a dry atmosphere and final weight (W_2) was recorded. The difference between the W_1 and W_2 give the quantity of mixed liquor volatile suspended solids (MLVSSs). The pH of the mixed liquor was measured in order to be kept within the range of 7- 8 by the addition of either 20 gm/lit Na_2CO_3 or a 1% HCL solution. DO was measured by using DO probe (Hach) probe. The DO probe was washed after each use. In all experiments DO and pH was 2-3 mg/lit and 7-8 respectively.

III. Results and Discussion

A. COD removal variation



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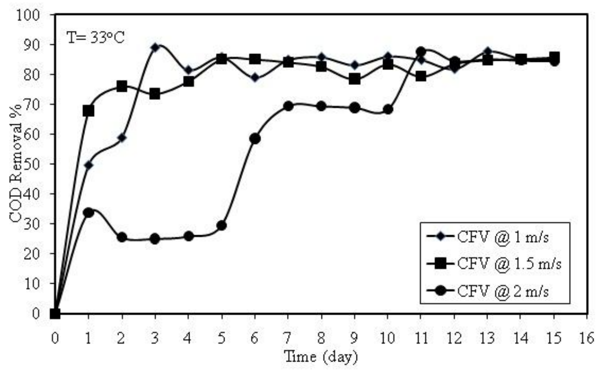

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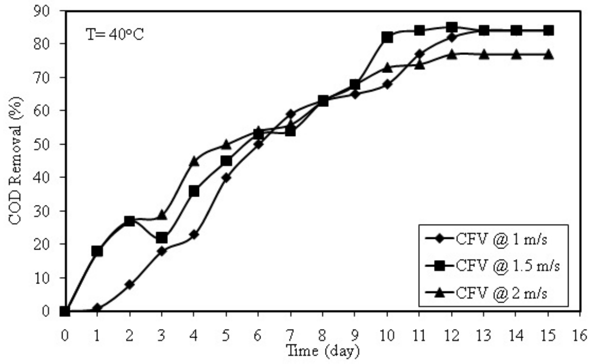


(c)

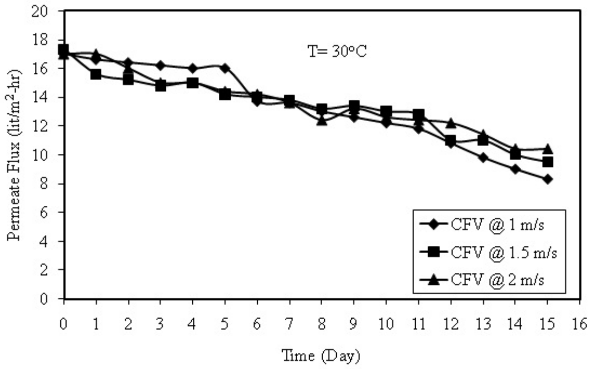
Fig.3 COD Removal vs time in sidestream MBR operation

COD of SWW was 1092 mg/lit. Fig 3 is the variation of COD removal (%) with time at various CVF and temperature. It is observed that maximum 93% COD removal is observed at 30^{o}C and 1.5 m/s. And minimum removal (50%) is obtained at 40^{o}C and 1 m/s. It is observed that above 60 % COD removal was obtained in first week of run. Steady state removal conditions where COD removal is almost constant are showing COD removal above 90%. Results are promising with the results of many researchers stating removal in MBR system is greater than 80% [27].

It is observed that trend of COD removal is increasing with respect to time, during initial period of run. Cao et al.[16] obtained same trend in MBR system. It is observed that COD removal is large at 30^{o}C for all CFVs. But flux declination is large at 30^{o}C as compared to flux declination in all runs at rest two temperatures for all CFVs. Sludge in terms of MLSS, production is large at 30^{o}C and minimum at 40^{o}C.This high concentration of MLSS is responsible for membrane fouling and cause high flux declination at 30^{o}C. Average removal of COD is high at 30^{o}C for all CFVs. At 40^{o}C COD removal trend is increasing in nature showing that microbes are trying to adapt the high temperature environment.

The analysis of this study investigates that in the continuous mode of operation, initially COD removal is small and over the period of time it reaches stable region with respect to time. Average COD removal is observed to be slowing down with increase in temperature [2]. Similarly flux declination decreases on increasing CFV. In general, at all CFVs the COD removal is greater at 30°C than 33^{o}C and 40°C. About 93% of COD removal is obtained at 30^{o}C with CFV 1.5 m/s.

B. Permeate Flux variation



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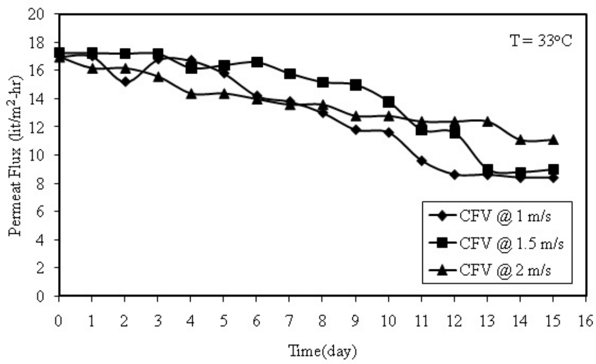

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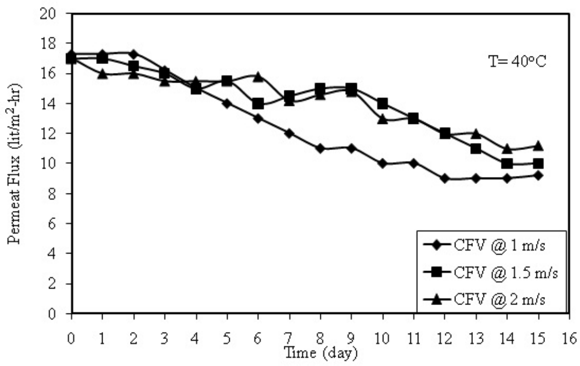

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Fig. 4 Permeate Flux vs time in sidestream MBR operation

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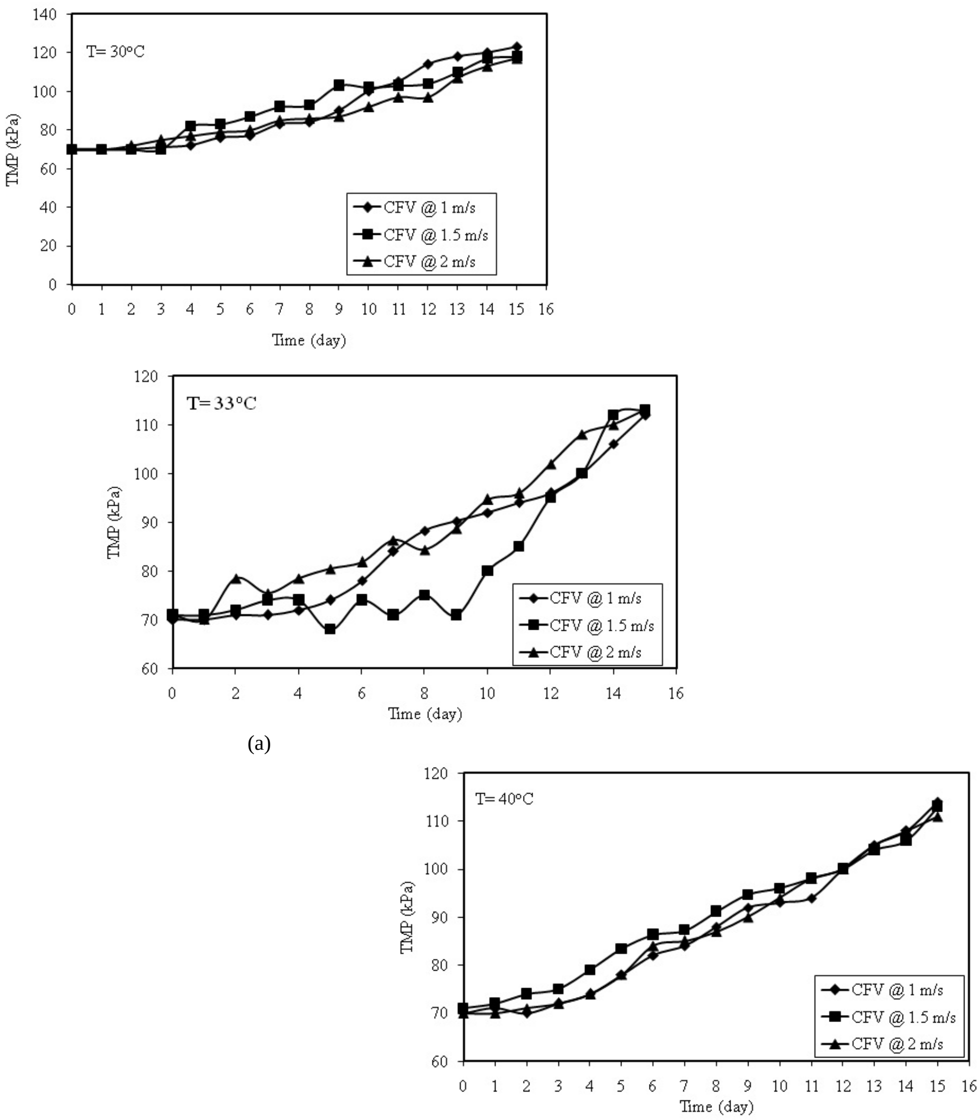
This study demonstrates that permeate flux declination is faster with decreasing cross flow velocity (see Fig. 4). In each run due to cake layer formation and fouling phenomena, flux regularly decreased at the end of MBR operation[4]. It is investigated that increase in flux with increase in CFV is due to the fact that at high CFV, the amount of accumulation of rejected biomass in the vicinity of the membrane surface is decreased declining the total resistance.

Therefore, drop in permeate flux is lower at higher CFV. It can be concluded that high CFV decreases the flux reduction which supports the trend of increase of permeate flux at higher value of CFV. Again, it could be concluded that on increasing temperature flux increases and flux declination decreases.
The thermophilic process has smaller flocs than the mesophilic process, again at high temperature viscosity reduction takes place[3] These small flocs could be lifted easily by cross flow with air scouring and removes the excess cake layer. Hence, accumulation of excess sludge on the membrane surface was limited in the thermophilic. The scouring works more effectively in thermophilic conditions than mesophilic conditions due to smaller floc size. Due to viscosity reduction with temperature, permeate flux increases with temperature [3].

C. *Transmembrane pressure (TMP) variation*



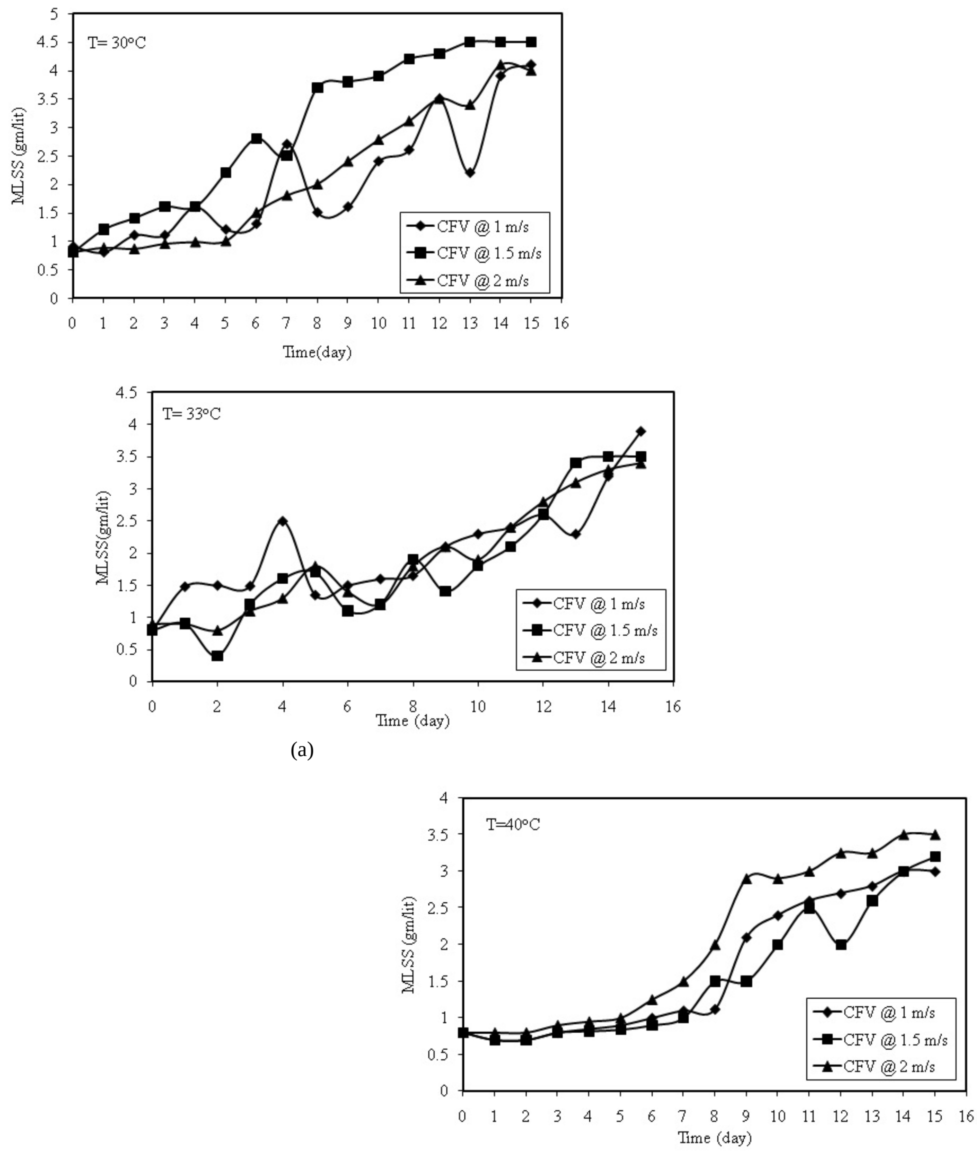
(a) (b)

(c)

Fig. 5 TMP vs time in sidestream MBR operation

When TMP increased and membrane flux decreased, they implied that membrane had been fouled (Cao J.H. et al. (2005)). In current study gradual increase in TMP was observed. Results of this study are in good agreement with results of Yeh H.M. & Wu H.H., 1997 that rising fluid velocity in the fiber tubes has two conflicting effects. First, the decrease in resistance to permeation due to reduction in concentration polarization, is good for ultrafiltration, while the other, the decrease in average transmembrane pressure due to increase in frictional pressure loss, is bad for ultrafiltration. It is observed that concentration polarization can be trimmed down at higher cross-flow velocities as turbulence increases near the membrane surface [24]. Altogether we can conclude that, percentage increase in TMP is significantly small with high CFV, towards the end of the experimental run. By investigating the data obtained in this study, we can conclude that at high temperature (40^{o}C) TMP increase is low as compare to low temperature (30^{o}C and 33^{o}C). It is due to the scouring works more effectively in thermophilic conditions than mesophilic conditions due to smaller floc size.

D. Mixed Liquor Suspended Solid (MLSS) variation



(a) (b)

(c)

Fig. 6 MLSS vs time in sidestream MBR operation

It is further observed that MLSS decreased with increasing temperature (Fig. 6). Results of this study are in good agreement with results of Abdullah Al-Amri et al. (2010) who demonstrated that the biomass reduction, the poor sludge settleability and the supernatant turbidity (visual perception) caused by increase in temperature. MLSS concentration is low at 40^{o}C than 30^{o}C and 33^{o}C. The thermophilic aerobic process produces lower amounts of net sludge compared to the mesophilic process. At higher temperatures the cells utilize a large fraction of the energy to maintain their vital function and not only to synthesize new cellular material, hence causing less sludge production (Abdullah Al-Amri et al. 2010).

E. Optimum condition for sidestream MBR

Selection parameter (SP) was used to optimize the operational condition of MBR system [6]. It is defined as follows,

$$SP = (PF \times R)/ FD \quad (3.1)$$

Where

PF- Permeate flux (lit / m^2 -hr),

R- COD removal (%),

FD- Permeate flux declination (%).

So, larger SP value for a run indicates higher flux or/and higher removal with a lower range of fouling. At T=33°C, CFV=2 m/s is found to give largest value of SP (27 lit/m^2-hr) while at T=33°C, CFV=1 m/s shows a minimum value of SP (14 lit/m^2-hr). Thus, condition T=33°C, CFV=2 m/s may be recommended for treating wastewater of COD 1092 mg/lit.

F. Observation of Submerged MBR operation

It is observed that TMP increase from 25 kPa to 68 kPa in one hour of operation while permeate flux drop from 70 lit/m^2-hr to 30 lit/m^2-hr. Corresponding values of permeate flow are 72 lit/hr to 36 lit/hr. Keeping in the view that water flow meter having range of 0.5 - 5 lit/min i.e 30 lit/hr to 300 lit/min and acceptable TMP limit of membrane module is 78 kPa, washing of membrane module is necessary after every hour. At the end of operation it is observed that about 74% COD removal is obtained but on the other hand increase in TMP is faster in submerged MBR than sidestream MBR similarly permeate flux also decline faster in submerged MBR, even though the starting operational parameters like MLSS concentration, aeration, pH and temperature are same. Sudden Increase in TMP and permeate flux declination indicate that scouring effect under this air flow rate is not significant which cause deposition of sludge on membrane surface. It can conclude that more power requirement is necessary in submerged MBR for cleaning and aeration than that of sidestream MBR. On comparison it is observed that sidestream MBR data is best suitable for waste water treatment.

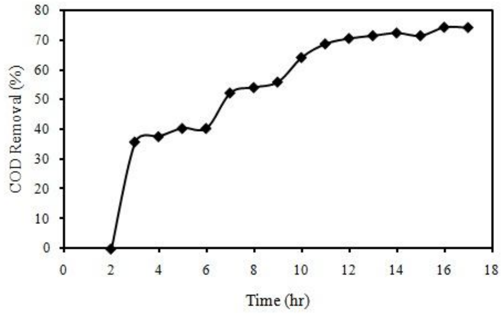


Fig.7 COD Removal (%) vs time in submerged MBR operation

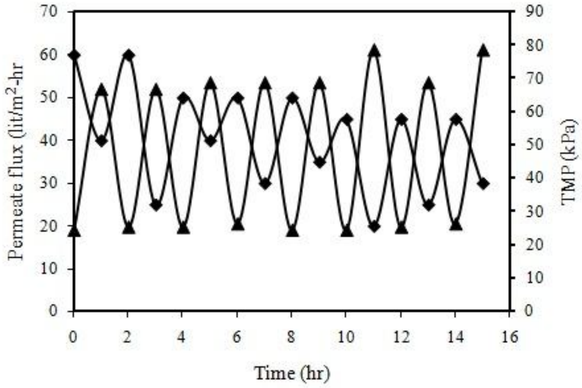


Fig.8 Permeate Flux and TMP vs time in submerged MBR operation

IV. CONCLUSION

It is observed that COD removal is large at 30°C for all CFVs. But flux declination is large at 30°C as compared to flux declination in all runs at 33°C and 40°C temperatures for all CFVs. Sludge production in terms of MLSS, is large at 30°C and minimum at 40°C.This high concentration of MLSS is responsible for membrane fouling and cause high flux declination at 30°C. The high temperature aerobic process produces lower amounts of net sludge compared to the low temperature aerobic process. This study demonstrates that permeate flux declination is faster with decreasing cross flow velocity. It can be concluded that high CFV decreases the flux reduction which supports the trend of increase of permeate flux at higher value of CFV.

Again, it could be concluded that on increasing temperature, flux increases and flux declination decreases. By investigating the data obtained in this study, we can conclude that at high temperature (40°C) TMP increase is low as compared to low temperature (30°C and 33°C). It is due to the scouring works more effectively in thermophilic conditions than mesophilic conditions due to smaller floc size (visual perception). MLSS concentration is low at 40°C than 30°C and 33°C.

We used the separation parameter [6] to select optimum combination of operational parameter. So, higher SP value for a run indicates higher flux or/and higher rejection with a lower range of fouling. At T=33°C, CFV=2 m/s is found to give highest value of SP (27 lit/m^2-hr) which can be used as based data for designing the MBR industrial scale. It can conclude that more power requirement is necessary in submerged MBR for cleaning and aeration than that of sidestream MBR. It is observed that sidestream MBR data is best suitable for waste water treatment at 33°C. MBR system can achieve high removal efficiencies in wastewater treatment and that MBR permeate is suitable for urban, agricultural and recreational reuse according to the quality criteria defined by the various International agencies like WHO, EPA for water reuse.

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