ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EVALUATION OF BIOFILM PERFORMANCE OF DIFFERENT STRUCTURES WITH INTEGRATED FIXED ACTIVATED SLUDGE AND MEMBRANE BIOREACTOR

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

ENTEGRE SABİT FİLMLİ AKTİF ÇAMUR SİSTEMİ VE MEMBRAN BİYOREAKTÖR İLE FARKLI YAPIDAKİ BİYOFİLM PERFORMANSLARININ DEĞERLENDİRİLMESİ

YÜKSEK LİSANS TEZİ

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Özgün YILMAZ, a M.Sc student of İTU Graduate School student ID 501171814, successfully defended the thesis/dissertation entitled “Evaluation of Biofilm Performance of Different Structures With Integrated Fixed Activated Sludge and Membrane Bioreactor”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my spouse,

FOREWORD

As a begin, I would like to thank my thesis advisor, my precious teacher, who never spared his support with his patience and knowledge. I would like to thank Assistant Professor Türker Türken. I would like to thank my honored teacher, Prof. Dr. İsmail Koyuncu, who has serve as a model for many like me with his determination and discipline to work, and who has always stood by me and supported me both in my education life and in all areas of my life. I would also like to thank my MEMTEK Family, where I started with my education life and continued my professional life.

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December 2022 Özgün YILMAZ
(Environmental Engineer)

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ABBREVIATIONS

APHA	**:** American Public Health Association
BEPR	**:** Biologically Enhanced Phosphorus Removal
BOD	**:** Biochemical Oxygen Demand
COD	**:** Chemical Oxygen Demand
IFAS	**:** Integrated Fixed Activated Sludge
MBBR	**:** Moving Bed Biofilm Reactor
MBR	**:** Membrane Bioreactor
MEM-TEK	**:** Prof. Dr. Dinçer Topacık National Research Center on Membrane Technologies
MLSS	**:** Mixed Liquor Suspended Solids
MLVSS	**:** Mixed Liquor Suspended Solids
NTU	**:** Nephelometric Turbidity Units
PLC	**:** Programmable Logic Controller
PP	**:** Polypropylene
PVDF	**:** Polyvinylidene Difluoride
RAS	**:** Reversible Activated Slude
SEM	**:** Scanning Electron Microscope
SSA	**:** Specific Surface Area
SVI	**:** Sludge Volume Index
TMP	**:** Trans Membrane Pressure
TN	**:** Total Nitrogen
TSS	**:** Total Suspended Solids
VSS	**:** Volatile Suspended Solids

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EVALUATION OF BIOFILM PERFORMANCE OF DIFFERENT STRUCTURES WITH INTEGRATED FIXED ACTIVATED SLUDGE AND MEMBRANE BIOREACTOR

SUMMARY

Water is an indispensable resource for living things to continue their vital activities although natural resources are limited. The intensification of water use with the rapid population growth and the rise of industrialization stands out as the main reason for the concept of global water scarcity. While the intensification of water use will increase the demand for water and the pressure on water resources, it will also cause the current water scarcity to turn into a “water crisis” in the coming years. Unless a precaution is taken, it is inevitable that this problem will reach an even more critical level as time goes on. In order to prevent this problem, wastewater should be well treated and reused. It is necessary to determine a good treatment technology within the scope of reuse of waste water. For a good treatment technology, it is necessary to focus not only on high removal efficiencies, but also on the feasibility of the technology. In this context, in big cities where space is an important issue, the small space requirement of treatment technology is a priority. In the scope of the thesis, considering this subject, the integration of the membrane bioreactor (MBR) systems, which take up little space and provide high removal efficiencies, and the biofilm system for the treatment of wastewater is examined.

Compact biofilm systems have become highly preferred today due to their low energy requirements and low labor requirement. Biofilm systems, which have become especially popular in organic matter removal, are used in villages, hotels, sites and similar low-population areas. In these low-population areas, compact biofilm systems are also more affordable than the design and implementation of a large-scale treatment plant.

The performance of the biofilm system is greatly affected by the loading conditions. High and very low loadings deteriorate the quality of the effluent. Optimum loading values in air biological treatment systems differ according to the type of reactor used. The effect of different operating parameters and active features on the behavior of IFAS-MBR systems was reviewed with the pilot scale system. Based on the main experimental findings, the following conclusions can be drawn:

- COD removal was generally satisfactory for most of the experiments. However, a sudden decrease in the incoming C/N ratio or a shock in the inlet salinity of the persistent pollutant can affect the behavior of the bacterial consortium in the IFAS-MBR that treats industrial wastewater.

- Thanks to the biofilm expertise, good nitrification ability of the system was achieved throughout the experiments. The long retention time of the biofilm enhanced the growth of nitrifications, thus promoting nitrification even for the lowest mixed liquor SRT values; The biofilm effectively contributes to the removal of more stubborn pollutants such as hydrocarbons, even in hostile environments (high salinity).

- Respirometric batch tests highlight the greater ability of suspended biomass to remove COD, while biofilm often contributes to nitrification or removal of specific persistent contaminants.

- Biofilm separation strongly influences membrane fouling. Biofilm separation can create a beneficial "seeding" effect on suspended biomass (nitrification, removal of hydrocarbons) and also provide the correct compactness to the cake layer.

Within the scope of the thesis, the effect of the media type on the removal efficiency was examined by using two different media types and studies were carried out on the optimum amount of use. With the MBR system, which is integrated with the biofilm system, high removal efficiencies have emerged, and it has been concluded that it is a technology that should be highlighted due to its low space requirement. The results and comments of the analyzes made during all these examinations are also detailed in the “Conclusions and Discussion” section. In addition, with the biofilm system in front of the MBR system, the load on the membrane is reduced, and the possibility of clogging of the membrane and the use of chemicals for backwashing are reduced. In this case, it has allowed the membrane to prolong its useful life and be more cost-effective than the systems using only MBR.

ENTEGRE SABİT FİLMLİ AKTİF ÇAMUR SİSTEMİ VE MEMBRAN BİYOREAKTÖR İLE FARKLI YAPIDAKİ BİYOFİLM PERFORMANSLARININ DEĞERLENDİRİLMESİ

ÖZET

Doğal kaynaklar sınırlı olmakla birlikte su, canlıların yaşamsal faaliyetlerini sürdürebilmeleri adına vazgeçilmez bir kaynaktır. Hızlı nüfus artışı ve sanayileşmenin yükselişiyle birlikte su kullanımının yoğunlaşması, küresel su kıtlığı kavramının başlıca sebebi olarak öne çıkmaktadır. Su kullanımının yoğunlaşması suya olan talebin ve su kaynakları üzerindeki baskının artmasına sebep olurken, mevcut su kıtlığının gelecek yıllarda “su krizine” dönüşmesine de sebebiyet verecektir. Bir önlem alınmadığı takdirde, zaman geçtikçe bu sorunun daha da kritik bir seviyeye ulaşması kaçınılmazdır. Bu sorunun önüne geçebilmek için atık suların iyi bir şekilde arıtılıp, yeniden kullanımı sağlanmalıdır. Atık suların yeniden kullanılması kapsamında iyi bir arıtım teknolojisi belirlenmesi gerekmektedir. İyi bir arıtım teknolojisi konusunda sadece yüksek giderim verimlerine değil, teknolojinin fizibilitesine de odaklanmak gerekir. Bu bağlamda, yer sorunu önemli bir husus olan büyük şehirlerde, arıtma teknolojisinin az yer ihtiyacı bir önceliktir.

Arıtma verimliliğini artıran yeni teknolojiler gelişirken bu yeni sistemleri birbirleri ile entegre kullanarak yer ihtiyacı ve işletme zorluklarını artıran hususların önüne geçmek mümkündür. Sistemlerin kendi içlerindeki iyileştirme çalışmaları yapılırken bununla beraber arıtma sistemlerinin entegre kullanılması atıksu arıtma kalitesini artırırken özellikle günümüzde çok önem kazanmış olan yer ihtiyacını azaltabilmektedir.

Tez kapsamında da bu konu dikkate alınarak, atık suların arıtımı için az yer kaplayan ve yüksek giderim verimleri sağlayan membran biyoreaktör (MBR) sistemleri ile biyofilm sisteminin entegrasyonu irdelenmiştir.

Entegre biyofilm sistemleri, gerekli enerji ve iş gücü girdileri azaltılarak organik madde yükü bakımından yoğun atıksuların arıtımında ekonomik bir çözüm olarak son yıllarda ön plana çıkmaktadır. Bu özellikleri sayesinde yerleşimden uzak tesislerde ve nispeten daha az nüfuslu yerlerde konvansiyonel atıksu arıtma tesisleri yerine daha uygun bir çözüm olarak değerlendirilebilmektedir.

Biyofilm sistemin performansı yükleme şartlarından çok etkilenir. Yüksek ve çok düşük yüklemeler çıkış suyunun kalitesini bozar. Havalı biyolojik arıtım sistemlerinde optimum yükleme değerleri, kullanılan reaktörün tipine göre farklılık gösterir.

Farklı işletim parametrelerinin ve etkin özelliklerin IFAS-MBR sistemlerinin davranışı üzerindeki etkisi, pilot ölçekli sistem ile gözden geçirildi. Ana deneysel bulgulara dayanarak, aşağıdaki sonuçlar çıkarılabilir:

• KOİ giderimi, deneylerin çoğu için genellikle tatmin ediciydi. Bununla birlikte, giren C/N oranındaki ani bir düşüş veya inatçı kirleticinin giren tuzluluğundaki bir şok,

endüstriyel atıksuyu arıtan IFAS-MBR'deki bakteriyel konsorsiyumun davranışını etkileyebilir.

• Biyofilm uzmanlığı sayesinde deneyler boyunca sistemin iyi nitrifikasyon kabiliyeti elde edildi. Biyofilmin uzun alıkonma süresi, nitrifikasyonların büyümesini arttırdı, böylece en düşük karışık likör SRT değerleri için bile nitrifikasyonu destekledi; Biyofilm, düşman ortamlarda bile (yüksek tuzluluk) hidrokarbonlar gibi daha fazla inatçı kirleticilerin giderilmesine etkin bir şekilde katkıda bulunur.

• Respirometrik kesikli testler, askıda kalan biyokütlenin KOİ gidermeye yönelik kabiliyetinin daha fazla olduğunu vurgularken, biyofilm çoğunlukla nitrifikasyona veya spesifik inatçı kirleticilerin giderilmesine katkıda bulunur.

• Biyofilm ayrılması, membran tıkanmasını güçlü bir şekilde etkiler. Biyofilm ayrılması, askıdaki biyokütle (nitrifikasyon, hidrokarbonların uzaklaştırılması) üzerinde faydalı bir "tohumlama" etkisi yaratabilir ve aynı zamanda kek tabakasına doğru kompaktlığı sağlayabilir.

Tez kapsamında da, iki farklı medya türü kullanılarak medya türünün giderim verimi üzerine etkisi iredelenmiş ve optimum miktarda kullanımı konusunda çalışmalar gerçekleştirilmiştir. Biyofilm sistemi ile entegre işletilen MBR sistemi ile yüksek giderim verimleri ortaya çıkmasıyla beraber, az alan ihtiyacı sayesinde öne çıkarılması gerekli bir teknoloji olduğu kanısına varılmıştır. Ayrıca, MBR sisteminin önünde yer alan biyofilm sistemi ile membrana gelen yük azaltılarak, membranın geri yıkaması için gerekli kimyasal kullanımı azaltılmıştır. Bu durumda membranın kullanım ömrünün uzamasına ve maliyet açısından sadece MBR kullanılan sistemlere oranla daha verimli olması sağlamıştır. Tüm bu incelemeler sırasında yapılan analizlerin sonuçları ve yorumları da "Sonuçlar ve Tartışma" kısmında detaylı olarak belirtilmiştir. Ayrıca, MBR sisteminin önünde yer alan biyofilm sistemi ile membrana gelen yük azaltılarak, membranın tıkanma olasılığı ile geri yıkama için gerekli kimyasal kullanımı azaltılmıştır. Bu durumda membranın kullanım ömrünün uzamasına ve maliyet açısından sadece MBR kullanılan sistemlere oranla daha verimli olmasına olanak sağlamıştır. Ana deneysel bulgulara dayanarak, aşağıdaki sonuçlar çıkarılabilir: KOİ gideriminde %94'lük bir verim elde edilmiştir. Biyofilm sayesinde deneyler boyunca sistemde iyi bir nitrifikasyon verimi sağlandı. Biyofilmin uzun bekleme süresi, nitrifikasyonu artırmış, böylece düşük SRT değerleri için bile nitrifikasyonu desteklenmiştir. Biyofilm ayrılması, membran tıkanmasını güçlü bir şekilde etkiler.

Su geri kazanımı konusunun önem kazandığı günümüzde konvansiyonel sistemler yerine geri kazanım sistemlerine olan ihtiyaç artmaktadır. Bu kapsamda geliştirilen membran biyoreaktör sistemleri daha az alanda daha fazla atıksu geri kazanımı sağlamaktadır. IFAS sistemlerinin MBR sistemlerine entegrasyonu sayesinde alan ihtiyacı minimuma indirilmiş ve kirletici konsantrasyonları yüksek atıksuların geri kazanılabileceği görülmüştür.

Teknoloji ile değişen dünyada gelişen arıtma teknolojileri ile beraber bu teknolojilerin birbirleri ile entegre olarak kullanılması tez kapsamında da görüldüğü gibi birçok avantajlar doğurmaktadır. IFAS-MBR entegre sistemine benzer şekilde farklı sistemlerin beraber kullanılmasıyla daha iyi arıtma verimlerine daha az alan, kimyasal kullanımı, işletme personeli gibi maddi yükümlülük ve işletme riski doğuran parametre ihtiyaçlarının azaltılması mümkün kılınabilmektedir.

Gelecekte, IFAS malzeme yapısı, yüzey alanı ve geometrik şekil gibi değerler değiştirilerek daha yüksek verimliliğe sahip sistemlerin geliştirilmesi öngörülmektedir. Bu çalışmada, daha pürüzlü bir yapıya ve daha yüksek yüzey alanına sahip olan biyotaşıyıcının daha yüksek verimliliğe sahip olduğu gözlenmiştir.

1. INTRODUCTION

1.1 Description and Significance of the Study

Increasing population and industrial activities increase the need for clean water and at the same time the need for water purification. Membrane technologies are treatment technologies used together with or outside of conventional treatment systems.

Membranes retain some physical or chemical components in water and wastewater treatment and pass some components. This feature of membranes with a selective permeability mechanism depends on the pore size of the membrane. In terms of pore size, four membrane processes stand out in water and wastewater treatment. These are microfiltration, ultrafiltration, nanofiltration and reverse osmosis membranes.

Membrane bioreactor (MBR) systems are technologies that provide biological treatment using membranes. MBR is a combination of these two treatment methods rather than the sequential application of biological treatment and membrane separation.

The hollow fiber membrane used in MBR can be easily damaged or broken during aeration disruption or backwashing. For this reason, a hollow fiber membrane with high mechanical properties was needed. Many studies have been carried out to improve the mechanical properties of hollow fiber membranes. A relatively simple and effective method is to coat a separation layer on a high-strength hollow tubular mesh (Fan et al., 2015).

The IFAS process is also one of the leading processes providing a sustainable solution for wastewater treatment. IFAS can be explained as an advancement of the moving bed biofilm reactor by integrating attached and suspended growth systems. It offers advantages over conventional activated sludge treatment such as improved nutrient removal, full nitrification, longer solids retention time. IFAS has been recognized as an attractive option, as indicated by the results of many pilots and full-scale studies. It improves sludge settling properties and provides operational stability. Recently developed IFAS reactors also include efficient results for methane production, energy generation via algae or microbial fuel cells.

For submerged membrane operated systems, the literature has shown that IFAS-MBRs have several advantages. Thanks to the biofilm immersed before the MBR, the membranes can be operated under higher permeability flow conditions, the pollution load on the membranes is reduced and requires less area as a more compact system. The pilot scale IFAS-MBR assembly established within the aim of this thesis was designed to remove both carbon and nutrients (nitrogen and phosphorus) and to determine the biofilm with the most suitable morphological structure.

1.2 Purpose and Scope of the Study

The scope of this thesis is to determine the most suitable biofilm by using biofilms with stable different morphological properties integrated with the membrane bioreactor formed with high performance reinforced hollow fiber membranes using PVDF polymers.

Within the range of the thesis, laboratory-scale experiments were carried out with the domestic wastewater sample to determine the appropriate biofilm and certain parameters were monitored. Two biofilms with different morphological structures and a high yield were selected by calculating the removal efficiencies by membrane bioreactor processes.

2. LITERATURE RESEARCH

2.1 Membrane Technology

Membranes are thin films produced from organic or inorganic materials that can produce a selective separation between a fluid and its components. Owing to its low cost and high efficiency, membrane technology is preferred in water treatment processes. Among the membranes, polymeric membranes come to the fore due to their economic and practical use (Madaeni, 1999; Basile et al., 2015). In recent years, the improvement of water quality with the treatments carried out with membrane systems has become an advanced treatment method that is used efficiently and effectively. Membrane systems have recently started to replace conventional desalination methods such as ion exchange, distillation, reverse electrodialysis and similar methods.

Membranes are used for the production of drinking water, desalination of seawater and brackish water, and treatment of industrial wastewater. Figure 2.1 shows forward osmosis, which is one of the most important membrane system used in the examples mentioned before, as schematically. In addition, membrane processes are used in the purification of drugs in food products and in medical devices such as hemodialysis, blood oxygenators, and controlled drug delivery products (Madaeni, 1999).

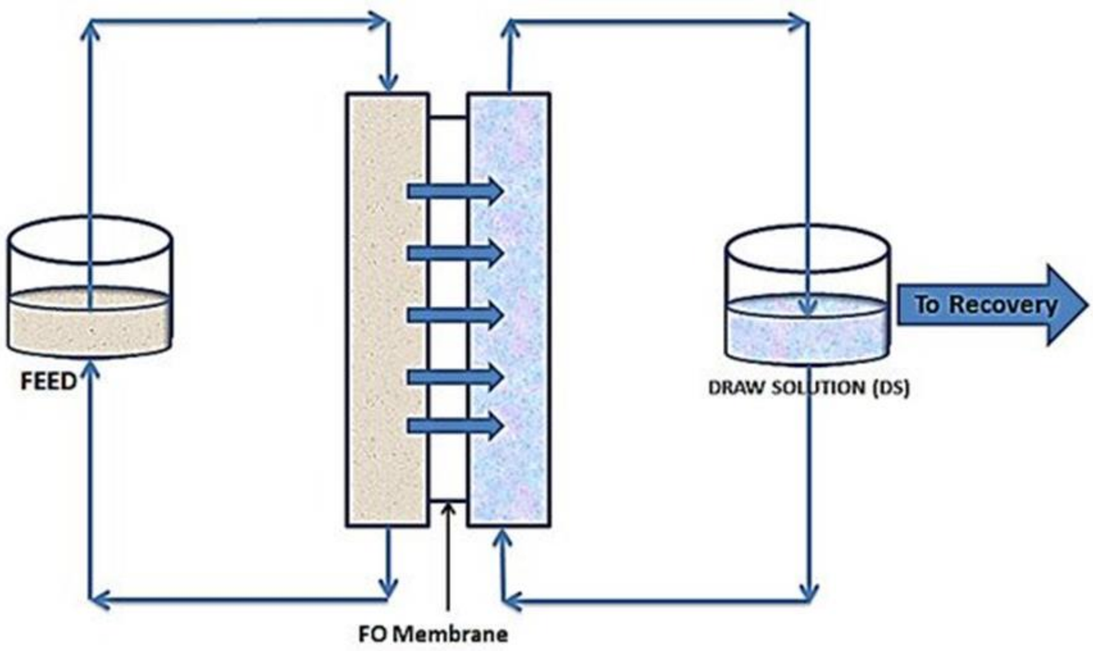

Figure 2.1 : Schematic Diagram of forward osmosis (Ezugbe and Rathilal, 2020).

The most important feature that distinguishes the membrane filtration process from other treatment technologies is that it can separate the removed material according to its size. Besides, membranes can be operated with different driving forces. While the driving force for the filtration process is the pressure difference across the filter, the driving forces such as concentration, electrical potential and temperature gradients are also effective in addition to this pressure difference in membranes.

Membranes are classified differently according to their morphological structure and driving forces. Classification of membranes according to their morphological structures is given in Table 2.1.

Table 2.1 : Membrane classification corresponding to their morphological structure.

Porous Membranes	**Microfiltration (MF), Ultrafiltration (UF)**
Large Porous	>50 nm
Medium Porous	2-50 nm
Small Porous	<2 nm
Dense (Non-porous) Membranes	**Nanofiltration (NF), Reverse Osmosis (RO)**
Composite Thin Film Membranes	
Supported Liquid Membranes	

2.1.1 Membrane bioreactor (MBR)

The membrane bioreactor (MBR) consists of a conventional activated sludge process combined with a membrane separation process used to capture biomass. MBRs are operated similarly to a conventional activated sludge process but do not require secondary treatment and tertiary stages (Melin et al., 2006). The separation process is carried out by pressure filtration in external MBRs and by vacuum operated membranes in submerged MBRs (Radjenovic et al., 2008). Because the effective pore diameter can be less than 0.1 μm, MBRs can effectively produce a clear and highly disinfected flow. In addition, MBR makes the biomass more concentrated, resulting in a reduced tank volume required and an increase in the efficiency of biological treatment. Therefore, MBRs tend to produce higher purity purified water in terms of removal of dissolved components such as organic matter and ammonia that can be removed in biological treatment. Moreover, by eliminating the need to precipitate biomass, the flow through the MBR cannot affect the effluent quality through sedimentation solids (McAdam & Judd, 2006).

MBR systems are generally installed with modules produced from microfiltration and ultrafiltration membranes. The cake/contamination layer that forms on the fibers over time during purification further shrinks these pores and increases the water/biomass separation, suspended solids and microorganism removal efficiency.

Table 2.2 : Historical Development of MBR Systems (McAdam & Judd, 2006).

Era	Incident
Late 1960s	• Dorr-Oliver developed the first external (sidestream) flat-sheet MBR
Early 1970s	• Thetford Systems commercialized external multitube Cycle-Let process to reuse of water in the USA
Early 1980s	• TechSep commercialized external flat-sheet Pleiade to reuse of water in Japan
Mid 1980s	• Nitto-Denko patented internal flat-sheet MBR in Japan University of Tokyo conducted experiments on MBR with internal space
Early and Mid 1990s	• Kubato commercialized internal flat-sheet MBR in Japan Weir Envig commercialized external ADUF system based on Membralox membranes • Zenon bought out Thetford in 1993 and commercialized ZeeWeed hollow fiber membrane technology with internal space in North America and Europe. • Wehrle commercialized external multitube biomembrane system • Mitsubishi Rayon commercialized MBR System with internal space that based on Sterapore membranes.
Early 2000s	• USF commercialized MEmJet hollow fiber membrane system • Huber commercialized rotating flat-sheet MBR • Norit developed external airlift multitube X-Flow technology • Puron commercialized internal hollow fiber membrane and bought by Koch company • Kolon ve Para (Korea) introduced hollow fiber membrane • Toray introduced flat-sheet MBR • Mitsubishi Rayon indroduced hollow fiber MBR • Asahi Kasei introduced hollow fiber MBR

The applied MBR systems are in 2 main configurations: external (liquid/biomass separation occurs in a separate unit with cross-flow membrane filtration) and internal-integrated (liquid/biomass separation occurs with submerged membranes in the bioreactor) (Figure 2.2.) Internal submerged MBRs operate at lower operating fluxes than external MBRs.

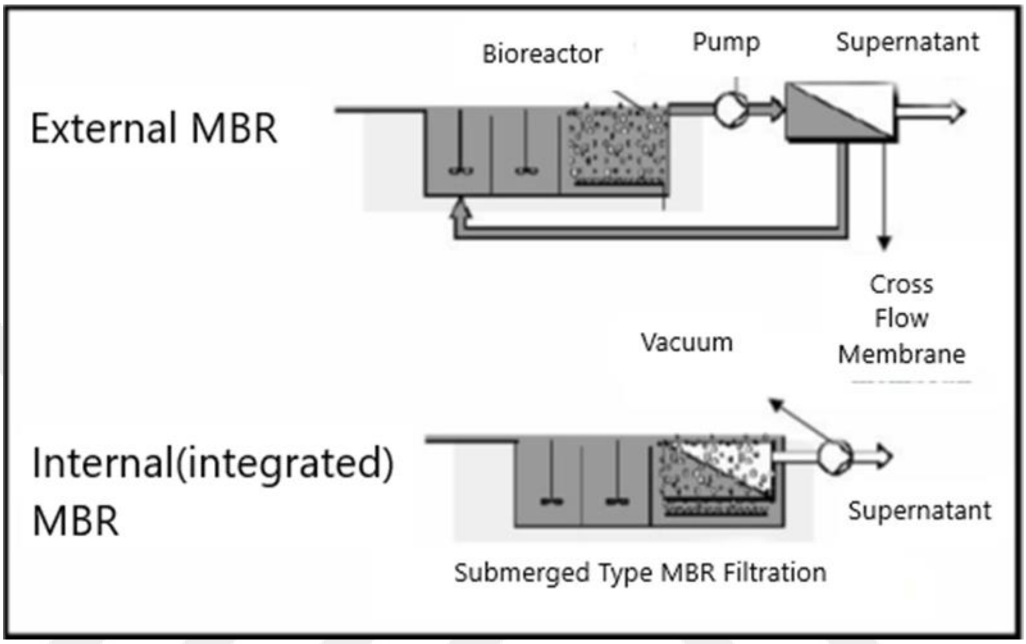

Figure 2.2 : MBR Types (Yiğit et al., 2008).

They have more permeability because they operate at low flux. Membrane fouling or fouling is relatively slow in internal MBRs due to low flux operation. However, a more intensive aeration process is performed in order to prevent membrane clogging in internal MBRs. Also, since internal MBRs work with low flux, more membrane surface is needed when considering a constant permeate process. More membrane surface requirements, on the other hand, require more initial investment costs. (Judd, 2002).

Advantages of MBR systems:

- Compared to other conventional treatment systems, the small space requirement gives MBR systems a great advantage (Visvanathan et al., 2000).

- The MBR process provides high quality waste in terms of turbidity, TSS, nutrients and COD. MBRs also offer the opportunity for disinfection using UF and MF with a low pore size ranging from 0.005 to 2 μm (Van Dijk & Roncken, 1997; Le Clech et al., 2006).

- With MBR systems, it can be operated with longer sludge retention age and high biomass concentrations (up to 20000 mg/L) with low sludge production and high COD and BOD removal (Defrance & Jaffrin, 1999).

- Since membrane bioreactors can treat wastewater both physically and biologically thanks to their special designs, they can eliminate many treatment units used in conventional treatment systems such as aeration, precipitation and disinfection (Gryta et al., 2001; Karakulski et al., 1998; Kitiş et al. , 2007; Rosenberger et al., 2002).

Disadvantages of MBR systems:

- The most important disadvantage of MBR systems is the operation and maintenance cost due to the high energy requirement for ventilation, mixing, periodic cleaning and replacement of membrane filters.

- If the flux cannot be increased to sufficient levels proportional to the membrane area, the MBR cannot be operated at full capacity due to increased energy consumption.

- Membrane clogging, which occurs as a result of the accumulation of components on the membrane surface over time; It causes a decrease in the flux value, a decrease in the membrane filtration performance and a decrease in the effluent quality (Marrot et al., 2004; Merz et al., 2007; Metcalf & Eddy., 2003; Stephenson et al., 2000).

Clogging in membrane biorectors is an important problem for membrane design and operation. Because with clogging, the need for cleaning causes extra costs: This affects membrane operating conditions and performance (Jefferson et al., 2000; Tomaszewska et al., 2005). Generally, internal MBRs are applied more frequently, although deciding on the configuration option depends on the specific application. The comparison of the two configurations is presented in Table 2.2 (Yiğit, 2007).

2.2 Integrated Fixed Activated Sludge (IFAS)

Biological treatment systems play a critical role in wastewater treatment. Biological processes can be examined in 3 groups as suspended growing processes, dependent growing processes and anaerobic processes.

In this part of the thesis, the main purpose is to describe and evaluate hybrid processes, especially in the integrated fixed film activated sludge (IFAS) process. This process basically combines fixed film and traditional suspended growing activated sludge treatment processes.

In attached growth systems, microorganisms attach and multiply on a surface. Attached growth systems have the potential to be applied as moving bed and fixed bed reactor systems. Compared to conventional treatment systems, biofilm processes are preferred due to some advantages such as less space and energy requirement, ability to operate at lower hydraulic retention times, high sludge age and high biomass concentration. In biofilm systems, a concentration gradient occurs along the biofilm thickness. Since it allows the development of different microorganisms throughout the biofilm thickness, there are microorganisms that are better protected against toxic molecules in the innermost layer, while a colony in which more sensitive microorganisms are formed in the uppermost layer is known.

The integrated fixed film activated sludge process (IFAS), which is among the dependent growing processes, has come to the fore in recent years. The main purpose of an IFAS treatment is to provide additional biomass within the reactor volume of the activated sludge treatment to improve the capacity or performance of the system. IFAS (Integrated Fixed Film Activated Sludge) offers a performance increase of around 40% without adding new aeration tanks to existing systems. IFAS adds high surface area to the activated sludge pool. This media/surface area provides additional biomass and increases the growth rate of microorganisms. This not only increases the sludge age, but also ensures high performance of the treatment efficiency. Treatment success is improved by a decrease in the sludge volume index (SVI) relative to constant film growth.

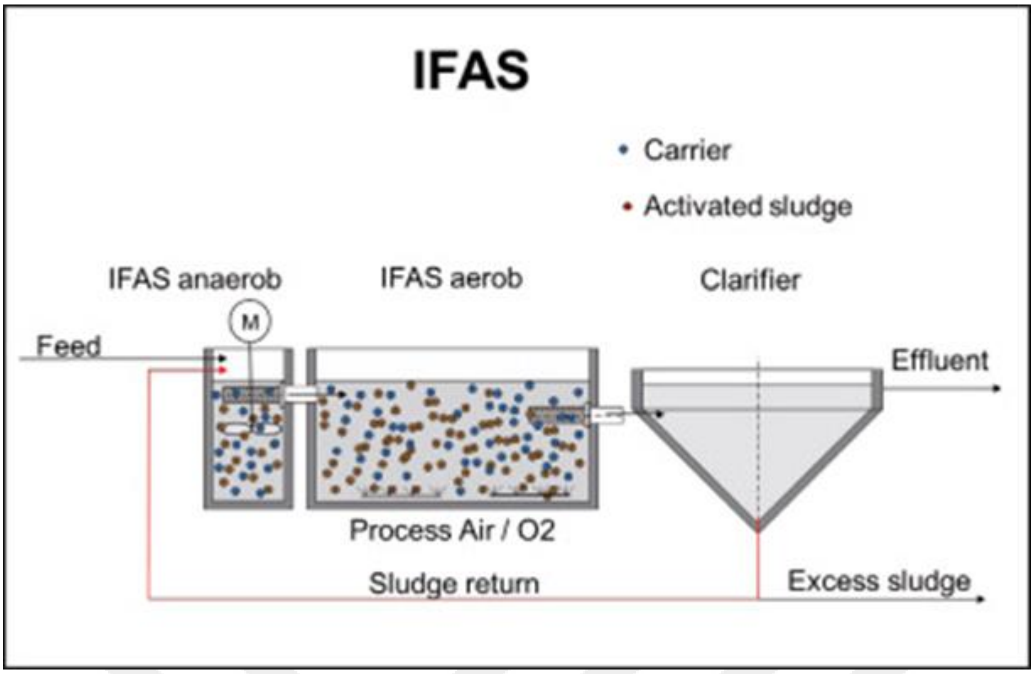

Figure 2.3 : IFAS Flow Chart.

In existing treatment plants that need to increase nutrient removal, ilthe IFAS approach has been universally regarded as a better choice. Because of the environment and biomass it supports, aerobic purification procedures can be carried out in a smaller volume, allowing for the conversion of some of the avaable tank capacity to an anoxic zone or the consolidation of an anaerobic zone for biologically improved phosphorus removal. Because clarifiers are not controlled for increasing mixed liquid concentration, greater capacity is achievable even if there are hydraulic constraints with an increase in capacity. In this way, IFAS offers a realistic and frequently cost-effective alternative to updating treatment plants in small areas that need to increase their performance.

Almost any process flowchart and reactor arrangement can be used with the IFAS method. It has mostly been utilized to boost biochemical oxygen demand (BOD) removal and nitrification in the aerobic zones of purification processes. As a result, the modified Ludzack-Ettinger process has been used in the majority of IFAS implementations. On the other hand, depending on the kind of environment, IFAS has been used to improve denitrification in anoxic zones. Although IFAS can be used in conjunction with a biologically enhanced phosphorus removal (BEPR) process, media was not employed in the anaerobic zone since the BEPR mechanism relies on biomass being vented to different anaerobic and aerobic conditions. However, some study has been done on the use of IFAS in an anaerobic zone to boost the generation of key fatty acids needed for BEPR.

The type of reactor layout that can be adapted to IFAS, as previously stated, can also be altered. The IFAS method has been employed in both full-mix and plug-flow reactors, although depending on the type of media used, each reactor type has its unique design application. Batch reactor sequencing has also been done using the IFAS method.

Because both processes employ the same type of media, the IFAS process is consistently blended with the moving bed biofilm reactor (MBBR) process. MBBR, on the other hand, is a true fixed film process because it does not consolidate a reversible activated sludge (RAS). The IFAS method uses a return sludge and keeps the mixed liquid concentrations that are typical of activated sludge (Figure 2.4).

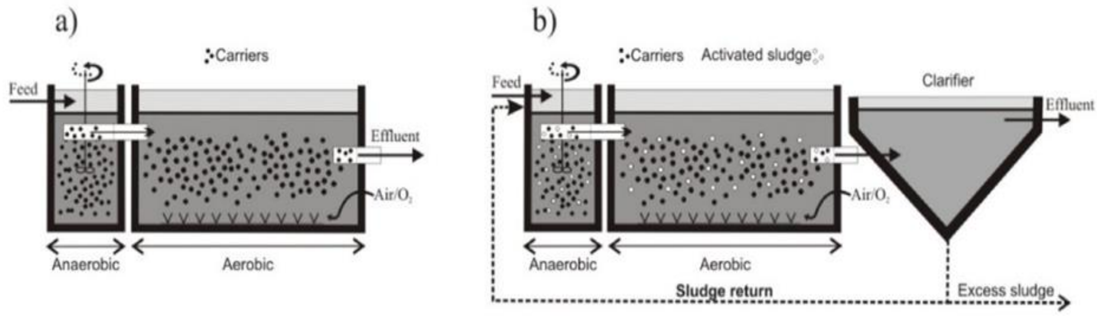

Figure 2.4 : Return Sludge System.

Advantages of IFAS system:

- Environmentally friendly, impact and aging resistant PP material is the most common production source.
- Provides simple renewal opportunity under operation.
- IFAS provides optimum water circulation with the vertical biomedia channels it has designed.
- Increases sludge age and active biomass without extra tanks.
- As the fixed film is not affected by bulky or point sludge, it creates increased system robustness.
- It gives the system better sludge settling properties.
- Provides optimum surface area for biofilm growth.
- Additional biomass for treatment without increasing solids loading to final clarifiers.
- High rate of treatment processes are possible, thus allowing more treatment in a smaller area.
- Simultaneous nitrification and denitrification

The disadvantages of the IFAS system can be stated as follows;

- Odor potential (if the tank is dewatered),
- Additional operating accessories,
- Required to change the location of the medium,
- Improved head loss associated with media holding screens.

Biofilms have been created using a variety of media, and some varieties have become standard in the industry. Media types can be classified as either fixed or free floating. Woven media in a string or hexagonal pattern is considered fixed media. In the activated sludge pool, the fixed medium is mounted on the frames and remains immobile. The free-floating media could be sponge cuboids or little plastic carrier pieces that look like wagon wheels.

Figure 2.5 : Different Media Types.

In an IFAS system, basically any fixed film media can be employed. Sheets of plastic material and trickling filter media were utilized experimentally at the start of IFAS's growth. Specific surface area (SSA), clogging susceptibility, ability to manage development on the media, durability, mounting requirements, and operator needs are all factors that influence a medium's potential usefulness.

The goal of an IFAS system is to improve BOD and nitrogen removal over that which can only be accomplished with the use of MLSS. In comparison to activated sludge and MBBRs, the consolidation of biofilm and removals in mixed liquor increases the complexity of IFAS system design. Membrane bioreactors with low MLSS concentrations in municipal power applications have limited mixed liquor removal and can be constructed as authentic biofilm systems. Integrated fixed-film activated sludge systems, on the other hand, must accept the biofilm's interaction with the mixed liquor.

2.2.1.1 Parameters affecting the removal of organics in the biofilm of integrated fixed film activated sludge systems

1. Biofilm flow rates

The rate at which a specific substrate or electron acceptor is moved across the liquid biofilm interface is known as biofilm flow rate. Gallons of substrate removed per square meter of biofilm surface per day ($g/m^2.d$ or $kg/1000\ m^2.d$) are the most used flux units. The biofilm surface is the area of the biofilm developing on the medium; it is not the uncoated media's surface area. COD, dissolved oxygen, oxidized nitrogen, ammonium nitrogen, inert solids, and volatile suspended solids are some of the factors that can be used to calculate flux ratios (VSS).

2. Biofilm removals per unit tank volume

The removal per unit of tank volume with the medium is determined by the biofilm specific surface area (square meter biofilm surface per cubic meter of tank volume) and the media fill %, in addition to the biofilm flow rate.

2.2.1.2 Parameters affecting the removal of mixed liquor suspended solids

The elimination of COD per unit of tank capacity in the IFAS system increases with the increase in MLVSS and the substrate and dissolved oxygen concentrations in the mixed liquor in activated sludge systems. An increase in mixed liquor raises MLVSS at the same tank volume. This enhances the COD uptake rate ($kg/m^3.d$) in MLVSS, lowering the quantity of COD that the biofilm must remove. This cuts down on the amount of biofilm surface area required.

The combination of an integrated fixed film activated sludge system and a membrane bioreactor (MBR) system is the study's fundamental concept. The major goal of this system is to expand the system's capacity and performance by adding more biomass to the reactor, which uses the same activated sludge process.

2.3 IFAS Application in MBR Systems

During the 1940s, trickling filters were frequently utilized for secondary wastewater treatment. Fixed film systems were less popular in the 1950s as suspended growth techniques (e.g. activated sludge) became more popular.

There were various innovations and researches on biofilm systems in the early 1980s, and fixed bed reactors became preferred due to the potential for energy savings. To be employed in trickling filters, new, flexible, and beneficial synthetic filter materials (crossflow plastic, horizontal redwood, and random plastic) are being developed. Because these systems are simple to operate and withstand peak loads, have a low rate of biological solid change, and require little energy, interest in them has grown, and they have begun to be employed alone or in combination with other systems. In most cases, biofilm systems are utilized to remove organic materials from wastewater. In recent years, these systems are also used for nitrogen and phosphorus removal.

Despite the fact that many large cities have their own sewage systems and wastewater treatment plants, smaller towns and rural areas do not. To safeguard clean water reservoirs such as lakes, rivers, and other bodies of water, wastewater from low-population areas should be cleaned before being discharged to the receiving body.

The popularity of the compact biofilm treatment system has grown as low-population areas prefer simple, easy-to-operate, and low-cost systems for the treatment of home wastewaters. Compact biofilm treatment plants can be built with the least amount of mechanical equipment and with the least amount of operation management and maintenance.

Biofilm is a layer formed by microorganisms adhering to the surface of a solid material. Biofilm begins to form on the filter medium as wastewater is fed into the system. Biofilm is a gel-like, viscous, and sticky covering formed by a wide variety of living microorganisms in large numbers.

90% - 99.9% of the biofilm in many natural water resources (particularly those with a large surface area and low nutrient concentration) is made up of bacteria.

Biofilms can be found on streambeds, groundwater aquifers, lake bottoms, water transmission pipes, and submerged ship sections. Biofilms are commonly employed in trickling filters, rotary disc filters, and submerged filters in Environmental Engineering. Since biofilms have gained popularity in nature and engineering designs over a broad range, research on the issue has accelerated.

The term "hybrid" can be used to describe any form of treatment method that incorporates elements from several different technologies. The main goal of this section of the thesis is to define and evaluate hybrid processes, particularly the integrated fixed-film activated sludge (IFAS) process. The fixed-film and traditional suspended-growth activated sludge treatment techniques are combined in this procedure.

The primary goal of an IFAS process is to provide more biomass within the reactor volume of an activated sludge process in order to increase the system's capacity or improve its performance. Because the biomass is fixed on a media system, the suspended growth mixed liquor concentrations are not raised, and the accomplishment of the downstream final clarifiers is not impaired by an increase in the solids loading rate. When compared to fixed-film growth, a drop in the sludge volume index (SVI) drives clarifier performance in many cases.

As a result, in existing treatment facilities that must consolidate nutrient removal, the IFAS technology is often recognized as a superior alternative. Because the media and biomass it supports enable aerobic treatment operations to be completed in a smaller volume, a portion of the existing tank capacity can be changed to an anoxic zone, or an anaerobic zone can be consolidated, resulting in biologically improved phosphorus removal. Even though an increase in capacity would be limited by hydraulic restrictions, extra capacity is possible because the clarifiers are not supervised in response to the higher mixed-liquor concentration. In this way, IFAS provides a practical and frequently cost-effective way to boost the performance of treatment facilities that are located on small sites.

The IFAS process can be applied with almost any process flow diagram and reactor layout. It has mostly been used to increase the elimination of biochemical oxygen demand (BOD) and nitrification in aerobic treatment zones. As a result, the modified Ludzack-Ettinger type technique has been used in the majority of IFAS applications. IFAS, on the other hand, has been utilized to improve denitrification in anoxic zones depending on the kind of media.

The type of reactor arrangement that can be converted to IFAS is also adjustable, as previously indicated. The IFAS technique has been used in both complete-mix and plug-flow reactors, despite the fact that each type of reactor has its own specific design application based on the type of media used. The IFAS approach has also been used to sequence batch reactors.

Because both procedures use the same type of media, the IFAS method is frequently confused with the moving-bed biofilm reactor (MBBR). An true fixed-film technique, on the other hand, does not accumulate a return activated sludge (RAS). The IFAS method uses a return sludge and maintains mixed-liquor concentrations similar to those found in a traditional activated sludge process.

Both the detached biofilm and the activated sludge flocs must be separated in the secondary settler in IFAS systems (operated with sludge recirculation). Because of the differences in operating parameters between MBBR and IFAS, the secondary settler separates a different quantity of SS. In MBBR, approximately 150–250 mgSSL-1 must be separated in the secondary settler, with the latter being nearly 20 times lower than in IFAS systems. Separation procedures such as settling, flotation, micro-screening, medium filtration, and membrane filtration can all be employed with pure MBBR and IFAS. Several researchers have noted that the IFAS design improves the settling qualities of activated sludge.

3. MATERIAL AND METHOD

3.1 Characterization of Wastewater

In the laboratory scale experiment, synthetic wastewater prepared as feed wastewater was used. Characterization information is given in the table below.

Table 3.1 : Synthetic wastewater receipt used in the experiment (Ergön-Can et al., 2017).

Parameter	Unit	Value
Glucose	mg/L	400
Bactopeptone	mg/L	115
$(NH_4)_2SO_4$	mg/L	104,8
KH_2PO_4	mg/L	21,75
$MgSO_4$	mg/L	15,63
$CaCl_2$	mg/L	2,45
$MnSO_4$	mg/L	1,8
$NaHCO_3$	mg/L	255,5
MLSS	mg/L	5580
Feed COD	mg/L	460
Seeding Sludge	-	Paşaköy WWTP

3.1.1 COD measurement

In order to find the COD removal efficiencies, COD analysis was performed by periodically taking samples from the feed wastewater from the inside of the reactor and from the effluent treated permeate water. As a method, 5220-C closed reflux method, one of the standard methods, was used. Prepared according to the chemical method to be used, 2.5 ml or 2,5 ml diluted sample, 1.5 ml standard $K_2Cr_2O_7$ solution and 3.5 ml H_2SO_4 reagent were added to the COD tube.

The tubes were placed in a Hach brand DRB 200 model thermoreactor at 150ºC for 2 hours. After 2 hours, the samples were allowed to cool to room temperature.

The cooled samples are taken into a flask and 1-2 drops of ferroin indicator are added and titrated with Iron Ammonium Sulphate (DAS) solution until a brick red color is obtained. Molarity of DAS Solution that used in experiment was calculated by Equaiton 3.1. COD values were calculated by Equation 3.2.

$$DAS\ Molarity = \frac{Volume\ of\ titrated\ Potassium\ Dichromate * 0{,}1}{DAS\ Volume} \qquad (3.1)$$

$$COD\ \left({}^{mg}/_{l}\right) = \frac{(A-B)*M*8000}{sample\ volume\ (ml)} \qquad (3.2)$$

A: Ammonium Iron(II) consumption for blank sample

B: Ammonium Iron(II) consumption for sample

M: Molarity of Ammonium Iron(II)

3.1.2 Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) measurements

The TSS and VSS values in the reactors were monitored at regular intervals. For this purpose, gravimetric measurement method was used.

The filter is placed in the filtration set. On the one hand, vacuum is applied and the filter is washed several times with distilled water. The vacuum application is continued until there is no water left in the filter and the washing water is poured. The filter is dried in an oven at 103-105°C for one hour and kept in a desiccator so that it is not affected by the humidity in the air and completely dried. The filter, which has reached constant weighing, is carefully taken from the desiccator and weighed.

20 ml is taken from the sample and filtered by applying vacuum. The filter is carefully removed from the apparatus with the help of a forceps and placed in an aluminum container. Drying is done at 103-105°C in an oven for at least 1 hour. After cooling in a desiccator, it is weighed. The filter and the residue on it are then burned in an oven at 550°C for 30 minutes. After cooling in a desiccator, it is weighed. TSS and VSS calculations were made by Equation 3.3 and 3.4.

$$TSS\left({}^{mg}/{}_{l}\right) = \frac{(A-B)*1000}{sample\ volume\ (ml)} \tag{3.3}$$

$$VSS\left({}^{mg}/{}_{l}\right) = \frac{(A-C)*1000}{sample\ volume\ (ml)} \tag{3.4}$$

A: Membrane filter + filtrated solid mass (mg)

B: Filter tare (mg)

C: Filter tare + inorganic residual mass (mg)

3.1.3 Total nitrogen

Ammonia, nitrate and nitrite are important compounds in the nitrogen cycle. Ammonia can turn into gray water through cleaning products and is commonly used as a fertilizer. In the nitrification process, through biological processes, ammonia is converted to nitrate and then to nitrite before being denitrified to form nitrogen gas. Denitrification is carried out by anaerobic bacteria. These levels are reported as ppm or mg/L.

In this study, ammonia and total nitrogen (TN) measurements were performed. Ammonia measurement was measured in accordance with the APHA standard, and TN measurement was measured with kits with a range of 5-40 mg/L supplied from Hach-Lange.

The measurement ranges determined for the kits show that if the results are between these values, it gives correct results. After the necessary procedures for the kits were applied, measurements were made with the Hach-Lange branded spectrophotometer in the ITU MEM-TEK Laboratory.

3.1.4 Total phosphorus

Total phosphorus analysis carried out according to the Standard Method (APHA, 2005). It was measured at a wavelength of 507 nm on a DR 5000 Hach Spectrophotometer with Hach-lange brand LCK 350 experiment kits.

3.1.5 Turbidity

Turbidity is a property of appearance, specifically a measurement of how the sample transmits light. Turbid water does not transmit light very well. This is due to light scattering due to colloidal particles in the water. Its units are standardized measurements known as Nephelometric Turbidity Units (NTU).

Blurring is a measurement primarily associated with aesthetics. However, turbid water usually has higher levels of BOD, COD, and pathogens. It is important to note that it is quite difficult to relate turbidity to TSS, as light transmittance depends on both the size and number of colloidal particles present. It is measured in units of mass per volume of TSS, while turbidity is determined by NTU. Two samples with the same TSS levels may have different turbidity readings if they have different particle size distributions.

3.2 IFAS-MBR process

The laboratory scale MBR system used within the scope of the thesis is controlled by a full automation system. Three different types of membrane modules formed from the produced membranes were placed in the same reactor.

The dissolved oxygen probe instantly measures the oxygen level in the reactor and the oxygen concentration in the MBR system is entered into the PLC system. The air pressure given to the diffusers covering the bottom of the MBR tank is adjusted by the valves connected to the air line. The instantaneous pH values in the MBR are measured with the pH probe and the temperature values of the reactor are measured with the temperature probe.

Keller brand 23E model external diaphragm pressure gauge was used to measure and fix the pressure at the desired value in the MBR. The pressure transmitter is resistant to pressure in the range of 0.2-1000 bar and can be measured in the range of 0-100 bar.

The measurement of the level in the system is provided by level sensors. In this way, the level in the reactor can be measured instantly. When the sludge level exceeds the desired level, the level sensor automatically detects this situation and stops feeding into the system by activating the overflow signal.

The filtrate obtained from the system is collected in containers on sensitive scales. With these scales, the amount of filtrate obtained from the membranes is transmitted to the PLC system. Flow rate is obtained by proportioning the amount of filtrate collected with the unit time.

Adjusting the amount of filtrate drawn from the membrane can be adjusted with flow meters as well as with the capacities of vacuum pumps. In this method, the flow rate can be adjusted by ensuring that the vacuum pump works at the desired capacity in the PLC system. In the MBR system, there are three vacuum pumps, one for each membrane module.

In addition to pulling the filtrate from the membrane, vacuum pumps are also used for backwashing the membranes by using the permeate water with 10-minute cycles (9 min 15 LMH filtration, 1 min 20 LMH backwash). During a certain time entered into the PLC system, the vacuum pump operates in the opposite direction of its normal operation and performs the washing process. Thus, some of the blockages are prevented and the filtration efficiency of the membrane remains at the desired levels. Feeding and vacuum pumps are peristaltic and have the capacity to provide 1-250 ml/min flow rate.

The level control in the reactor can be made by entering the desired sludge level value in the MBR into the PLC system. As the permeate water is withdrawn from the reactor with the help of the membrane, the level drops below the entered value and the system automatically starts the feeding pumps. The feeding pumps continue to operate until the level reaches the desired value again and the feeding pumps automatically stop when the desired height is achieved.

The laboratory scale MBR system used in the thesis is connected to the PLC system and all controls can be made with this PLC system. In the MBR system, there are two different processes: filtration and backwashing. The entire system diagram can be seen on the PLC screen and the operating parameters related to the units can be changed from this screen when necessary. All operations such as backwashing, chemical dosing, opening and closing of valves and adjustment of pressure are carried out through the PLC control system.

3.2.1 Manufacturing of IFAS module

IFAS modules with the same material, different surface areas and characteristic features were created according to the IFAS modules are placed to cover 40 percent of the performance tank volume. In this way, it will be tried to analyze which one is more efficient when the membrane works integrated with the biorector.

Figure 3.1 : Two Different IFAS Module Fibers.

3.2.2 Manufacturing of MBR module

Reinforced hollow fiber membranes need to be made into modules. For this reason, according to the calculation given below, a test module with a surface area of 0.137 m^2 was prepared from the membranes as shown in Figure 3.2. 104 fibers were used for the module working from outside to inside. Fibers were placed in the test module and left for 2 days for the adhesive to dry.

Membrane fibers calculations are given below:

System flow rate is 50 L/day.

According to the literature data, the selected flux value in the treatment of wastewater with domestic characterization varies between 14 – 16 L/m^2H. The flux value chosen in line with these data is 15 L/m^2H.

According to the calculations given below, the required membrane area was determined as 0.137 m^2.

$$Required\ Membrane\ Area\ (m^2) = \frac{\text{Average Flow Rate } (m^3/\text{h}) * \ 1000}{\text{Flux (lmh)}}$$

$$Required\ Membrane\ Area\ (m^2) = \frac{0{,}002\ (m^3/\mathrm{h}) *\ 1000}{15}$$

$$Required\ Membrane\ Area = 0{,}137\ m^2$$

Membrane length was chosen as 20 cm. The area of one membrane fiber was calculated as:

$$Membrane\ Fiber\ Area\ (m^2) = \frac{0{,}0021 *\ \pi *\ (\mathrm{Fiber\ Lenght\ (m)} * 1000)}{1000}$$

$$Membrane\ Fiber\ Area\ (m^2) = \frac{0{,}0021 *\ 3{,}14 *\ (0{,}2 * 1000)}{1000}$$

$$Membrane\ Fiber\ Area = 0{,}0013\ m^2$$

The area of one 20 cm long membrane fiber is calculated as 0,0013 m^2.

The required number of membrane fibers was calculated as follows:

$$Required\ Membrane\ Quantity\ (pc) = \frac{Required\ Membrane\ Area\ (m^2)}{Membrane\ Fiber\ Area\ (m^2)}$$

$$Required\ Membrane\ Quantity\ (pc) = \frac{0{,}137\ (m^2)}{0{,}0013\ (m^2)}$$

$$Required\ Membrane\ Quantity\ (pc) = 104\ Fibers$$

Figure 3.2 : Membrane Module.

3.3 Laboratory Scale System

3.3.1 Equipments of laboratory scale system

The elements of the laboratory scale system and their intended use are given in Figure 3.3.

Figure 3.3 : Pilot System.

It is the system element where all controls related to the system can be made and thus can be operated as desired. It can be operated automatically as well as manually.

Figure 3.4 : PLC Screen.

Synthetic wastewater is fed to the tanks with the feed pump, and the activated sludge in the MBR tank is transferred to the IFAS tank in order to control the MLSS concentration by means of to the recirculation pump.

Figure 3.5 : Feed Pump(left) and Re-Circulation Pump(right).

Blower is used to bring the dissolved oxygen necessary for the microorganisms to continue their activities to the tank. Within the scope of the experiment, 30% capacity of the blower was operated.

Figure 3.6 : Blower.

IFAS modules are placed on the left side of the tank, which is divided into two in the middle. On the right is the MBR module. In this way, wastewater will first contact IFAS modules and then be transferred to the MBR tank by flume.

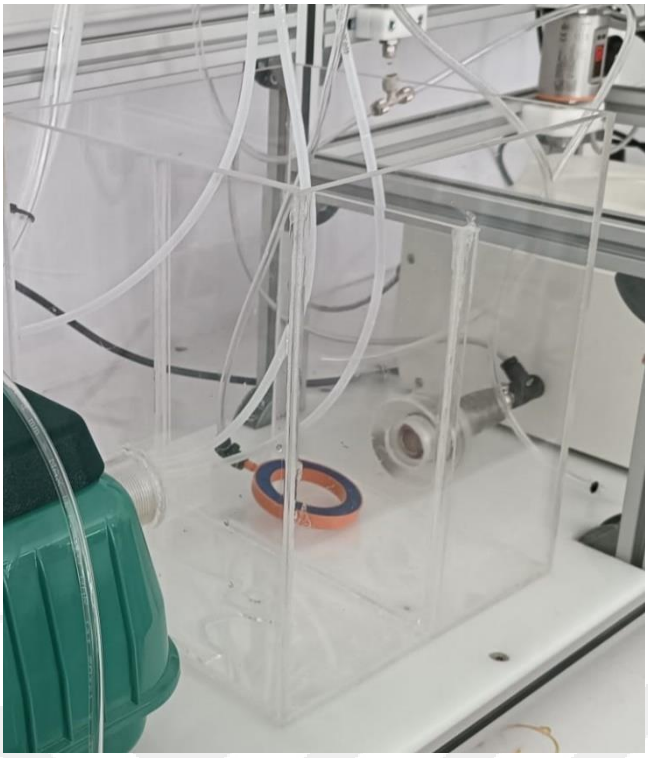

Figure 3.7 : IFAS-MBR Tank (Left side IFAS, right side MBR).

Unlike normal pumps, with lobe pumps the flow of water can be provided in both directions. In this way, backwashing of the membrane module, which filtration for nine minutes, can be ensured from the same line for one minute.

Figure 3.8 : Lobe Pump.

In order to provide filtration in the domestic wastewater operating flow, the value set with the flowmeter can be controlled. In addition, a leak that may occur in the membrane module can be detected with the flowmeter.

Figure 3.9 : Flowmeter.

3.3.2 Operation of laboratory scale system

The modules placed in the IFAS tank in order to analyze their efficiency are shown below.

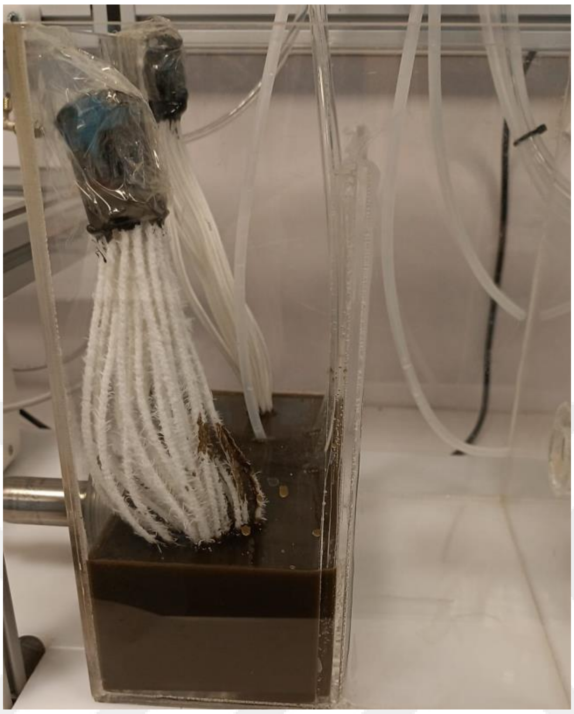

Figure 3.10 : IFAS Modules placed in the tank.

The MBR module, with vacuum and ventilation lines connected, is placed in the tank as in the figure. After the IFAS tank, the wastewater will be flumed into this section.

Figure 3.11 : MBR Modules placed in the tank.

After inoculation with the sludge obtained from Paşaköy wastewater treatment plant, it is fed to the IFAS tank by means of a domestic synthetic wastewater feeding pump. In the experiment, which is controlled by the PLC screen, the wastewater slurry from the IFAS tank to the MBR tank is collected into the permeate tank after being purified by the lobe pump.

In the pilot system, which is operated under the conditions of a domestic wastewater treatment plant, the system is monitored by taking samples from the feed water, activated sludge and permeate water.

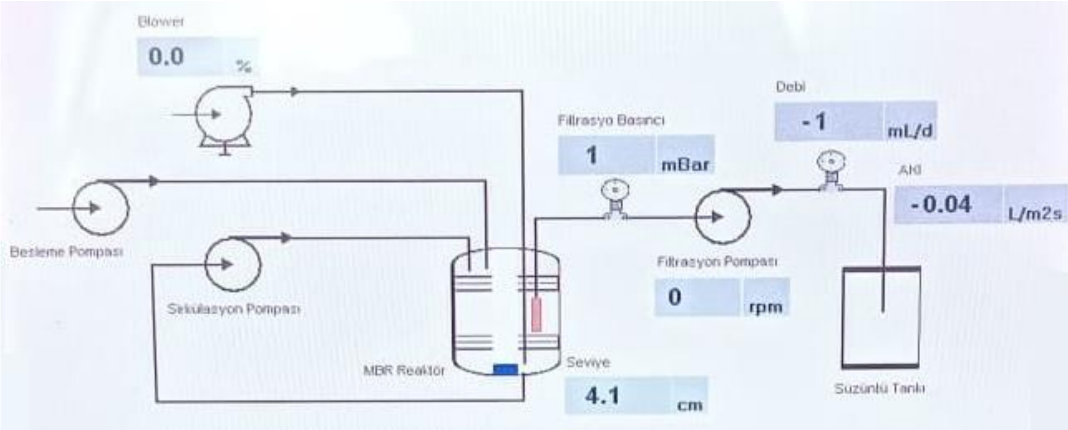

Figure 3.12 : Flow Chart of Laboratory-Scale System.

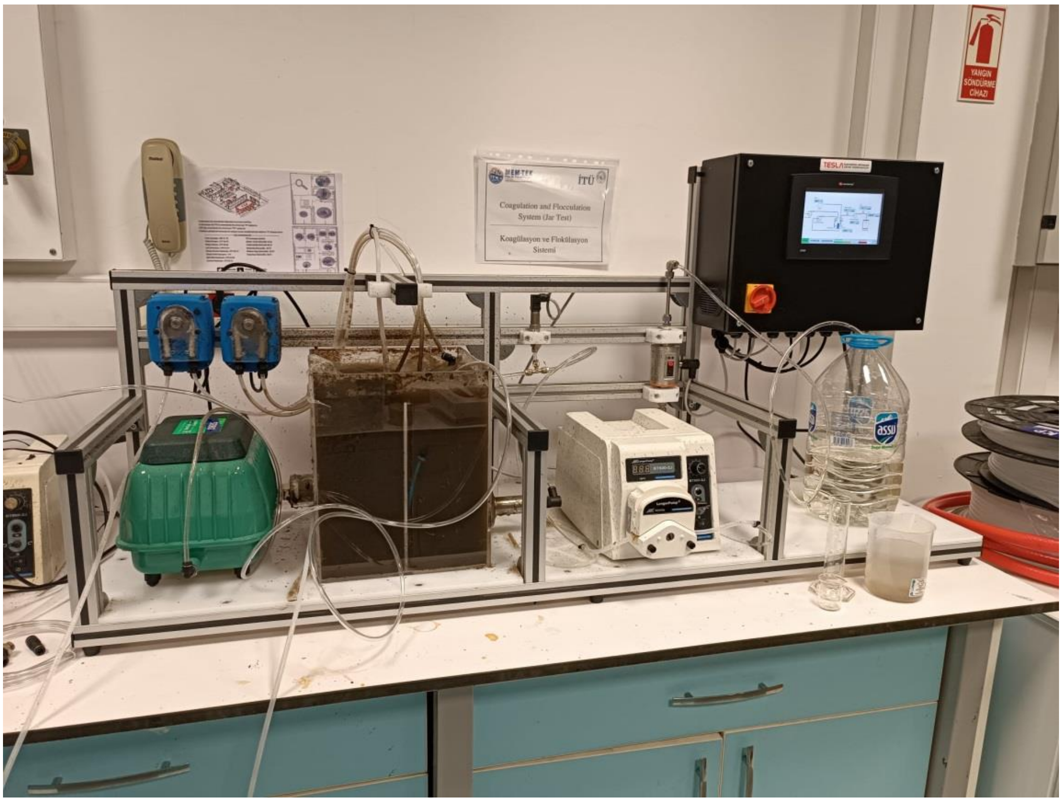

Figure 3.13 : Operated Laboratory-Scale System.

3.4 SEM Analysis

Scanning Electron for determination of surface properties of membranes Microscopy analysis was performed. The device used in the measurement FEI brand Quanta It is a model of Feg 250 and MEM-TEK (National Membrane Technologies Research Centre). Membrane samples were soaked in distilled water before measurement is preserved. However, the measurements of the samples in the SEM device are dry and It is carried out in conditions where the ambient humidity is very low. Therefore, the membrane samples were taken out of distilled water, first 30%, then 60% and 100%. It was washed in a solution containing ethanol/water mixture and dried at room temperature. Next, The samples were placed in the device-specific sample cells and the surfaces were determined with Au-Pt. covered in voltage and time. Au-Pt coating device and SEM device in Figure 3.14 shown.

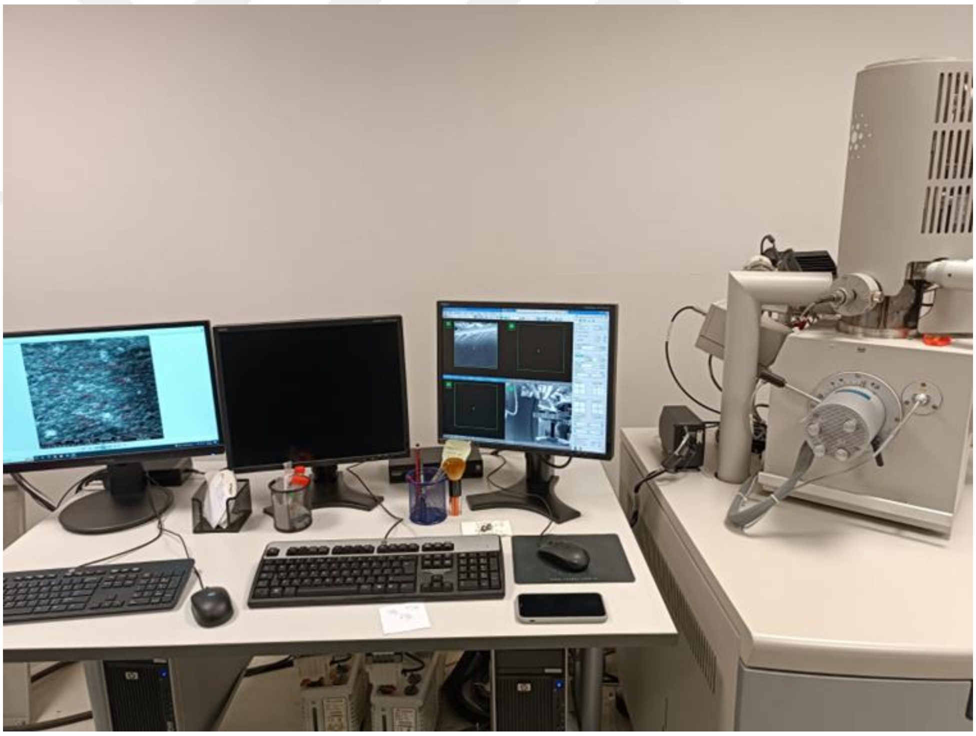

Figure 3.14 : SEM.

4. RESULTS AND DISCUSSION

According to the laboratory scale IFAS – MBR system test operating results, it has been observed that IFAS modules have various effects on the MBR system operation. IFAS material, due to its large surface area, allows MLSS to adhere on it, thus reducing the need for aerobic reactor volume. As indicated in the SEM images, IFAS material with rough surface retained more biofilm than IFAS material with smooth surface. In this context, the aerobic reactor volume can be kept lower in systems where IFAS material with a rough surface is used.

Although the output purpose of both MBR and IFAS systems is to reduce the space requirement of the treatment plants, the space requirement of the IFAS - MBR System is much lower compared to conventional systems. The space requirement of the IFAS – MBR system was also found to be lower compared to both fixed or moving biocarrier systems and MBR systems. It has been observed that the chemical washing frequency of the MBR system can be reduced due to the biofilm adhesion on IFAS carriers. In this way, it is thought that the lifetime of the membrane modules can be extended.

4.1 IFAS-MBR Analytical Results

Average influent and effluent characterization values are given in the table. The prepared synthetic wastewater sample has domestic wastewater characterization. The removal efficiency of the IFAS – MBR System is given in the graph.

Table 4.1 : Average Influent/Effluent Values of Parameters.

Parameter	Unit	Average Influent Value	Average Effluent Value
COD	mg/L	360	22,9
TN	mg/L	40	26
TP	mg/L	8,83	3,4
MLSS	mg/L	7155	-

The system was fed with synthetic wastewater. For this reason, there is no TSS value in the inlet wastewater. However, the MLSS concentration of the activated sludge taken from the Paşaköy Wastewater Treatment Plant was measured as 5580 mg/L. In this context, the MLSS concentration change graph of the MBR tank is given below (Figure 4.1).

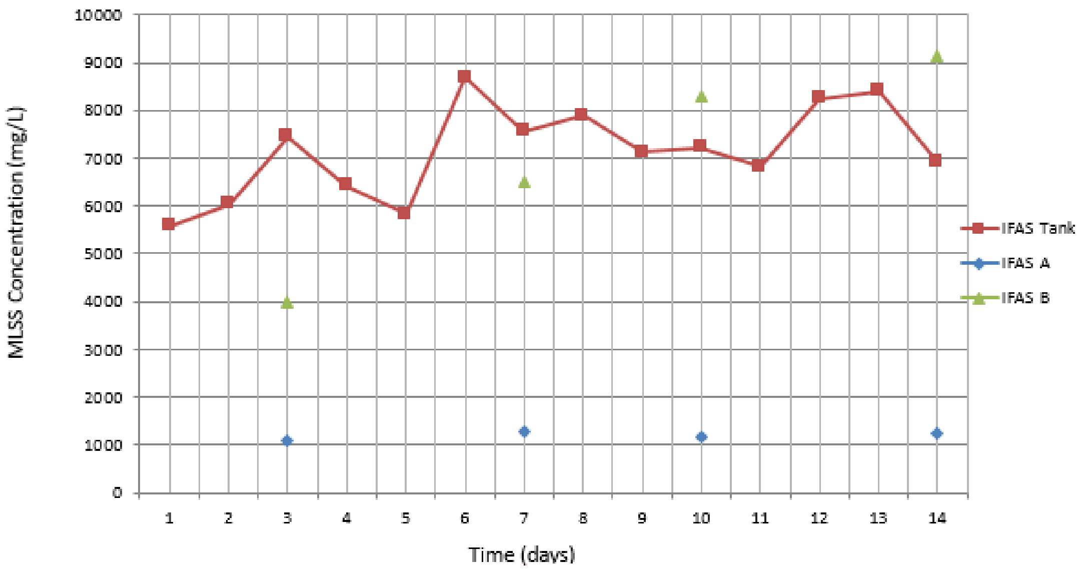

Figure 4.1 : Change in MLSS Concentration-Time Graph.

At the same time, since the TSS concentration at the MBR outlet was below 10 mg/L, TSS measurement was not performed in the effluent, and turbidity measurement was made. The turbidity change graph of the water sample taken from the outlet of the IFAS – MBR system is given below (Figure 4.2).

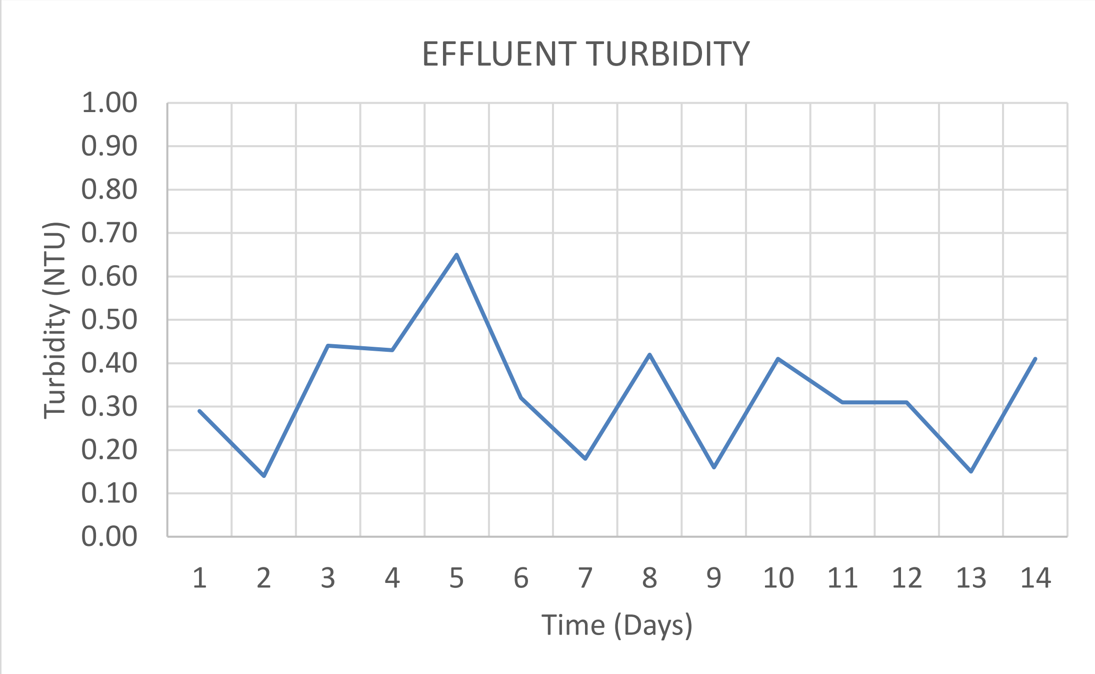

Figure 4.2 : Turbidity Effluent Graph.

4.2 System Performance Results

The filtration cycle of the MBR system is set to be 9 minutes of filtration and 1 minute of backwashing. In the given graphic (Figure 4.3), the change of filtration pressure (TMP) according to time, flux and flow rate values is prepared according to PLC data. Sudden pressure changes appearing in the graph indicate that the filtration has completed its 9-minute cycle and the 1-minute backwashing has begun. At the same time, the reason for the sudden decrease in flow and flux values is that backwashing has started. The pressure on the MBR is read as negative pressure, and an increase in pressure over time is observed when looking at the graph. Depending on this increase, the chemical washing process of the membranes is carried out.

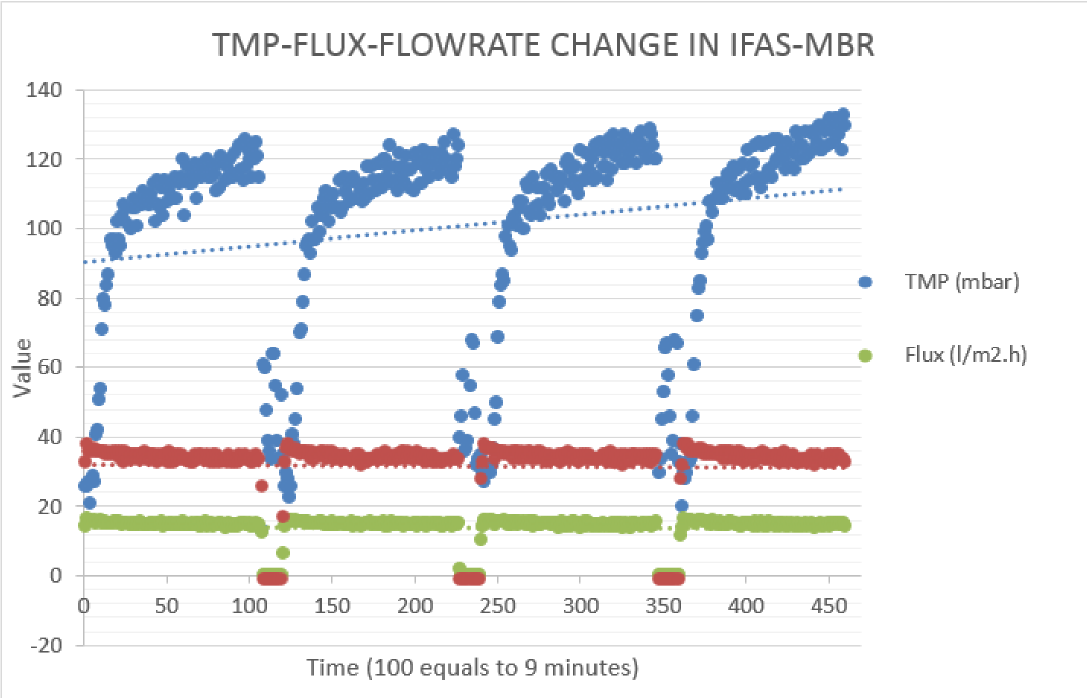

Figure 4.3 : Graph of TMP-Flux-Flowrate change in IFAS-MBR.

The 14-day removal efficiency graph is given below as a result of the laboratory-scale IFAS-MBR study (Figure 4.4.). According to this graph, efficiency values not deviate much from the average value. The high nitrogen removal observed on the fifth day can be explained as the result of the denitrification process that occurs with the formation of anoxic zone in the bottom layer of the biofilm accumulated on the IFAS module. The high phosphorus removal on the fourth day can be explained by precipitation due to the $FECl_3$ concentration present in the synthetic wastewater. As expected, efficiency values are generally high on the seventh day.

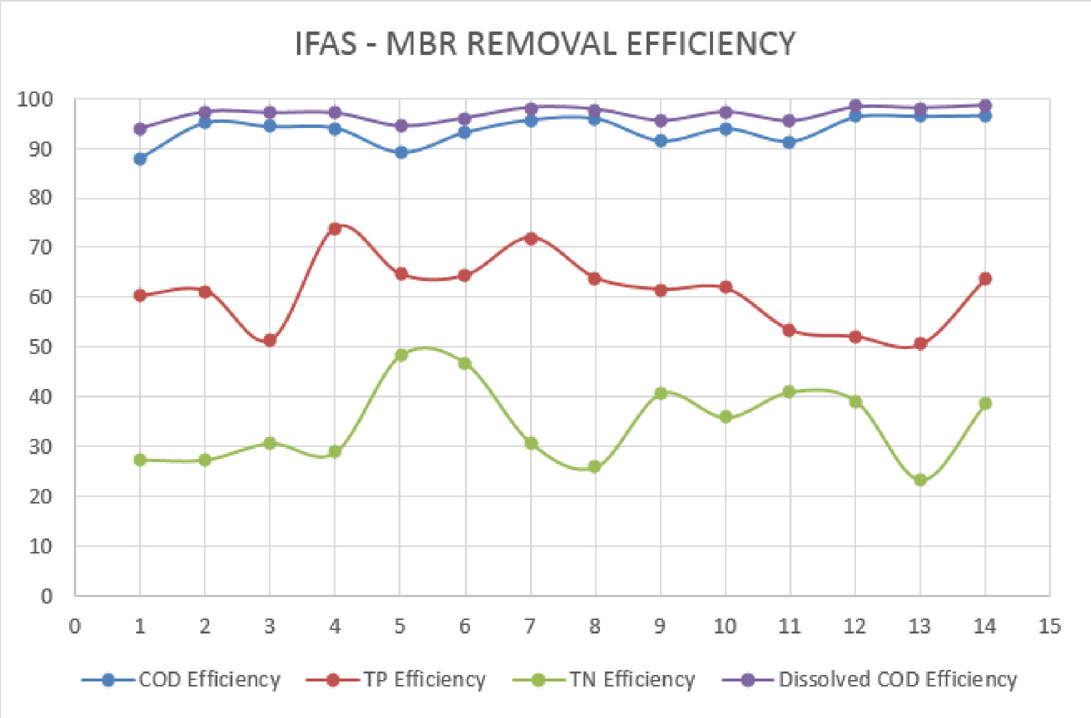

Figure 4.4 : Graph of IFAS-MBR Removal Efficiency.

As can be seen from the figure (Figure 4.5.), more biofilm adhesion was observed in IFAS B. The reasons for this are explained in detail in the next section. Certain sections were taken from IFAS modules and dried at room temperature for twenty-four hours. SEM analysis was performed with the dried sections.

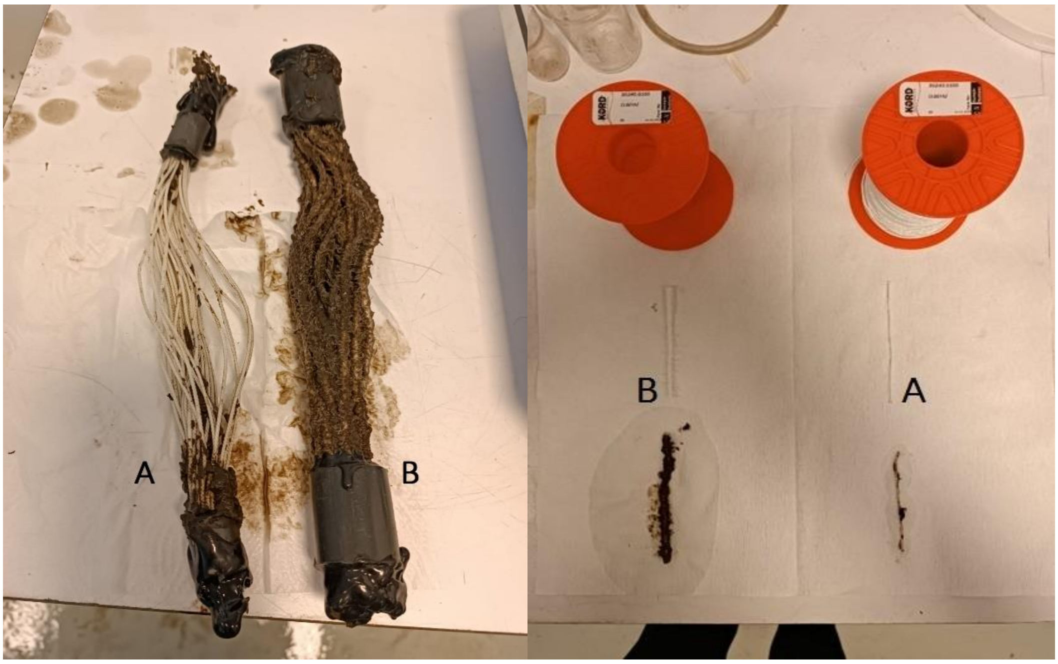

Figure 4.5 : IFAS Modules after lab-scale operation.

4.3 SEM Results

SEM imaging was performed at three particular magnifications. According to the SEM outputs, while the biofilm attach on the IFAS material with minor surface area was thin nevertheless it is seen on the fringed IFAS biocarrier with major surface area biofilm attach was thick and compact. It has been concluded that the reason for this result is the greater surface area on which the biofilm will adhere and the rougher texture in terms of texture (Figures 4.6, 4.7, 4.8, 4.9, 4.10, 4.11).

It has been determined that the biofilm adhesion on the IFAS modules and the clogging and accumulation in the membrane bioreactor are delayed and the economic life is extended. In addition, the need for costly inputs such as backwashing and membrane aeration is reduced by extending the filtration time. The use of biocarriers such as IFAS reduces the volume of aeration ponds compared to conventional wastewater treatment systems. It is also known that with the use of MBR in conventional systems, the required space requirement is reduced by half (Bengtsson et al., 2019). In this context, it has been seen that the required area can be significantly reduced as a result of the integrated use of IFAS and the MBR system. There are studies in the literature that with the increase in the thickness of the biofilm layer formed on the surface of IFAS, an oxygen-free environment (anoxic) is formed in the inner parts of the layer, and thus the nitrification process takes place (Albizuri et al., 2010).

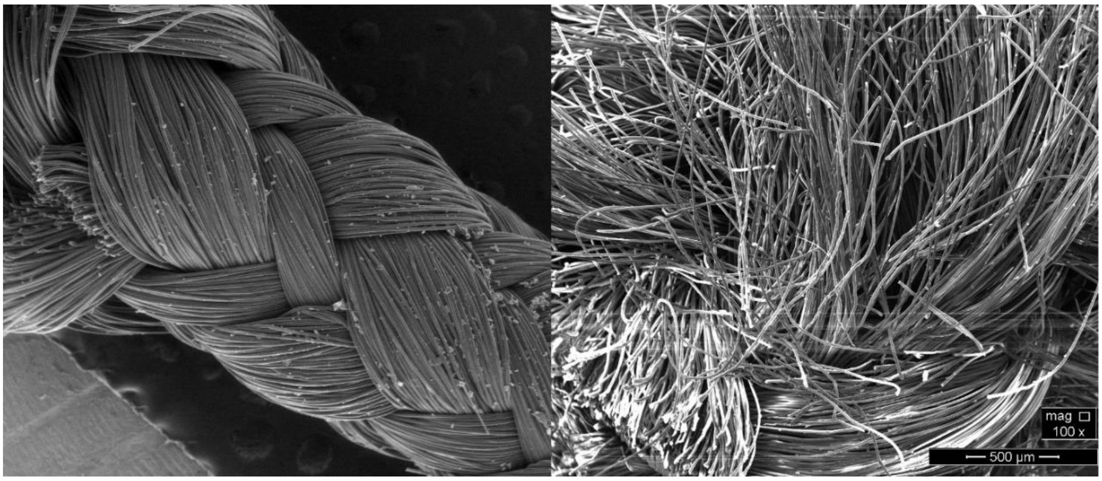

Figure 4.6 : Clean Media 100x Magnification.

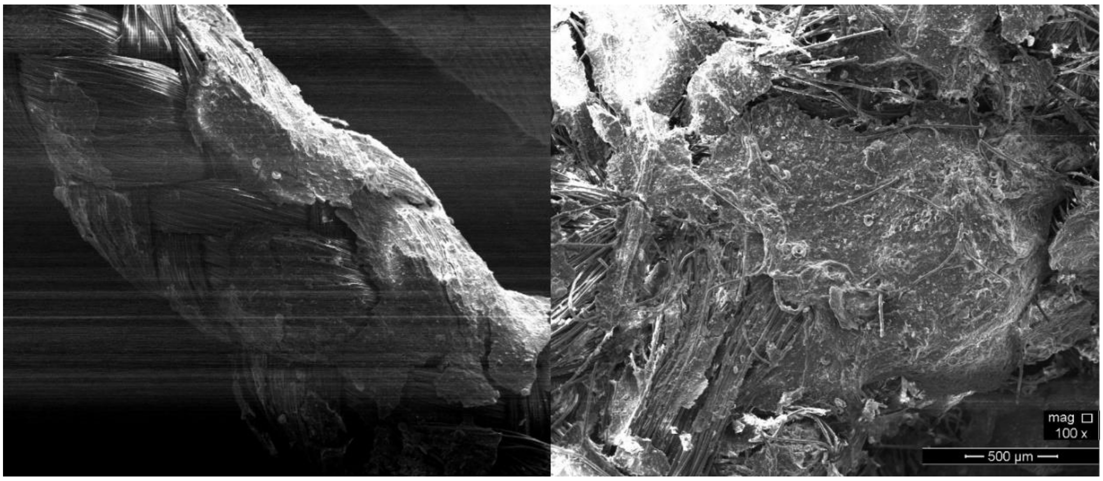

Figure 4.7 : Attached Media 100x Magnification.

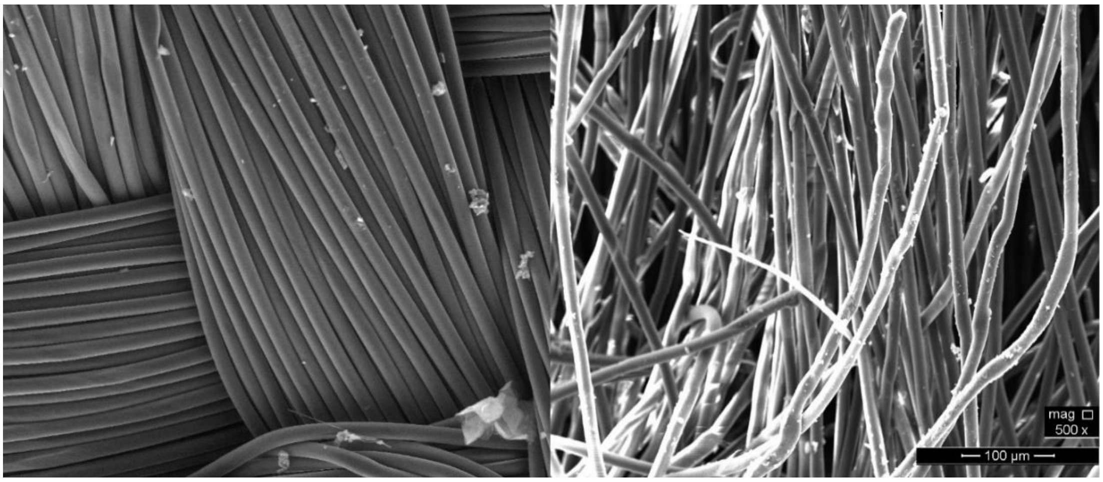

Figure 4.8 : Clean Media 500x Magnification.

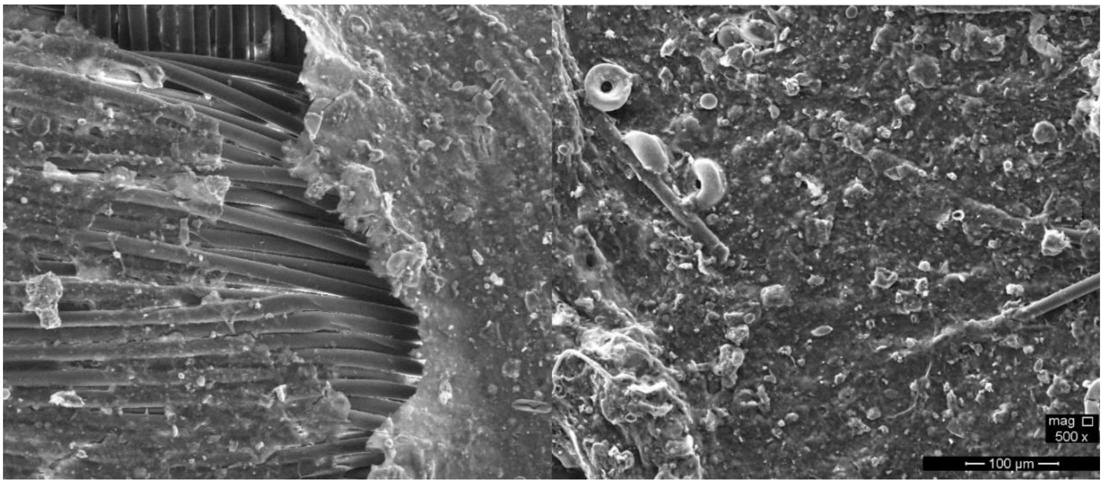

Figure 4.9 : Attached Media 500x Magnification.

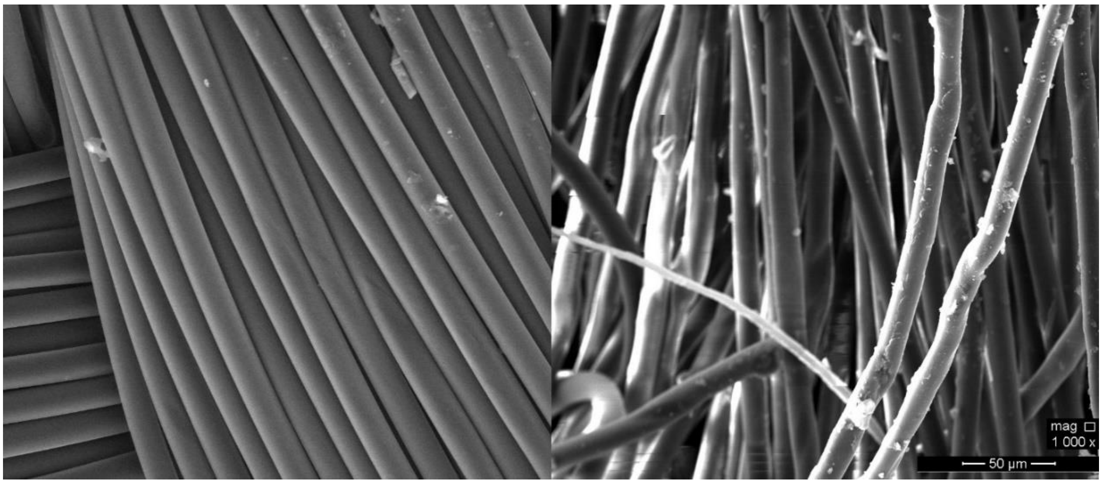

Figure 4.10 : Clean Media 1000x Magnification.

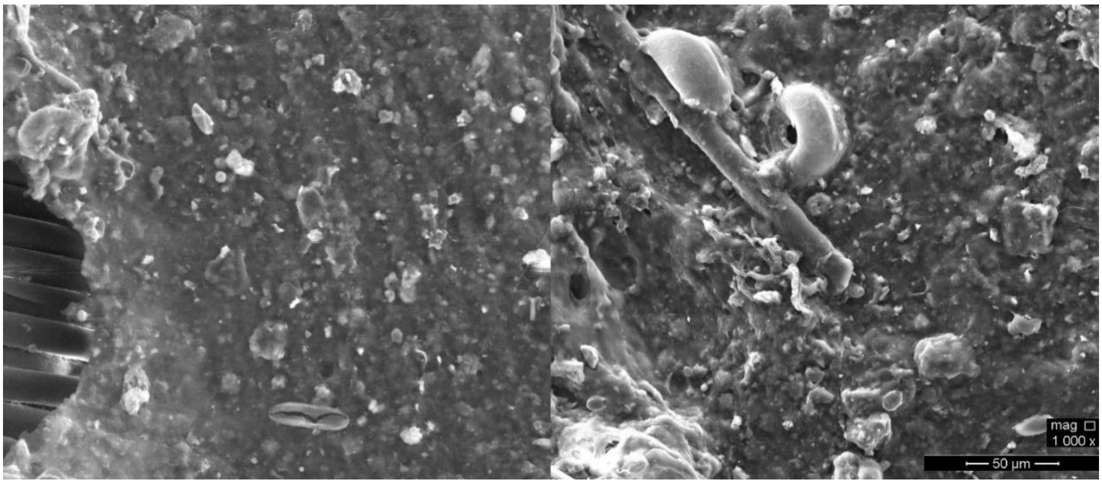

Figure 4.11 : Attached Media 1000x Magnification.

5. CONCLUSIONS

Nowadays, when the issue of water recovery gains importance, the need for recovery systems is increasing instead of conventional systems. In this context, the developed membrane bioreactor systems provide more wastewater recovery in less area. Thanks to the integration of IFAS systems into MBR systems, the need for space is minimized and it has been seen that wastewater with high pollutant concentrations can be recovered. In the future, it is envisaged to develop systems with higher efficiency by changing values such as IFAS material structure, surface area and geometric shape. In this study, it was observed that the biocarrier with a rougher structure and higher surface area had higher efficiency.

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