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Comparison of Performance of Conventional Membrane Bioreactor with Dynamic Membrane Bioreactor

Mehmet Akif Veral[1], Abdullah Kizilet[2], Ozer Cinar[1]*

[1]*Yildiz Technical University, Department of Bioengineering, 34210, Esenler/İstanbul, Turkey.*

[2]*Department of Bioengineering and Sciences, Kahramanmaras Sutcu Imam University, 46100, Kahramanmaras, Turkey.*

[3]*Yildiz Technical University, Department of Environmental Engineering, 34220, Esenler/İstanbul, Turkey..*

**CorrespondingAuthor email: ocinar@yildiz.edu.tr*

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Abstract

The purpose of this study is about comparison of non-woven and 0.45 µm pore size real membrane placed in one aerobic tank and under same conditions. Comparison has been made between dynamic membrane bioreactors (DMBR) and membrane bioreactor (MBR), which have been employed in a widespread manner, to develop a convenient solution of high membrane cost handicap. Both membrane types operated under same aerobic conditions such as; volume, LMH and SADm. In addition, they have been fed with synthetic municipal wastewater and operated periodically to hinder membrane fouling. At the end of approximate one-month adaptation time course, bioreactors, which have reached stable conditions, have been operated to gather the data throughout 60 days. COD removal rates and turbidity results have been compared and non-woven dynamic membrane results have shown similar results to real membrane in terms of efficiency. Furthermore, dynamic membrane has exposed air back wash and pressure changes examined. While average COD removal is determined 93% for non-woven dynamic membrane and 95% for 0.45 µm pore size real membrane, turbidity values haveobtained1,5 NTU and 0,7 NTU for non-woven and 0.45 µm real membrane, respectively.

Key words

Dynamic membrane, membrane bioreactors, non-woven and 0.45 µm membrane

1. INTRODUCTION

There has been growing relevance for biological wastewater treatment methods using membranes. Solid-liquid separation processes are being done in the way of biological wastewater treatment and in particular, membrane bioreactors (MBRs) are playing essential role in treatment processes [1]. With the benefits and usage of micro/ultrafiltration, MBR ensures significant benefits and progression if it is compared with conventional active sludge processes (CASP), while pore size of the membrane doesn't allow to pass all substances or colloidal particles through the pores whose range is between 0.05-0.4 µm [2].MBRs are combination of permeable membranes and they include the physical separation of refined water and biomass. In conventional active sludge process, biochemical oxidation and water/biomass separation occurs in two different tank but MBRs make it convenient to proceed in one tank [1, 3]. Therefore, membrane bioreactors hinder the production of sludge whose amount normally increases throughout the process and employ high concentration of constituents of mixed liquor that comprises colloidal particles or solid substances suspended in the reactor. It also provides high dispelling yield of biological oxygen demand (BOD) and chemical oxygen demand (COD) [3]. While process has been done by using aerobic and anaerobic bacteria cultures, different types of membranes are being tested for better performance. Combination of the reactors and more convenient module designs ensures visually induced footprint. Throughout the separation process, usage of the membrane that filtrates the mixed liquor enhances the quality of excreted effluent. Therefore, MBR systems permit engagement of the bacteria in each other and forming flocs through the surface of the membrane and it also blocks the transition of colloidal particles from the pores and sustains sterilization [4, 5]. However, there are wide spread applications of aerobic MBR studies in the literature, there are also anaerobic processes in the applications of MBR system [6, 7]. Although, effluent quality and low system footprint are mentioned as benefits of MBRs, it has some primary limitations like; low flux, energy demand, membrane cost and clogging control. All those problems can be solved by using dynamic membrane technology (DMBR) [1, 8, 9]. Generally, membrane pores are plunged because of organic materials orcolloidal particles. DM layer hinders the blockage of support material by biomass filtration layer that underlies on DM itself [10, 11, 12]. Throughout the process, transition/movement of the suspended solid particles creates a cake layer on the membrane. Generation of the cake layer can decide the refusal characteristics of the process because cake layer itself plays the secondary membrane role hence after [13, 14, 15]. Water backwash, air backwash or scrubbing methods can be efficient to clean the dynamic membranes without using chemical substances [16]. Nevertheless, cleaning without using chemical substances may employ transient deprivation of effluent. One of the most critical properties for the dynamic membranes is the preclusion of the solid substances through the surface of the secondary membrane which can be comprised or regenerated by itself called self-forming dynamic membrane (SFDM). However, formation and/or reformation of the dynamic membrane layer may diminish the transmissivity of the membrane which is similar hitch that has been seen in conventional MBRs [17]. Micro/ultrafiltration membranes are overpriced than other low cost materials like mesh, non-woven fabric and woven wire cloth which can be used as support material for the generation of dynamic layer [9, 18, 19, 20]. In addition, employing low cost materials, which are mentioned above, instead of using traditional materials ensures high rate flow of liquid at lower transmembrane pressure (TMP) in cost saving field [3, 15, 21, 22].

In this study, two different types of membranes, non-woven and 0.45 µm pore size real membrane, have been employed and compared in each other in terms of Turbidity, TMP, SMP, EPS and CST analyses.

2. MATERIAL AND METHOD

Two different membrane modules were performed and one lab scale aerobic membrane bioreactor (AeMBR) tank was designed. It was made of plexiglas at dimensions of 8x14x38 cm operated in total volume of around 3000 ml and active volume of 2500 ml. Suspended solids concentration was stabilized at 5000 mg AKM/L. Reactor was equipped with water level sensor and aeration device, which procures mixing and continuous physical membrane cleaning, at the bottom. Inside of the tank, two different membrane types, non-woven flat-sheet polyethersulfone (PES) microfiltration and0.45 µm pore size real membrane, were employed for the operation and double-sided support layer was utilized for the membrane stableness. Each membrane module, made of 12x12 cm plexiglas, had volume of 217 ml and active surface area was adjusted to 7.5x7.5 cm2(Fig.1).

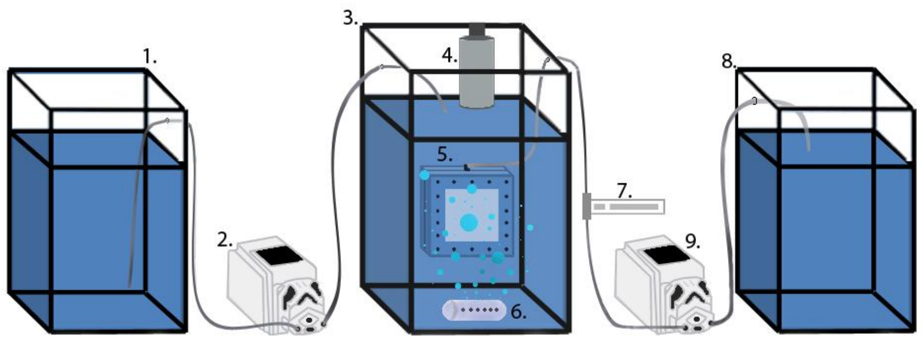

Fig.1. Schematic representation of MBR system: 1. Feed Tank, 2. Feed Pump, 3. Reactor, 4. Level Sensor, 5. Membrane Modules, 6. Air Diffuser, 7. Air Flow Regulator, 8. Permeate Tank, 9. Suction Pump

MBR system was operated at 11.11 LMH flux and 10 LMH net flux. SADm value and membrane suction pumps' flow rate was 1 Nm^3 (air)/m^2.hour and 2.08 ml/minute, respectively. Membranes were operated 4.5 min. and kept 0.5 min rest. When the membrane pressure reached 250 mbar pressure, dynamic membrane module was subjected to physical cleaning process. Every day, air backwash operation implemented to the membranes to reduce plugging at 22.5 L (air)/hr. flux through 1 minute. It was noticed that physical cleaning and air backwash pressure values were at desired level, in terms of transmembrane pressure (TMP).

Synthetic Wastewater Characteristics and Operation Procedures

The feed water of the MBR system was synthetic wastewater and feed chamber was filled regularly as 7000 ml every day. Chemicals of synthetic wastewater were represented at Table 1 and sucked permeate accumulated into two different tanks. Established AeMBR was operated interminably, because throughout its operation no kind of sludge elimination process was employed. However, pumps were adjusted 4.5 minutes of suction pressure so as to apply 30 seconds rest. This is one of the methodologies widely used to prevent plugging. To prevent clogging, non-woven dynamic membrane was administered for backwash operation each day, one minute and 0.45 µm pore size membrane was not employed for the same operation.

Table 1. Synthetic Wastewater Content

Chemicals	Concentration (mg/L)
$C_6H_{12}O_6.H_2O$	500
$NaHCO_3$	2754
NH_4Cl	230
K_2HPO4	37
KH_2PO4	67
$MnSO_4.H_2O$	0.4289
$ZnSO_4.7H_2O$	0.1053
$NaSO_3$	0.2811
$CuSO_4.5H_2O$	0.0556
$FeSO_4.7H_2O$	5.92
$NiSO_4.6H_2O$	0.1
$CoCl.6H_2O$	1

Net Flux Calculations

Amount of water passing along the unit surface area of membrane per unit of time is simply called flux, J. In this context, flux can be formulated as [3];

$$Flux = \frac{Flow}{Area} \qquad J = \frac{Q}{A} = \frac{Volume}{Time\ x\ Area} \tag{1}$$

MBR system was operated in 5 minutes periods, as 4.5 min. working and 0.5 min. rest. Net flux is represented with the following formula [3];

$$Net\ flux = flux \times \frac{running\ \ time}{waiting\ \ time + running\ \ time} = 11{,}11 \times \frac{4{,}5\ min.}{(0{,}5+4{,}5)\ min.} \cong 10\ LMH \tag{2}$$

2.1. Surface area, Flow and SADm Calculations

Dimensions of the membrane were 7.5cmx7.5cm. Active surface area calculation is presented with an equation below;

$$Active\ surface\ area = 7{,}5\ cm\ \times 7{,}5\ cm \times 2(membrane\ modules), = 0{,}01125m^2$$

Flow, can be calculated by multiplying the flux and membrane surface area. Active surface area and flux are calculated as 0.01125 m^2 and 11.11 LMH (L/m^2.saat), respectively. Flow is calculated by the following equation [3];

$$Flow = 11{,}11 \frac{L}{m^2.hour} \times 0{,}01125\, m^2 = 0{,}125\ L/hour \tag{3}$$

Volume of permeate which should be evacuated from the operation and volume of flow that should be sucked by the pumps were computed via following balance, respectively;

$$Permeate = 0{,}125 * 24 = 3000\ L$$

$$Flow = \frac{Volume}{Time} = \frac{3000\ L}{1440\ min.} = 2{,}083 \cong 2{,}08\ ml/minute$$

System was operated under 1 Nm^3xhr/m^2 SADm value and required oxygen amount is calculated as;

$$SADm = \frac{Q(air)}{Area} \qquad SADm = \frac{Nm^3/hr}{m^2} \quad 1 = \frac{Nm^3(air)}{0.1125 \times 1hr} \tag{4}$$

Amount of air for a membrane module calculated as 11.25 L/hour. In our system, two membrane modules were operated, so total amount of air for the reactor was calculated as 22.5 L/hour.

2.2. Analytic Methods

2.2.1. Chemical Oxygen Demand

While samples taken from feed tank were two times diluted for analysis, samples taken from permeate tank were not diluted and directly utilized in the NTU experiment. There were four experimental tubes reserved for the COD process. 2 individual, 2.5 ml, samples were taken from real and dynamic membranes permeate and 2.5 ml distilled water was taken as witness sample. On the other hand, 1.25 ml sample from the feed tank was mixed with 1.25 ml distilled water for two times dilution. These four different types of samples were stored individually to the tubes and 1.5 ml potassium dichromate and 3.5 ml silver sulfuric acid (AgSO4) were added inside of the tubes. After then, tubes were stored inside of the thermoreactor, for 120 minutes at 1500C. WTW CR 3200 brand thermoreactor was used and after two hours, tubes were taken from thermoreactor and allowed to cool down. Titration process was ensured by using magnet inside beaker placed on mixer. While beaker was stirring the mixture, two drops of ferroin indicator were added and titrated with the FAS solution. At the end, consumptions were noted.

2.2.2. Determination of Turbidity, Transmembrane Pressure, CST

Suspended solids inside of the water and soluble inorganic constituents can cause and also increase the turbidity parameters. Unit of the turbidity is NTU in nefolometric turbidimeters. In experimental phase, WTW TURB 550IR type turbidimeter instrument was employed. Therefore, determination of the turbidity was done by two individual 35 ml samples taken to the 50 ml falcon tubes from the permeate of 0.45 pore size real membrane and non-woven dynamic membrane. Before turbidimeter was run, 1000 NTU, 10 NTU and 0.02 NTU standard solutions glass tubes were cleaned up painstakingly with glass-cloth and put to dedicated wells of the instrument respectively for calibration process. Turbidimeter glass tube was washed with the soap and rinsed. Then, washed with distilled water, wiped with glass-cloth, shaken two times with few drops of sample of interest for the measurement and 25 ml sample was put inside of the tube which was shaken at that moment. Tube was placed inside of the instrument and measurement results were noted for both sample types. Transmembrane Pressure (TMP) Measurement: Throughout the experiment, pressure measurements were done daily with TMP instrument. As a result of dynamic membrane pressure reach of 250 mbar it was sentenced to backwash. Increase in pressure indicates that membrane blockage occurred. All pressure measurements were carried out programmable digital manometer (KELLER-Leon record, Swiss), and Installerlogger5 the software. Air Backwash: Backwashing the membrane with water and the negative or positive pressure to be lifted to rest on was one method for preventing the blockage problem. Membranes operated at high flux can run in a shorter time period and blockage can be prevented by more frequent backwashing or rest periods applying (D.C. Stuckey, 2012). In this experiment, backwash was employed only for non-woven dynamic membrane, daily. Backwashing was done for 1 minute, while flux was kept constant. Capillary Suction Time (CST), SMP, EPS Analyses: Capillary suction time (CST) is a widely utilized methodology to measure the filterability and related with the movement of water from the sludge through 1 cm path in a particular time period, in a porous capillary membrane. In experiment, the determination of sludge filtration properties and to determine the relationship of capillary absorption time with obstruction, CST instrument (Triton 304M, England) was used to determine CST. SMP was determined after centrifugation of the samples at 4000 rpm for 10 min. from the reactor effluent obtained at experimental stages of filtering supernatant samples and amount of protein and carbohydrates obtained from filtrate. Samples taken from reactor were centrifuged for the EPS analyze and EPS in biomass was extracted. EPS extraction process was carried out just as specified in the book of Judd (2006) with the heating. EPS value was stated as protein and carbohydrate concentration. Analyses were made by Bradford (1976) and Dubois (1956) methods, respectively.

3. RESULTS AND DISCUSSION

3.1. COD Experimental Results

Through the operation of MBR system, COD experiment results are represented at Fig. 2 by the samples taken from influent synthetic feed wastewater, non-woven dynamic membrane and 0.45 μm pore size real membrane permeate. COD tests were made every three days for 60 days. During the experiment, it was noticed that COD concentrations of non-woven dynamic membrane was lower than 0.45 μm pore size real membrane. COD concentration of dynamic membrane was time to time higher than the real membrane because it takes time to ensure the stability of the dynamic membrane and backwashing operations from time to time when membrane stableness was disrupted.

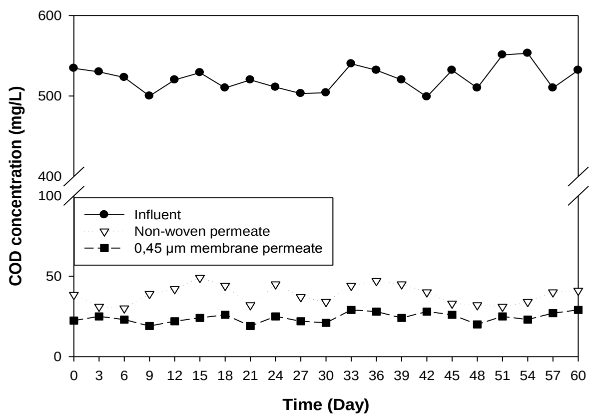

Fig. 2: COD concentrations of influent, real and dynamic membrane Throughout MBR operation.

Until reactor reaches decisive condition, COD concentrations are high. In this context, COD data taken from the samples were imprinted when the reactor come up with stable standards. There has been reduction of COD concentrations of non-woven dynamic membrane after day 42. It was thought that this reduction occurred due to inefficient removal yield of cake layer that formed on the surface of membrane by plugging.

COD concentrations of non-woven dynamic membrane were quite close to the real membrane when the cake layer on membrane surface became stable. Throughout the operation duration, total COD concentration of influent wastewater was maximum 551 mg/L and COD concentrations from permeate were 19 mg/L and 30 mg/L for real and dynamic membrane, respectively. COD values from influent wastewater may change due to the environmental circumstances which can be affected. Through 60 days, COD removal performance results of 0.45 µm pore size real membrane and non-woven dynamic membrane were given at Fig.3. Along the operation, it was noticed that COD removal yield of non-woven dynamic membrane was lower than 0.45 µm pore size real membrane. It was because of non-woven dynamic membrane permeate contains high COD causing bacteria concentration. COD analyses were not exposed any kind of filtration operations and directly performed with titrimetric method in terms of representing real values.

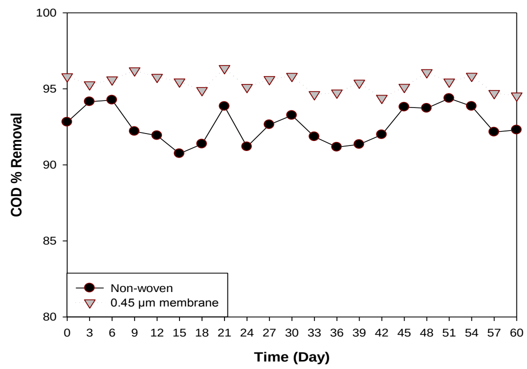

Fig. 3: COD removal yields of real and dynamic membrane through the MBR operation.

Close COD concentration percentages between non-woven and dynamic membrane from permeate was already noticed in research made by Lee et al. [23]. However, some studies employment of non-woven fabric filter and micro-filter membranes showed convenient performance for mixed liquor separation [24].

3.2. Turbidity Results

Turbidity results of the samples taken from non-woven dynamic membrane and 0.45 µm pore size real membrane are represented at Fig. 4. Samples were taken every three days and determination of turbidity was made through two mounts for every three days.

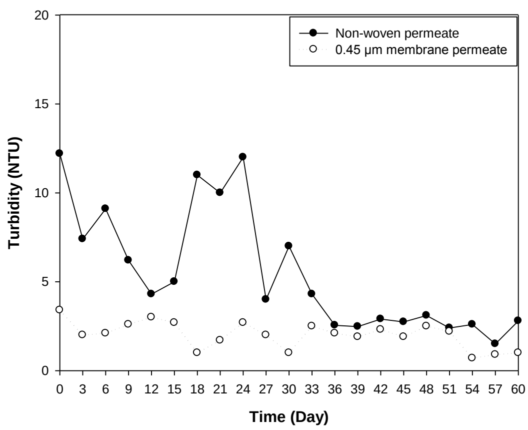

Fig.4: Turbidity results of dynamic and real membrane through MBR operation.

In the filtration of the standard turbidity solution, turbidity removal of the dynamic membrane showed [3, 25]. There have been changes at the removal performance of the membranes in MBR. The reason of high turbidity results of dynamic membrane is because of the membrane stability which was ensured at first 24 days. 0.45 µm pore size real membrane came up with much better turbidity results. Last 30 days of the experiment, turbidity values of dynamic membrane were quite close to the real membrane due to the plugging and increase at the removal yield.

3.3. TMP Measurements

In the experiment, distilled water transition was ensured over the membrane surface for both membrane types and pressure measurements were recorded. Even though the pressure values were obtained when distilled water released for 24-hour measurements, operation was repeated for better performance and comparison. Pressure measurements of real membrane were made and noted every three days. Fig. 5 represents the pressure measurement of the real membrane. After then, the system has been started to run and synthetic wastewater feeding.

In MBR system, synthetic wastewater from 0.45 µm pore size real membrane was filtered. It was observed for the real membrane that the pressure was below 100 mbar when the system at stable condition and pressure value rose to levels of 250 mbar. Beside of interrupted suction operation, any physical or chemical washing was not applied.

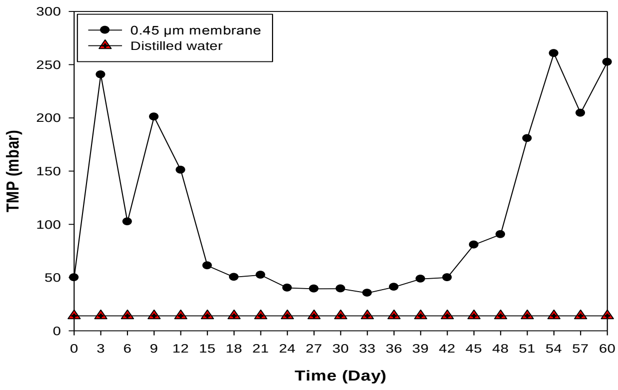

Fig.5: Pressure measurement of the real membrane through MBR operation.

Dynamic membrane was also exposed to interrupted suction operation, 4.5 minutes working and half a minute rest, and 1-minute back washing. In MBR system, synthetic wastewater prepared from non-woven dynamic membrane was filtered and while the system was operating, pressure measurements of dynamic membrane and released distilled water were recorded and represented at Fig. 6. When the measured pressure reached 250 mbar, non-woven dynamic membrane exposed to physical washing. Pressure increment is the result of membrane plugging. During the experiment, physical cleaning was applied three times. Physical cleaning was applied as removal of membrane module and skinning the cake layer from the surface of the membrane. After physical cleaning, significant pressure reduction has been observed. After physical cleaning, increment in pressure is because of the permanent plugging of the pores of the membrane and there are a lot of experiments indicated for this situation.

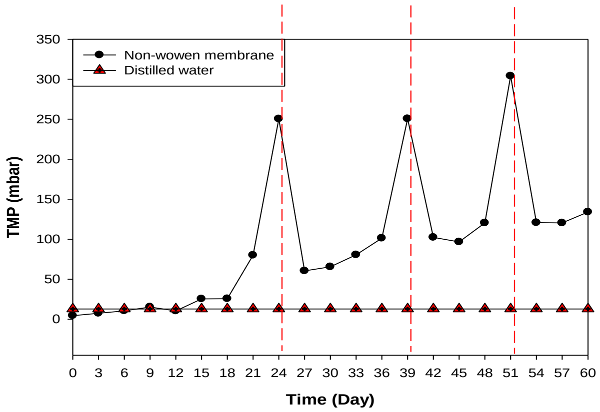

Fig. 6: Pressure measurements through MBR operation.

3.4. The Effect of Air Backwash

It was only wanted to examine the effect of air backwash for non-woven dynamic membrane, before backwashing and after air backwashing, 12-hour pressure measurement additionally made. Fig. 7 represents the pressure reduction after air backwash. The effect of air backwash has been made for once throughout the MBR operation. TMP values for 30th day were saved with 12-hour period and 2-minute intervals. After 1-minute air backwash operation, TMP values again observed with 12-hour period and effects of air backwash were recorded. Findings showed that air backwash reduced the present TMP value averagely 20%.

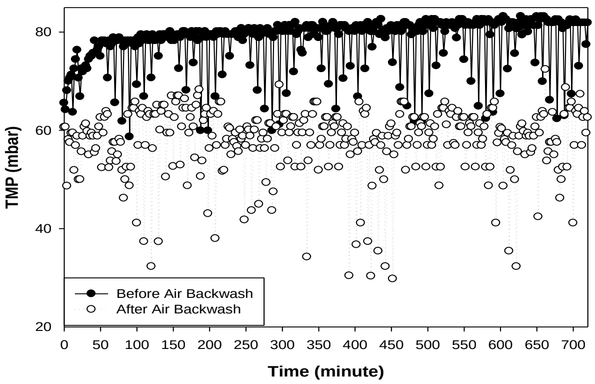

Fig. 7: Pressure values before and after air backwash.

3.5. SMP EPS Results

Throughout the experiment, SMP and EPS analyses were made firstly at day-15 and secondly at day-30. Protein and carbohydrate dependent SMP and EPS concentrations are represented at Table 2. It was noticed that, day-15 SMP and EPS concentrations were higher than the day-30. These results shows gradually heal of COD removal inside of the reactor.

Table 2. SMP and EPS results regarding permeate of dynamic membrane, real membrane and mixed liquor.

	Non-woven		0.45 membrane		Supernatant			
	SMP		SMP		SMP		EPS	
Time	Protein (mg/L)	Carbohydrate (mg/L)	Protein (mg/L)	Carbohydrate (mg/L)	Protein (mg/L)	Carbohydrate (mg/L)	Protein (mg/L)	Carbohydrate (mg/L)
Day 15	0,05989	24,601	0,07567	85,261	0,999	147,943	0,1465	171,533
Day 30	0,18964	59,649	0,27584	195,46	0,431	99,752	0,1379	66,389

At day-15, analyze results of permeate of dynamic and real membrane were lower than the results of day-30. When this situation is examined with the turbidity values of both modules, it can be noticed that COD removal yield is lower than for the first time in days.

Figures and tables must be numbered. Figures and tables captions must be centered in 8 pt italic with small caps. Captions with figure numbers must be placed after their associated figures, as shown in Figure 1. Captions with table numbers must be placed before their associated tables, as shown in Table I.

3.6. CST Results

CST is used to identify the sludge characteristics and it measures the time of water drop from the sludge moved 1 cm path in a porous membrane. CST results of fully mixed liquor samples are represented at Fig. 8.

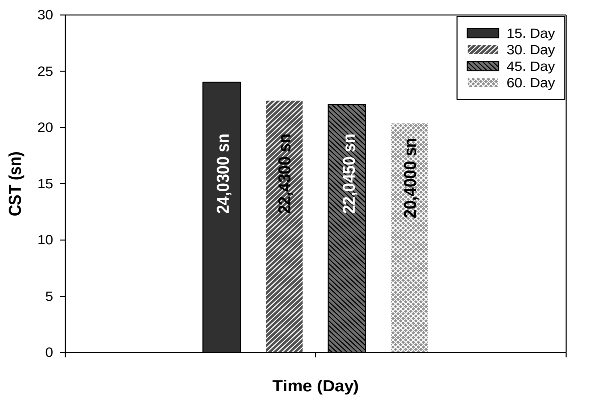

Fig. 8: CST analyzes results of the MBR mixed liquor.

CST analyses from day 15, 30, 45 and 60 were found as 24.03 sec., 22.43 sec., 22.045 sec. and 20.40 sec., respectively. Findings showed that CST values are gradually reducing. This shows the increment in viscosity of the sludge in the reactor, and thus demonstrates that the membrane filtration rate gets better.

4. CONCLUSION

In this study the comparison of DMBR and MBR was studied. Both membrane types operated under same aerobic conditions such as; volume, LMH and SADm. At the end of approximate one-month adaptation time course, bioreactors, which have reached stable conditions, have been operated to gather the data throughout 60 days. COD removal rates and turbidity results have been compared and non-woven dynamic membrane results have shown similar results to real membrane in terms of efficiency. Furthermore, dynamic membrane has exposed air back wash and pressure changes examined.

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