DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

URBAN WASTEWATER MANAGEMENT FOR SMALL COMMUNITIES IN TURKEY: DEVELOPMENT OF AN INNOVATIVE AND ONSITE TREATMENT SYSTEM

by
Sinem GÜNEŞ

January, 2021
İZMİR

URBAN WASTEWATER MANAGEMENT FOR SMALL COMMUNITIES IN TURKEY: DEVELOPMENT OF AN INNOVATIVE AND ONSITE TREATMENT SYSTEM

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled "**URBAN WASTEWATER MANAGEMENT FOR SMALL COMMUNITIES IN TURKEY: DEVELOPMENT OF AN INNOVATIVE AND ONSITE TREATMENT SYSTEM"** completed by **SİNEM GÜNEŞ** under supervision of **PROF. DR. AZİZE AYOL** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

....

Prof. Dr. Azize AYOL

Supervisor

....

Prof. Dr. Ayşe FİLİBELİ

(Jury Member)

....

Prof. Dr. Bülent KESKİNLER

(Jury Member)

Prof. Dr. Özgür ÖZÇELİK

Director

Graduate School of Natural and Applied Sciences

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Sinem GÜNEŞ

URBAN WASTEWATER MANAGEMENT FOR SMALL COMMUNITIES IN TURKEY: DEVELOPMENT OF AN INNOVATIVE AND ONSITE TREATMENT SYSTEM

ABSTRACT

With increasing population and industrialization, increasing water need for different use purposes, is the most important issue all over the world. An understanding of the wastewater nature, is a fundamental factor in the selection of treatment techniques. United Nations World Development Report (2017), indicates that discharging of wastewater without inadequate treatment plays a critical role as high operating and maintenance costs and high energy consumption in wastewater treatment plants. The classical treatment systems used for large settlements may not be economical for small settlements due to their large size and construction costs. Toprak, (2000) indicates that the cost per capita in the population of 1000 people is 2 to 4 times higher than the cost per capita in the population of 100,000.

Within the scope of this research project, it is aimed to develop an innovative reactor system for small settlements. For this purpose, wastewater passing through the filter system after SBR operation aimed suitable for domestic wastewater treatment, the different filtration times and optimization of operating conditions were examined during the study. To improve the quality of treated water, some textile materials with impregnated activated carbon into to effectiveness of activated carbon on treatment efficiency was investigated. In the project, evaluations made on the applicability of the prototype to be producing on a larger scale. Besides, for the implementation of this treatment system to be developed, a wastewater management model belonging to these settlements proposed by identifying the locations of the small settlements in Manisa, Gediz Basin.

Keywords: Small settlements, domestic wastewater treatment, filtration, modelling, wastewater management model

TÜRKİYE'DE KÜÇÜK YERLEŞİM YERLERİ İÇİN KENTSEL ATIKSU YÖNETİMİ: YENİLİKÇİ VE YERİNDE UYGULANAN BİR ARITMA SİSTEMİNİN GELİŞTİRİLMESİ

ÖZ

Artan nüfus ve endüstrileşmeye bağlı olarak, farklı kullanım amaçlarına yönelik olarak artan su ihtiyacı, mevcut su kaynaklarının korunumu, öncelikli konular olarak tüm dünyada en çok gündeme alınan ve üzerinde araştırma yapılan konular olarak kendini göstermektedir. Yeni çözüm önerileri atıksu arıtma tesislerinin sürdürülebilir olarak işletilmesi üzerine yoğunlaşmakla birlikte, atıksulardaki kirliliğin form değiştirmesinden daha çok tamamen giderimini hedeflemektedir. Birleşmiş Milletler Dünya Su Gelişme Raporu, atıksuların yeterince arıtılamadan deşarj edilmesinde, atıksu arıtma tesislerindeki yüksek işletme ve bakım maliyetleri ile yüksek enerji tüketimlerinin önemli bir payı olduğunu belirtmektedir. Her ne kadar bu yerleşim birimlerinde oluşan atıksu miktarı az da olsa, çevresel sürdürülebilirlik ve kaynak korunumu açısından, bu suyun iyi kalitede arıtılarak geri kazanılması sulama suyu ihtiyacının fazla olduğu, tarımsal uygulamaların yapıldığı kırsal yerleşimler için önemli bir kazanımdır.

Bu amaçla geliştirilen yenilikçi sistem geliştirilmesi hedeflenmektedir, sistemde evsel nitelikli atıksuyun arıtılmasına yönelik atıksuya uygun tekstil materyalden üretilmiş olan filtreden suyun geçirilerek, farklı filtrasyon sürelerinde arıtımı ve işletim koşullarının optimizasyonu incelenmiştir. Çıkış suyunun kalitesinin arttırılmasına yönelik olarak, denenecek tekstil materyallerden bazılarının içine aktif karbon emdirilerek, aktif karbonun arıtma verimi üzerindeki etkinliği araştırılmıştır. Üretilen prototipin daha büyük ölçeklerde uygulanabilirliğine yönelik değerlendirmeler yapılmıştır. Arıtma sisteminin uygulanmasına yönelik olarak, Gediz Havza'sında bulunan Manisa iline bağlı küçük yerleşim birimlerinin konumları belirlenerek, bu yerleşim birimlerine ait bir atıksu yönetim modeli önerilmektedir.

Anahtar Kelimeler: Küçük yerleşim birimi, evsel atıksu arıtımı,filtrasyon, modelleme, atıksu yönetim modeli

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Ecology has been the focus of attention throughout human history. Even in old inscriptions, the value and methods of environmental care are mentioned. In today's limited resources and conditions, a clear understanding and enforcement of environmental impacts are more important than ever. Rural areas become popular when attention is paid to water pollution (Taouraout et al., 2019). As with any other resource, using less and wasting less are considered as two main properties on the economy of water use, moreover, the both property are becoming more important when they are coupled with finding or making available alternative water sources (Sutherland, 2008b).

Most of the water abstracted is used for various need as domestic, commercial, industrial and agricultural activities and returned to the earth. Among the activities, the agricultural – *which largely returns at once as water for irrigation*, and cooling water for power generation – *which also usually returns quickly to its source* are the most water consuming ones (Sutherland, 2008b).

The birth of the developments in the architecture of water structures goes back to 3000 BC and 4000 BC. It has been recorded that structures such as toilets, baths, and sewers were built in Mohenco Daro, ancient India, up to 4500 years B.C. The oldest complex builted drainage systems known in Babylon and Eshuanna cities (Today Iraq, Iran, Syria) were built with clay pipes between 4000 BC and 2500 BC in the Euphrates River region in the Mesopotamian Civilization. Archaeological records of the construction of the central water supply and wastewater disposal system goes back to five thousand years ago (the city of Nippur built by the Sumerians). In the ruins of Nippur, an arched wastewater channel was found. The first information about the Shieroglyphs. There is demonstrate that in the city of Bunzlau in Silesia, in 1531 and later, the water collected in the city was treated by decharge into the fields. Although there are examples of uniting to these canals from some houses and palaces, these are exceptional cases and it is seen that most of the houses are not connected to the canals.

Over one billion people can not get to affordable, clean and safe water for domestic use affecting negatively the well-being of people (Maifadi, Mhlanga, Nxumalo, Motsa & Kuvarega, 2020). In many countries, water scarcity, nutrient-depleted soils, and pollution are the major challenges especially in urban and rural settlements (Magwaza, Magwaza, Odindo & Mditshwa, 2020). Climate change effects related to the conventional energy sources created a global stress for the minimizing energy needs for wastewater treatment (Sarpong, Gude & Magbanua, 2019). As a result of the growth of population and developing technologies, the sustainable operation of wastewater treatment plants has got importance and it is aimed to eliminate the pollution rather than the forms of pollution (e.g. from water to air). The increasing water needs due to globalization, population growth and industrialization, the use of water for various purposes such as drinking and utility water, industrial and agricultural irrigation, and the fact that water is not shared fairly, and this research topic is increasing is the focus of attention. While meeting the water demand with today's technologies, reuse of treated wastewater is a solution alternative (WWAP (United Nations World Water Assessment Programme), 2017). There is a tend towards applications that contain solutions against water need. The historical development of treatment systems is shown in Figure 1.1.

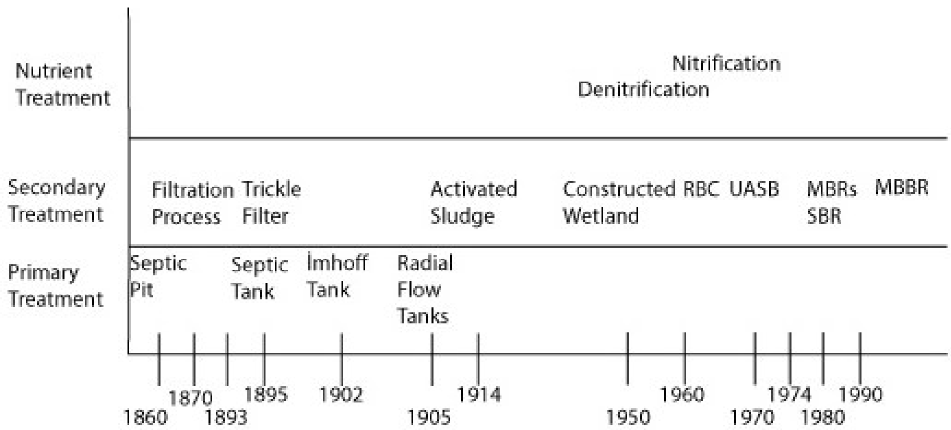


Figure 1.1 Historical development of wastewater treatment systems (adopted from Lofrano & Brown, 2010)

Productive operation of wastewater treatment systems goes back to 1860's. These systems, which started with only suspended solids (SS) removal, were expand on the removal of organic matter (BOD or COD), and nowadays additional parameters like Nitrogen, Phosphorus have been added to these parameters. Today's technologies allow very high quality treatment with the removal of micro pollutants and the reuse of treated water.

While providing these expenses, different factors affect the selection of suitable technologies. When designing new systems, operational constraints, environmental factors, and economic constraints should be taken into considereation together. The functionality, volume, and eutrophication formation of the units in the facility are seen as significant decision parameters, however, there is a close tie between selected technologies and arrangements, and the use of sensitive technologies for certain parameters is absolute (Rodriguez-Garcia et al., 2011). Understanding the source of wastewater, both qualitatively and quantitatively, is a key factor in the selection and development of treatment techniques. This is even more important for wastewater generated by small communities because of their discharges are subject to more change. Under these conditions, treatments and reuse applications have come to the fore, considering a large number of wastewater sources, not only those contaminated as a result of large-scale consumption but also small-scale ones.

Although extensively used in the treatment of urban wastewater, nowadays traditional and modern municipal sewage treatment plants (STP), designed lagoons around the world are often used to treat domestic wastewater generated by rural communities in the United States and Europe (Li, Zheng & Kelly,2013). However, there are important problems in the set up and operation of treatment systems in small settlements. While conventional treatment systems are picked in urban settlements, they may not be economicly suitable for small settlements in terms of their large sizes and construction costs. The United Nations World Development Report (2012) shows that both high operational and maintenance costs and high energy consumption plays a critical role in the inadequate treatment of wastewater (UNDP, 2012). As central systems appear in the collection and treatment of wastewaters, the sustainable operation of treatment systems can be achieved more easily in urban settlements, together with the decrease in operating costs, whereas in small settlements this is not the case. The traditional continuous technologies may waste energy at night when there is no or little wastewater inflow into the reactor. Besides, nutrient removal from wastewater using biological approaches needs both anoxic and aerobic conditions that consumes high energy in wastewater treatment facilities (Li et al., 2020). Toprak (2000), state that the cost per capita in the population of 1,000 people is 2 to 4 times higher than the cost per capita in the population of 100,000. However, it is stated that economic resources and technology are more limited for small settlements. For this reason, the development of innovative, on-site treatment systems suitable for small settlements around the world is the subject of research. Besides, although the volume of wastewater produced in such settlements is small, the number of small settlements is an important gain for rural settlements where agricultural practices are needed in terms of environmental sustainability and conservation of resources.

Assorted systems are developed for the treatment and reuse of wastewater in urban areas, applications of them for the wastewater reuse in rural and / or small settlements may be limited. For this reason, treatment and reuse techniques that are specifically designed for small and agricultural settlements become important. Most decentralized wastewater treatment systems including conventional septic tank-soil trench systems, land treatment systems, sand filter systems etc., can contribute advanced treatment for rural wastewater in certain conditions. However, it would be important to develop an effective wastewater treatment system adapted to context with a low cost, because the main barriers to access to the sanitation service in these areas are mainly in terms of investment and operating costs (Taouraout et al., 2019).

Today, due to water stress in many countries, wastewater generated in small settlements is treated with various technologies. This result shows that the value of wastewater produced in rural areas has increased as a result of rapid urbanization and industrialization (Dong, Qiang, Wang & Jin ,2012). The selection of appropriate wastewater treatment technology with all its pros and cons is an extraordinarily complex process (Molinos-Senante, Gómez, Caballero, Hernández-Sancho & Sala-

Garrido, 2015). Also, it is possible to make use of life cycle analysis in the effective and economical application of existing technologies to small scale. In small settlements, secondary improvements may be required to adapt existing systems and technologies to changing leaving water treatment level demands to meet today's needs. It is possible to make these improvements by making use of environmental decision support systems.

In this study, the current literature is reviewed and the current technologies are examined in terms of environmental, economic, design, and power consumption, and it is aimed to develop the application that will provide the highest benefit in small settlements. There is not much study and data in the scientific literature concerning the operation of such plants over a longer period. Some research studies like one done by Mažeikienė & Grubliauskas (2020) reported that the scientific literature was lacking in information about how small activated sludge WTPs operate.

1.2 Aim of the study

Within the scope of this proposed research project, it is aimed to develop an innovative reactor system for small settlements. The specific objectives of the thesis are therfore:

- To develop a prototype for domestic wastewater applicable for rural areas,
- To determine the filtration performance properties of different types of textile materials on treatment efficiency at different filtration times and optimization of operating conditions,
- To improve the quality of treated water, investigation of some textile materials with impregnated activated carbon into to effectiveness of activated carbon on treatment efficiency,
- To develop a wastewater management model belonging to the small settlements in a selected basin in the Aegean Region.

All pursits from the thesis will provide the highest benefit for small settlements in terms of environmental, economic, design, and power consumptions of existing technologies in Turkey.

CHAPTER TWO
LITERATURE REVIEW

2.1 Domestic Wastewater Treatment Methods for Small Settlements

The notion of building low capital and operating cost treatment facilities in rural areas is not something new. In April 1977 the U. S. Environmental Protection Agency (EPA) held a national conference in Reston, Virginia, entitled "Less Costly Wastewater Treatment Schemes for Small Communities'' and for lower 2,000 p.e. agglomerations, stated that appropriate treatment must be implemented.

The development of economies and societies led to increase the cognisance of environmental protection. This situation also remarks to the comfort requirements people in rural areas . However, many small communities and rural areas, particularly in developing countries, are still endeavour with aging or unsufficient decentralized wastewater treatment (Li et al., 2020). As a result of urbanization and industrialization rate wastewater generated in rural areas increased in value. Many countries treat wastewater which have been produced in small settlements, with different technologies, to overcome water stress. While in rural and/or small settlements using the same technology applications for the reuse of wastewater may be limited in urban settlements, some solutions for the treatment and reuse of wastewater have been introduced. Especially the on-site treatment and reuse techniques that have designed for small and agricultural settlements become more important of an issue (Dong et al., 2012).

Up to now, an assortment of decentralized technologies have published, ranging from septic tanks to advanced treatment systems able to meet the limits set by regulation for different requirements such as agricultural irrigation (Li et al., 2020). In rural areas lagoons, some septic tanks and primary treatment applications are commonly used. However, they have some drawbacks like temperature dependancy of septic tanks (Mažeikienė & Grubliauskas, 2020). The use of lagoons to provide secondary treatment for either municipal or industrial wastewaters is common. However, regarding the world population growth and inadequate efficiencies of existent systems many of these treatment systems do not meet sufficient efficiency. Rural wastewater has distinct characteristics of high variability in influent loading rates, long idle periods, and scattered distribution when comparing to urban wastewater. It is no chance to have a sufficient number of high quality technical operators for operation and maintenance of wastewater treatment systems, which is the most important disadvantage on the operation and development of decentralised wastewater treatment (DWWT) systems. In addition to this, increasingly stringent discharge standards are becoming more critical for domestic wastewater treatment in rural areas. If rural wastewater is not sufficiently treated, it may lead risks to aquatic ecosystems and human health (Li et al., 2020).

When comparing central and decentralised activated sludge WWTPs, small activated sludge systems are more responsive to fluctuations in wastewater flow and level of contamination, they are strongly affected by temperature decrease, and lose efficiencies at treatment of nitrogen and phosphorus from the wastewater (Mažeikienė & Grubliauskas, 2020).

Two main approaches for wastewater treatment as intensive and extensive approaches can be identified for example, extended activated sludge system (AS) is considered as intensive technology in small WWTPs as well as rotating biological contactors (RBCs) or tricking filters (TFs) (Matamoros, Rodríguez, & Albaigés, 2016). The intensive treatment scheme for small communities is the constructed wetlands. Other configurations also include trickling filter, activated sludge, membrane and an integrated step-feed biofilm process, respectively.

In former studies, constructed wetland, stabilization tank, green filter, peat filter, anaerobic treatment, and thickening and rotating bio-disc reactor technology performances were monitored by TSS, BOD_5, COD, N, P, and fecal coliform parameters. Lately the construction of aeration facilities decreased but the activated sludge systems still remain the main systems that are used for wastewater treatment in small settlements and rural areas (Dauknys, 2019).

Economical easily operation advantage of constructed wetlands makes it most preferred systems with for domestic wastewater in rural areas (Ye & Li, 2009). However, constructed wetlands have one of the biggest problem which is limited phosphorus removal performance, and the problem needs overcome by using improved media and adapted microorganisms (Vymazal, 2018). BOD_5/P ratio is important for biological treatment when it is higher 20, the biological method of treatment of wastewater is suitable for removing phosphorus (Mažeikienė & Grubliauskas, 2020). Despite they highly preferred constructed wetlands are not good at removing nitrogen (Liang, Liu, Wei & Guo, 2010). Small and compact activated sludge processes can not be replicates of large treatment plants. Small activated sludge systems do not need preliminary sedimentation tanks. Organic substances in the wastewater are consumed by microorganisms, and this protects a higher C:N:P ratio, so system achieve a higher effectiveness in removing N and P compounds from the effluent (Mažeikienė & Grubliauskas, 2020).

The former studies carried out on the development of performance and design in constructed wetlands are quite small-scale, while constructed wetland systems improved with sedimentation tank integration, their efficiencies increased on BOD_5, TSS, NH_4^+-N, and TN parameters (Wu, Austin, Liu & Dong 2011).

María Molinos-Senante et al. (2015) studies the determining of the best system among 7 different technologies including constructed wetland, long aeration, MBR, pond, RBC, batch fed reactor and trickle filter applied for rural areas. They found the wetlands and pool systems were the best interims of the operation and their costs. From small-scale treatment systems, activated sludge systems and constructed wetlands are the most environmentally friendly option with 93% rate (De Feo & Ferrara, 2017).

Commonly used treatment sytems for small communities can be considered as conventional activated sludge process (CAS), membrane bioreactor (MBR), Pond system (PS), constructed wetland (CW), Rotating biological contactor (RBC), Sequencing batch reactor (SBR) where all the operations (fill, react, settle and draw) are achieved in the same reactor (single batch reactor), and Trickling filter (TF) Batch feeding reactors can be used in the scope of the operability of rural wastewater according to self-specificity. CW is a unique system designed to utilise the natural functions of wetland vegetation, soils and their microbiological populations to treat wastewater (Matamoros et al.,2016). However, some researchers indicated that even they have high performance, CWs are conventional technologies, which can not provide desired recovery efficiency (Rodriguez-Garcia et al., 2011). Matamoros et al., (2016) investigated the performances of different domestic wastewater system designed for decentralized communities. Table 2.1 gives the summary of their findings.

Molinos-Senante et al. (2012) developed some scenarios based on treatment technologies, wastewater characteristics, and water reuse, it has been observed that the long aeration system was the most cost-effective system and the pool system was the most economical option. However, in all their scenarios, the membrane-discharge reactor achieved the best standard, while the medium loading the batch feed MBR give the best results.

Hu, Li, Wu, & Yang (2020) studied on subsurface wastewater treatment sytems for the removals of chemical oxygen demand (COD), total phosphorus (TP), and NH_4^+-N parameters. The sandy soil system reached 94.81%, 97.25%, and 75.02%, respectively. However, subsurface wastewater infiltration systems have disadvantages as their clogging risk and unstable performance.

Khalifa et al. (2020) worked on plastic gravel rubber plastic-foam gravel-foam rubber-foam used in constucted wetlands and evaluated the efficiencies before and after foam addition. The removal efficiencies of COD, BOD_5, total suspended solids NH_3, TP increased from 71% to 88%, from 72 to 88%,from 83 to 88.5%, from 66 to78%, and from 78% to 85%, respectively. A slight modification of total coliform from 98.4–98.6% was found.

Dong (2012), reported that the most suitable treatment methods was the activated sludge system for heavily inhabited and the constructed wetlands were the most suitable for sparsely populated areas in comparison to the septic tank, anaerobic treatment, constructed wetland, stabilization tank and activated sludge systems.

A moving bed biological reactor installed following the septic tanks to treat the septic tank effluent. In the system, wastewater runs through the septic tank and then pumped to the downstream aerobic biofilter. Trickling filters also used to treat the septic tank effluent, but at least two separate treatment chambers were necessary (Mažeikienė & Grubliauskas, 2020). With a multi-soil layering system which was developed for environmental, economical and easy construction considerations, COD and BOD_5 removal values were achieved as 98.53% and 93.66%, respectively (Song et al., 2018).

Result of developed speed algae pool system was found as feasible in terms of climate, continuous pond conditions, wastewater sampling, and analysis. It was concluded that the system provided adequate BOD_5, TN and fecal coliform disinfection for the Mediterranean climate (Buchanan, Young, Cromar, & Fallowfield, 2018). In addition, in selection technology step a common management approach can be monitored in integrated and decentralized integrated organic waste and wastewater management systems. Thus, wastewater treatment, biogas production and composting processes can be carried out (Lijó et al., 2017). Step-feeding bioreactors also enhanced the nutrient and phosphorus removals (Li et al., 2020).

Treatment processes as inexpensive and compact ones can be applicable for small communities like those intended for just one family. Compact activated sludge treatment processes have become popular recently. These systems needs do all the treatment in one chamber (Mažeikienė & Grubliauskas, 2020). In small settlements environmental conditions can be hard and would effect systems performance. Suggested compact, using a combination of septic tank and sprinkling biofilter system to place near dwellings can be appropriate to treat better (Mažeikienė & Grubliauskas, 2020). If the regulations are tightened for wastewater treatment in the future, studies on improved filtration systems will be promising alternatives.

Table 2.1 Summary of performances regarding different domestic wastewater system designed for decentralized communities (Matamoros et al., 2016)

Technology	Constructed Wetland	Towery hybrid constructed wetland	Anaerobic digester-constructed wetland	Vegetated sequencing batch coal slag bed	Integrate step-feed biofilm process	UASB+ SBR
Description	Sedimentation tank+ vertical flow constructed wetland with one willow	3 stages; stage 1 and 3 are rectangle subsurface horizontal flow constructed wetlands and stage 2 a circular constructed wetland	2 UASB in series + subsurface flow constructed wetland + surface flow constructed wetland	Different from conventional constructed wetland, the system worked as a batch reactor using coal slag as substrate and Umbrella glass as the plant component	Drop-aeration biofilm combined with thw step-feed process: 3 stages anoxic/oxic reactors+ secondary clarifier	UASB for biogas production + SBR for nutrient removal using fermented DOW as carbon source +composting for sludge treatment
Country	China	China	Spain	China	China	Italy
Population Equivalent	1 household	40	30	pilotscale		2,000
Flow (m^3/d)			3.2			400

Table 2.1 continues

Technology	Constructed Wetland	Towery hybrid constructed wetland	Anaerobic digester-constructed wetland	Vegetated sequencing batch coal slag bed	Integrate step-feed biofilm process	UASB+ SBR
Removal efficiency	COD (%)		84.5	92.2	63.58	80
	BOD_5 (%)	95.7		90.3	59.72	
	TSS	96.8	88.6	92.7	80	90
	TN		82.9	53.1	50	
	NH_4^-	87.3	83.1	52.3	50.51	90
	N					
	TP	87.9	64.2	51.4	40	15

2.2 Current Applications In Wastewater Management and Small Settlements In Turkey

In some Eastern and South Eastern European countries, including Turkey, wastewater treatment applications, the ratio of the population benefiting from the sewage system and central wastewater treatment facilities to the total population are given in Figure 2.1. Although secondary treatment mainly including biological treatment applications, is applied, advanced treatment applications have also accelerated recently as shown in Figure 2.1.

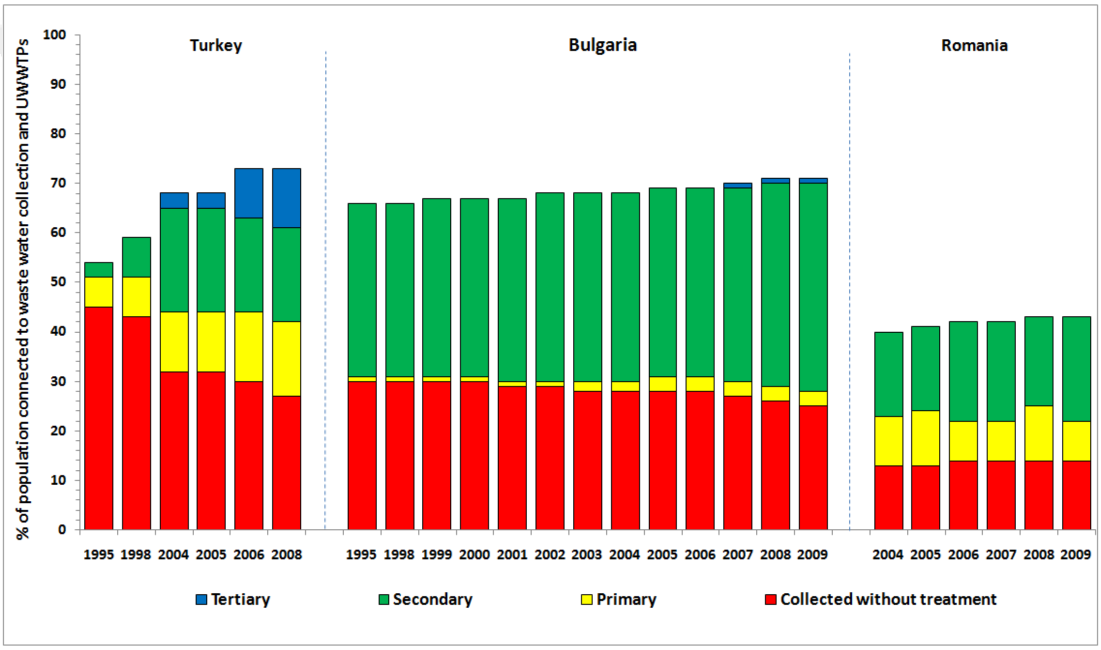


Figure 2.1 Spreading of South - East European treatment systems (European Environment Agency, 2015)

Turkey's domestic / urban wastewater treatment plants approximately 900 WWTPs have daily treated as 8,080,959 m^3 of wastewater. The regional distribution of this amount is 3,397,237 m^3/d, 394,611 m^3/d, 1,192,371 m^3/d, 1,024,487 m^3/d, 1,439,462 m^3/d, 401,491 m^3/d and 231,300 m^3/d for Marmara Region, Black Sea Region, Aegean Region, Mediterranean Region, Central Anatolia Region, Southeastern Anatolia Region, and Eastern Anatolia Region, respectively (TUBITAK-KAMAG 108G167 Project Report, 2013). The rate of population served by treatment facilities in our country has increased significantly, at the level of 91%. According to the "Environment" chapter launched by our country in 2009 within the scope of harmonization with the European Union acquis, there are significant progress, especially in wastewater treatment.

The municipalities in Turkey about 1/ 3 of the population is below 2,000 It is reported that a total of 1,023 residential. 59 of these municipalities are district and 964 are town municipalities. The population of 250 of them is less than 1,000. The municipality with a population of less than 2,000 in Turkey and its distribution by province are presented in Table 2.2. There are mostly septic tanks and packaged biological treatment applications in small residential units of Turkey.

Septic tanks (ST) are the oldest known pre-treatment method, in wastewater treatment they are used for solid matter stabilization. In the septic tank , sludge degradation and precipitation are carried out in the same tank. Septic tanks can be used individually or jointly for entegrated small flow rates, they generally consist of three chambers. The working mechanism of ST provides an additional area of sludge decay and sedimentation after water passes through the impermeable first chamber. Thus, possible discharge of sludge and material can be prevented (Metcalf&Eddy, 2013).

Imhoff tanks are the improved versions of septic tanks, they also can be used at small flow rates according to their compact design and can be preferred for small flow rates as they do not require mechanical equipment. In the system the sedimentation and decay zone are separated from each other. During gasification of solids, it is important not to let gas pass into the upper chamber. Imhoff tanks are generally rectangular shaped. The effluent is decomposed from solids, however continues to threat health. Because of sufficient biodegradation pathologically treatment performance, therefore the discharge water can be improved by treating with another continuation process (Metcalf&Eddy, 2013).

Table 2.2 Numerical distribution of municipalities with population below 2000 by city in 2011 (Republic of Turkey Ministry of Interior General Directorate of Local Administrations, 2017)

Municipality Number	City
110	*Konya*
51	*Kütahya*
45	*Afyon*
43	*Tokat*
41	*Denizli*
36	*Yozgat*
32	*Manisa*
31	*Isparta*
26	*Kayseri*
25	*Çorum*
24	*Aksaray, Antalya, Sivas*
21	*Kırşehir, Ordu*
20	*Amasya, Nevşehir, Niğde*
18	*Çankırı*
17	*Ankara, Burdur, Malatya*
15	*Eskişehir*
14	*Adana, Aydın, Trabzon*
13	*Balıkesir, Giresun, Kırıkkale*
12	*Bursa*
11	*Çanakkale, İzmir, Uşak*
10	*Edirne, Erzurum, Maraş, Muğla, Samsun*
8	*Elazığ, Erzincan, Tekirdağ*
7	*Bilecik, Kırklareli, Zonguldak*
6	*Gümüşhane, Mersin*
5	*Hatay, Karaman, Kastamonu, Rize, Tunceli*
4	*Adıyaman, Bayburt, Kilis, Muş, Sakarya, Sinop*
3	*Ağrı, Ardahan, Artvin, Bingöl, Bitlis, Bolu, Diyarbakır, Gaziantep, Mardin, Osmaniye*
2	*Bartın, Batman, Karabük, Siirt, Şırnak*
1	*Iğdır, Kars, Yalova*

Sand filters; the septic tank outlet can be discharged into the receiving environment after being purified and disinfected in a controlled manner with slow sand filters. The filter thickness can be 60-90 cm. It is applied in three different ways. These are sand filter ditches, (buried) batch, and reciprocating filters. Simple operation is their most important advantage. However, they require large areas (Ministry of Environment and Forestry, 2010). For reuse purposes, in some wastewater treatment plants (WWTP), sand filters after the final sedimentation tank and disinfection unit (especially ultraviolet rays) are added. In recent years, instead of conventional treatment processes, use of membrane processes (MBR) and disinfection unit are also considered as in Muğla Konacik Municipal WWTP. However, this is not so applicable when it comes to small settlements (Maryam & Büyükgüngör, 2019).

Small membrane bioreactor systems can be applied for rural areas with high life standards. In this method, the septic outlet is drawn under vacuum with the membrane immersed in a separate tank. While vacuuming, air must also be supplied continously. The effluent by filtering from the membrane is of a quality that can be reused as irrigation water (Gürel & Büyükgüngör, 2011).

Leakage systems are systems in which water that has passed a pre-treatment is discharged to the ground. This discharge is done if the ground water level and ground conditions are found as suitable. It is a priority not to contaminate the groundwater, so the leveling facilities are constructed in a way that their bottom and outer walls are impermeable. Leakage wells are deep wells. The water level should be deep. The pits can be 2-4 m wide and 3-6 m deep. Usually, there is leakage from the side walls. The hydraulic load is 8-16 L/ m^2 days (Ministry of Environment and Forestry, 2010).

Among the treatment systems, stabilization ponds for small communities (< 20,000 Population equivalent (PE)), trickling filters for medium-sized community, and activated sludge or extended aerated activated sludges for a large-scale community have been commonly applied in Turkey (Maryam & Büyükgüngör, 2019). However, the treatment technologies providing better treated effluents should be applied for reuse of the wastewaters regarding the negative effects of climate change and other socio-economic conditions.

2.3 Filtration Technologies

Filtration is one of important processes used in water and wastewater treatment. It is based on the capturing of particles through a porous media rather than removal of solids. Its efficiency in wastewater practice is determined by the removal of total suspendend solids (TSS) (Adin & Elimelech, 1989). The filtration process can be combined into 4 main categories as in the form of centrifuge, pressure, vacuum and gravity. Each of them is divided into two as continuous or intermittent operation. The filtration system used in the scope of this thesis can be positioned in the gravity filtration category. In this category, most of the studies in the literature include grids, rotary screen, vibratory screen, strainer or nutsche, and sand/ charcoal.

Darcy announced the flow in the porous media in 1856. The first filters were constructed by trial and error method. After the Carmen-Cozeny equation (1937) developed in a filter bed, research studies focused on the design of granular filters, which are commonly used for water and wastewater treatment to catch the suspended solids. The filter medium commonly includes granular particles like sand and anthracite materials (Kumar & Thakur, 2017).

Darcy's law: (2.1)

$$\frac{\Delta P}{L} = \frac{\mu}{k}\frac{dV}{dt}\frac{1}{A}$$

Carmen–Cozeny equation: (2.2)

$$\frac{\Delta P}{L} = \mu\left(\frac{5(1-\varepsilon)^2 S_v^2}{\varepsilon^3}\right)\frac{dV}{dt}\frac{1}{A}$$

Filtration is known as a complex process for different reasons including the availability of *a large number of individiual variables, mirroring characteristics of the filter bed, the suspended particles, the water properties, and the operation mode*. Effluent quality and head loss parameters are very important in filter design and its operation. Particle size distribution in a wastewater filter is generally much broader and the concentrations more variable than those entering a water filter.

In filtration process, four mechanisms can be seen as sedimentation, impaction, diffusion, and interception. The particles in the fluid first hold on the surface of the porous filter media. Then, the retaining of particles in the filter media depends on the equivalance between the particles and the filter medium via the superficial forces for collision and attachment in the filter bed . These conditions should be considered in the design and operation of wastewater and water filters (Kumar & Thakur, 2017) .

Over the past 20 years, numerous filter technologies have been introduced regarding the better filtration performance (Ding et al., 2017; Caliskaner et al., 2020). Ncube et al. (2018) conducted a study by using quadruple granular media filter adapted from a FilterClear pressure filtration system filtering real secondary treated wastewater effluent which its upstream units included grit removal, primary sedimentation, alum dosing, trickling filters, and secondary sedimentation. The experimental findings from the study based on the removal performance of each media at different pH values ranged between 3.5- 10 showed that the removal effectiveness was more dependent at pH and less on Zeta Potential (ZP) which was found as stable -13 mV (Ncube et al., 2018).

In CWs, sand, diatomite, coal, cotton or wool fabrics, metal wire cloth, porous quartz plates, chamotte, sintered glass, metal dust, and powdered ebonite are commonly used as a filter media. During the treatment, CWs included gravel as a filter media have very limited reduction capabilities for many pollutants (Abou-Elela et al., 2019; Khalifa et al., 2020). Some studies mentioned that CWs having filter media *such as minerals, marine sediments, soils, rocks, synthetic (man-made) materials and industrial byproducts* may improve the nutrient removal rather than reducing clogging potentials (Darby, Lawler & Wilshusen, 1991).

Garnet black having the properties as particle size $\Phi = 0.5–1.2$ mm, d10 = 0.56 mm, specific surface area $S = 0.32 \times 10^4$ cm^2 /g, porosity $\varepsilon = 51\%$ and quartz sand having the properties yellow color, particle size Φ= 0.5–1.2 mm, d10 = 0.60 mm, specific surface area S= 0.15 × 10^4 cm^2 /g, porosity ε = 41% were used as filter media were capable of removing COD as 47.7% (Huifang et al., 2020).

Activated carbon (AC) capabiling of adsorbing organic compounds from solutions and removal of odor, unwanted taste, and color from waters is commonly used in filtration technologies (Maifadi et al., 2020).

Membranes are accepted as an advanced filtration technology. However, the proper selection of membrane materials and their operational conditions are very critical. For example, high water pH can negatively affected to the separation properties of membranes such as permeability, structural configuration, and contamination retention (Maifadi et al., 2020).

Maifadi et al. (2020) compared the performances of activated carbon from corncob pyrolyzed at 250 °C in the absence of oxygen used slow sand filtration combined with a layer of activated carbon and a membrane bioreactor that involved a natively developed ceramic ultrafiltration membrane on saloon wastewater, however none of these could not manage all the emerging contaminants of saloon wastewater. In addition to studies, in comparing the structure using of the multimedia granular filter as pretreatment of the wastewater, declined in TDS 4% for site 1 and 28% for site 2.

In another study, a filter bed consisted of three granular media: sand, crushed activated charcoal, and clinoptilolite zeolites used for wastewater treatment. While the aim of the sand layer use was removing of colloidal matter, the goals for activated charcoal and clinoptilolite zeolites uses were removing of odor, taste, and color causing compounds and heavy metals (Pb, Cd, Zn, Cr, Fe, etc.), respectively. Multimedia filtration resulted 9.1 and 9.0 % decrease in EC due to the removal of the ions in the wastewater and the clinoptilolite layer effected adsorption and ion-exchange reactions (Maifadi et al., 2020).

Lohani et al. (2020) used an upflow anaeorobic sludge blanket (UASB) effluent to filter in a 1 m^3 sand filter unit by gravity flow for two months at average air temperature of 19 ºC. They observed the treatment performances of TSS, COD, and Faecal Coliform parameters as 93%, 87%, and 93%, respectively. Top layer of the sand in the filter was replaced in every two to three months to keep the continous filtration capacity. They concluded that the UASB with Sand Filter was appropriate; however, it needed to investigate a safe route of sand replacement and handling as well as alternative economic filtration media (Lohani et al., 2020).

Ibrahim et al. (2020) studied various filtration types to improve the quality of the agricultural drain in Egypt for domestic wastewater treatment. The plastic medium mixed with the sand medium gained the lowest removal contaminants removal efficiency. The sponge medium mixed with sand medium have the highest contaminants removal efficiencies with the optimum filtration depth 140cm. Due to its high surface area, active carbon had also been tried in sand. Study were made in 60, 90, and 120 cm deep tubes. At the end of 28 days of operation, only sand was able to reach 60%, the other two had 80% COD removal efficiency. For TSS removal, this ratio was found as 53%, 97%, 97%. No significant effect of flow rate increase on efficiency was observed.

Table 2.3 gives a summary on the different filtration technologies for primary filtration including various filter media. Apart from the methods, filtration types are available; surface (membrane) filtration and depth filtration. Membranes are not applicable for small residential areas due to economic constraints. Membrane filtration techniques have the promising feasibility for wastewater treatment and resource recovery providng the higher permeate quality for water reclamation, meanwhile, the high up-concentration of feed water is advantageous for nutrient, energy and chemical recovery (Hube et al., 2020).

Table 2.3 Filtration application for primary effluent and primary filtration (Caliskaner et al., 2020)

Filter Characteristics			
Technology	Filter Medium	Effective Size, mm	Size, µm
Primary effluent filtration			
Pulsed bed filter	Sand	0.35-0.65	
Upflow sand filter	Sand	0.45-0.65	
Compressible media filter (fuzzy filter)	Compressible synthetic fiber	25-30	
Compressible media filter (flex filter)	Compressible synthetic fiber	25-30	
Cloth disk filter (submerged)	Various synthetic fabrics		5-10
Cloth disk filter (partially submerged)	Various synthetic fabrics		10-20
Primary filtration			
Rotary disc filter(partially submerged)	Stainless steel		250
Rotary drum screens, fine	Synthetic fabric or stainless steel		500-1,000
Rotary drum screen, micro	Synthetic fabric or stainless steel		150-350
Rotary belt filters (microscreen)	Various synthetic fabrics		150-350
Cloth disk filter (submerged)	Various synthetic fabrics		5-10
Compressible media filter (flex filter)	Compressible synthetic fiber	25-30	

2.3.1 Textile Filtration

Wool, cotton and the felts made from them known as natural fibres also having absorbent property can be limitedly used as absorbent filters. However, they could be also used as filter media with their absorptive properties of secondary or negligible significance (Sutherland, 2008a). Textile fibers can have different sources either natural or synthetic ones. While the natural sources include wood/cellulosic and vegetable origin materials like cotton, flax, jute, and materials that came from animal, as silk, wool, fur, and hair. The natural sources are constituents of synthetic sources (Kumar & Thakur, 2017).

Maifadi studied with the filter bed having a depth of 1 m with sand and coal. They applied chemical and thermal treatment as 10 % v/v HCl and finally heat at 180 °C to clean the filter media (Maifadi et al., 2020). In filtration systems, easy operation of the equipments and easy disassembly and installation are important. Their easy operability makes wool and nonwoven fabrics, natural or synthetic fibers often preferred. Textile materials can be used in filtration systems as membranes, their performances are both dependent on physicochemical properties of filter surface (Kumar & Thakur, 2017).

Although screen filters performed very low removal efficiency was about 1%, they are capable of the development of a clogging index that would help in defining the clogging potential of different types of water (Adin & Elimelech, 1989).

As filtering continues, effective pore size decreases and flow resistance increases this situation occurs because of the clogging problem in membrane surface. Therefore, investigation for new filtration methods are needed. Especially, these days, the strict regulations are applied in wastewater treatment. So, the studies are focusing on the improved membrane and sand filters with different materials like graphene (Hegab et al., 2018).

2.4 Sequencing Batch Reactor (SBR)

SBR process is an effective wastewater treatment process in which carbon, nitrogen and phosphorus removals are performed in a single tank in a certain order. It is generally used for small plants (Metcalf&Eddy,2013). SBR can include the following steps as filling, anaerobic, aerobic, anoxic, settling, and idle, respectively (Lohani et al., 2020).

Lohani et al. (2020) have pointed out that a possible way to improve SBR performance was to combine it with a textile filter post-treatment, which is a low cost option. Dissolved oxygen (DO) concentrations in aerobic zones were maintained above 3.0 mg/L, and below 0.2 mg/L in anoxic zones. Although, MLSS concentration in activated sludge systems can be kept as 4-5 g/L, whereas in small treatment systems, it can be kept as 6 g/L or more as in SBRs. With the contaminant load of the activated sludge (F/M ratio), the contaminants can be removed more effectively as time passes (Mažeikienė & Grubliauskas, 2020)

2.5 Challenges in Small Wastewater Treatment Systems

Even their high-performance, constructed wetlands are conventional technologies and they can not provide desired recovery efficiency under today's conditions. Recently, original studies are carried out to increase the wastewater treatment performance in rural areas. Specific problems, such as removals of organic matter and nutrient, can be seen where non-sensitive technologies are used (Rodriguez-Garcia et al., 2011). Current treatment technologies have some challenges as size, operational capacity, technology, lack of automated / online monitoring, and discharge requirements. Besides generic problems, the factors affecting small WWTPs are as follows:

a) A larger daily fluctuations in sewage loading and flow resulting over or under loading of the plant,

b) Lack of combined sewer overflows causing higher intensity storm flows,

c) Variation in the influent quality such as unexpected high ammonia, suspended solids, and BOD levels,

d) Excess grease and fibrous debris resulting in blockage in the plant, and

e) Smaller plants are more susceptible to short circuiting (Europian Comission,2006).

In order to adapt existing systems and technologies to changing treatment level demands in small settlements, it may be necessary to install secondary refinements. Current rural wastewater treatment systems encounter problems such less-matching the emission characteristics of rural wastewater, high energy consumption, and lack of operators (Li et al., 2020). Molinos-Senante et al. (2012) showed that some benefits of environmental decision support systems for small settlements. Scenarios have been developed by taking into consideration the treatment technology, wastewater characteristics, and water reuse. Lohani et al. (2020) indicated that the simple and cheap solution investigations could be significant for safer reuse of water while recovering nutrients and the energy potential of domestic wastewater, especially in developing regions lacking resources and infrastructure for more advanced centralized solutions. Most of the studies remarked safer procedures in order to reuse of the treated wastewater and its nutrients for crop harvesting (Lohani et al., 2020).

2.6 Comparison of Some Technologies applied for Small Settlements

The methods that can be applied for small settlements having some innovative aspects developed with non-conventional and / or hybrid applications are presented in Table 2.4 their advantages and disadvantages .

Table 2.4 Comparison of some wastewater treatment technologies applied for small settlements

Technology	Advantages	Disadvantage
Trickling Filter	They are effective in removing of BOD, pathogens, and nutrients.	Pre-treatment units are needed and they are sensitive to change.
Septic Smart	Zero Waste	Pre-treatment units are needed. It needs energy.
Moving Bed Membrane Bioreactor (MBBR)	It is highly efficient. It is resistant to fluctuations. It is a reliable and robust option for small scale facilities. High quality water is obtained.	Maintenance and operation is costly due to the need for pump and ventilation..
Rotating biological contactor	It does not need a ventilation system due to the rotational motion.	It should be considered together with pre-treatment units. It may be necessary to use micro sieves.

Table 2.4 continues

Technology	Advantages	Disadvantage
Septic Tank with Textile Filter Added	Provides high treatment efficiency in small volume. Effluent water quality is high. It is economical and does not require energy consumption. No sludge is formed.	Needs pre-treatment.

CHAPTER THREE
MATERIAL AND METHODS

3.1 Introduction

This chapter introduces materials and methods used in this research in detail.

3.2 Materials

Throughout the study, various textile materials were used in the cassette system designed for filtration process. After the operation of this filtration mechanism, the system was also integrated with a sequencing batch reactor (SBR) system. During the operation of SBR, four different types of textile filter materials were used for wastewater treatment.

Synthetic wastewater and real domestic wastewater were used in the experimental studies. Inoculum activated sludge used in SBR was supplied from the recycling line of Çiğli Municipal WWTP having advanced biological nutrient removal units, located in Izmir, Turkey.

3.2.1 Synthetic Wastewater

Synthetic wastewater was prepared to simulate domestic wastewater. Synthetic wastewater simulating high-strength municipal wastewater was used to feed either filtration unit alone or in conjuction with SBR. The recipe of synthetic wastewater was mainly comprised of as follows: CH_3COONa, NH_4Cl, KH_2PO_4, $FeSO_4.7H_2O$, $CaCl_2$, $MgSO_4.7H_2O$ and trace solution as detailed in elsewhere (Li et al., 2007).

3.2.2 Domestic Wastewater

Experimental studies were also conducted by real domestic wastewater including some industrial contributions from food industry. The real wastewater after primary treatment units was taken from Akhisar WWTP having advanced biological units located in Manisa, Turkey.

3.2.3 Filtration System

Laboratory- scale filtration system is displayed in Figure 3.1. The filtration system has two parts, first part is rectangular reactor which has 24 L volume and 2 tap to fill and discharge the water (Figure 3.1), the second part of the system is rectangular filtration cassette that has 18 cm × 20 cm × 5 cm (L ×W× H) dimensions (Figure 3.2). Active filtration surface area obtained as a result of system dimensions is 0.056 m^2. A feeding tank having 40 L volume was used to store the synthetic wastewater or real wastewater. The wastewater was pumped by using a diaphragm pump to the filtration system. A flowmeter having five different stages was used to control the flowrate as 13, 37, 61, 80 and 90 mL/min of synthetic wastewater, respectively. Flux values were 13.93, 36.64, 65.36, 85.71 and 96.43 LMH ($L/m^2.h$) respectively. The filtration materials were placed at both sides of the filtration cassette as single layer or multilayers depending on the experimental trial.

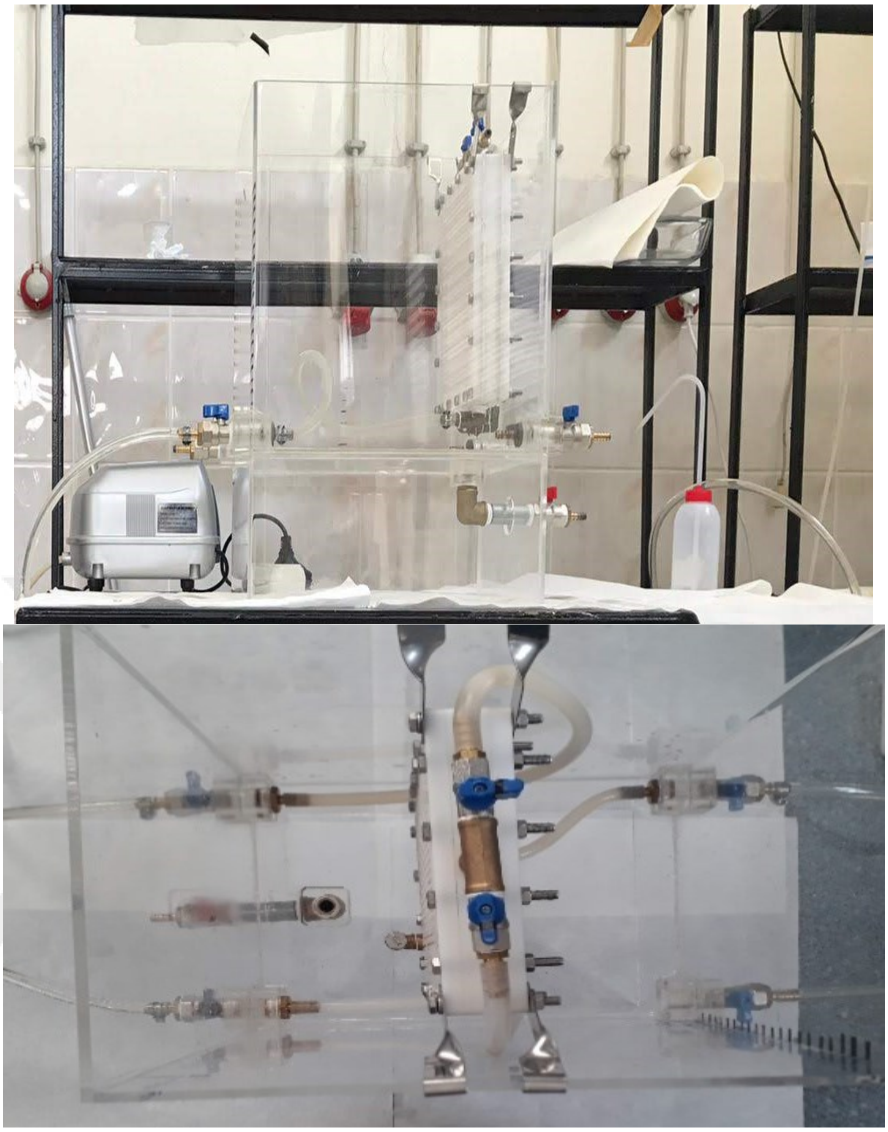


Figure 3.1 General view of filtration system (Personal archive, 2019)

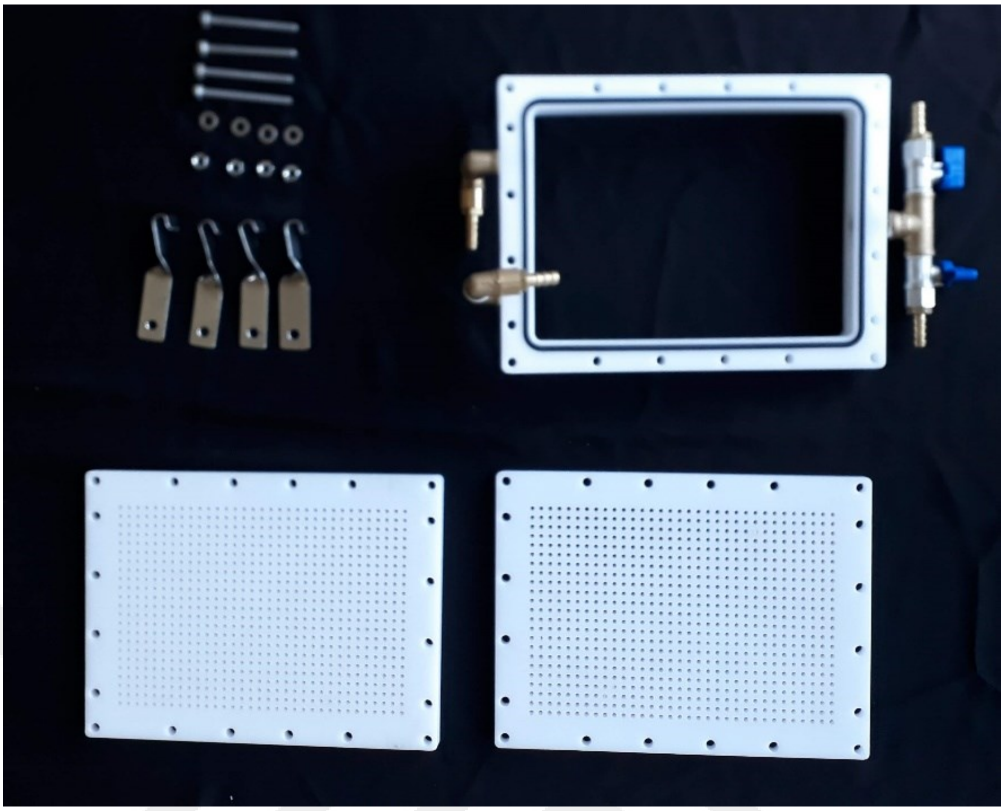


Figure 3.2 Cassette filtration system in details (Personal archive, 2019)

3.2.4 Textile Materials

Specially developed textile materials, placed in the cassettes are mentioned as filter materials in the study. Five different textiles were used throughout the system operation, which were cotton textile fabric (TF), metal braided cotton-polyester fabric (MBTF), %1 activated carbon coated cotton textile fabric, %3 activated carbon coated cotton textile fabric and activated carbon woven fabric respectively. TF and MBTF filtration materials were used to compare the best treatment performance on COD and BOD parameters. And then, depending on the previous results, the other three materials were mounted to the cassette system to increase the treatment efficiencies. MBTF was woven with 50 micron stainless steel wire and has 30µm pore size. Both of the weaved fabrics were developed under R&D studies. The properties of the textile materials is given in Table 3.1. Textile filter (TF) was coated with 1% and 3% by weight of powdered activated carbon purchased from Merck by using sol-gel method. The coating studies were done by Textile Engineering Department of Dokuz Eylul

University.The coated textile materials were denoted as S1 and S3. Activated Carbon woven textile filter produced from %100 activated carbon was 2,100 m²/g of specific surface area. This material was supplied form a R&D company located in Marmara Region, Turkey. The activated carbon woven textile material was thicker than other fabrics. For the first time, this material was used for wastewater treatment purpose. Fabric materials may carry a heavier pollutant load per unit area by their thickness. Fabric filters may be preferred when large size filters are enough or needed via adsorption in addition to mechanical screening. The photographs of the unused filtration materials are given in between Figure 3.3.

Table 3.1 Properties of textile filters (Ayol, Demiral & Güneş, 2020)

Filter material	Fiber thickness (Ne)	Weft warp density (wire/cm)	Pore size (µm)
Cotton Textile Filter (TF)	30x30	27x30	20
Metal Braided Textile Filter (MBTF)	12 for cotton	50 µm for stainless steel wire	30

Cotton textile fabric (TF)

Stainless-steel metal braided textile fabric (MBTF)

Activated Carbon coated TF (S1)

Activated Carbon coated TF (S3)

Activated Carbon Woven

Figure 3.3 Textile materials used in the experimental studies (Personal archive, 2019)

3.2.5 SBR Sludge

Activated sludge plays an important role in operating the SBR system. The activated sludge used during the operation has high efficiency and appropriate to use in the facilities. The supplied inoculum activated sludge, after brought to the desired MLSS level which was between 3,000 mg/L and 5,000mg/L, was fed to the SBR system. The remaining sludge was kept in the standby reactor by continuously aeration and feeding the synthetic wastewater as substrate. Al-Rekabi et al. (2007) have pointed out that SBR requires alternating conditions of low and high dissolved oxygen concentrations. After adjusting the MLSS value, the SBR tank (right) and the tank where the residual sludge was kept alive (left) are shown in the Figure 3.4. During the experimental studies, the lockdown was applied because of the Covid-19 pandemic about three months. Therefore, new inoculum sludge was taken from the same WWTP and then the reactor was operated. The schematic diagram of the treatment system is depicted in Figure 3.5.

Figure 3.4 Activated sludge tank and SBR (Personal archive, 2019)

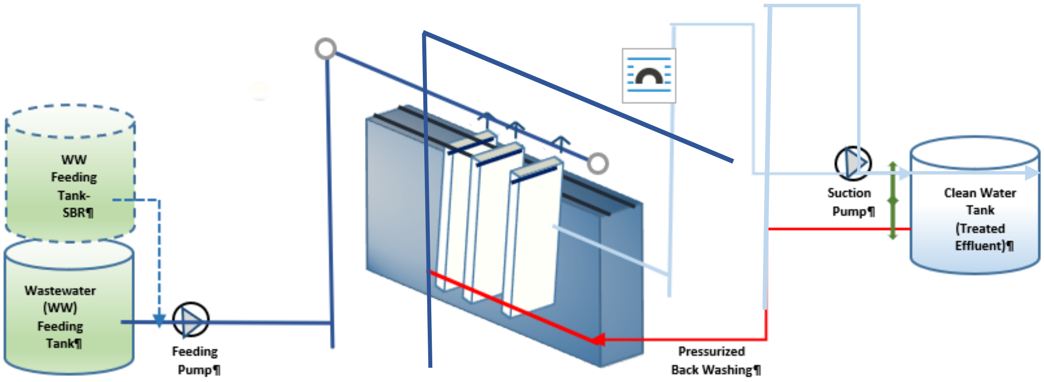


Figure 3.5 The schematic diagram of filtration unit used in experimental studies

3.3 Methods

The analyses were done in Department of Environmental Engineering, Sludge Laboratory at Dokuz Eylül University according to standard Standard Methods (APHA, 2005). In the lack of any standard methodology, the most accepted protocols in the scientific studies were used. Only some analyses results as SEM-EDS and FTIR were obtained through service procurement from research centers of Dokuz Eylul University. During the filtration operation, samples taken analysis parameters, applied standard methodology, and analysis frequency were summarized in Table 3.2 summarizes analyses and methods in detail. Analyzes for all parameters were performed at least in three replicates and values are expressed as means.

Table 3.2 Analysis parameters, frequency and methods used in experimental studies

Sample Name	Analysis Parameters	Analysis Frequency	Method or Device and Equipment
Influent Wastewater	BOD_5	Once in each operating mode	SM 5210 B, Merck Test Kit No: 00687
	COD	Once in each operating mode	SM 5220B, Merck Test Kit No: 14541
	SS	Once in each operating mode	SM 2540 D
	VSS	Once in each operating mode	SM 2540 E
	pH, Salinity, Conductivity	Once in each operating mode	WTW Multiparameter 304i
	Alkalinity	Once in each operating mode	SM 2320 B, Merck Test Kit No: 01758
	TN	Once in each operating mode	SM 4500 Norg B, Merck Test Kit No: 00613
	TP	Once in each operating mode	SM 4500-P B, Merck Test Kit No: 14543
	Sulphate	Once in each operating mode	SM 4500- SO_4^{2} C, Merck Test Kit No: 1454
	Viscosity	Once in each operating mode	ASTM D2196, Brookfield RVDV III type rheometer (Spindle no SC 27)
	Particle Size Distribution	Once in each operating mode	Malvern Mastersizer 2000
	Zeta Potential	Once in each operating mode	Zetameter 3+
Effluent	BOD_5	Once in each operating mode	SM 5210 B, Merck Test Kit No: 00687
	COD	Once in each operating mode	SM 5220B, Merck Test Kit No: 14541
	pH, Salinity, Conductivity	Once in each operating mode	WTW Multiparameter 304i
	Alkalinity	Once in each operating mode	SM 2320 B, Merck Test Kit No: 01758

Table 3.2 continues

Sample Name	Analysis Parameters	Analysis Frequency	Method or Device and Equipment
Effluent	Sulphate	Once in each operating mode	SM 4500- SO_4^{2} C, Merck Test Kit No: 14548
	TDS	Once in each operating mode	SM 2540 C
	SS	Once in each operating mode	SM 2540 D
	VSS	Once in each operating mode	SM 2540 E
	Residual Chlorine	Once in each operating mode	SM 4500-Cl B, Merck Test Kit No: 14730
	Fluoride	Once in each operating mode	SM 4500-F B and D
	Viscosity	Once in each operating mode	ASTM D2196, Brookfield RVDV III type rheometer (Spindle no SC 27)
	Particle Size Distribution	Once in each operating mode	Malvern Mastersizer 2000
	NH_4^+-N, NO_2^-, NO_3^-	Once in each operating mode	SM 4500, Merck Test Kit No: 14558, 00609, 14513
	TN	Once in each operating mode	SM 4500 Norg B, Merck Test Kit No: 00613
	TP	Once in each operating mode	SM 4500-P B, Merck Test Kit No: 14543
	EPS - Polysaccharide	Once in each operating mode	Extraction for EPS analysis: Goodwin & Forster (1985). For polysaccharide analysis: Dubois et al. (1956)
	Heavy Metals (Al, As, Be, B, Cd, Cr, Co, Cu, Ni, Zn, Fe, Pb, Mn, Mo, Se, Na, Ca)	Once in each operating mode	ICP-QMS (Perkin Elmer-Optima 2100 DV)
	E-Coli	Once in each operating mode	SM 9222 B
From Support Material	SEM & FTIR	Once in each operating mode	Service Procurement

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This study carried out at Sludge Treatment Laboratory of Dokuz Eylül University. The pilot-scale system was designed, built, and operated between November 2019 and September 2020. The experimental results of the study are presented and discussed with previous findings in the literature in this chapter.

4.2 The Characteristics of Synthetic Wastewater

The characterization studies of the prepared synthetic wastewater simulating domestic / urban wastewater were done for each experimental trial. Content of the prepared synthetic wastewater and COD, BOD, PM, TN etc. values are as follows. Prepared wastewater has been fed to the filtration system.

Table 4.1 Synthetic wastewater content

Parameter	Unit	Value (Average ±SD)
Biochemical Oxygen Demand (BOD_5)	mg/L	690 ± 11.6
Suspended Solids (SS)*	mg/L	56 ± 12.2
Chemical Oxygen Demand (COD)	mg/L	1,021 ± 60.2
Alkalinity	$mgCaCO_3$ /L	386 ± 28.3
Total Nitrogen (TN)	mg/L	108.5 ± 2.6
Ammonia (NH_4^+-N)	mg/L	85.1 ± 5.7
Total Phosphorus (TP)	mg/L	4.29 ± 0.5
Sulphate ($SO_4^{=}$)	mg/L	18.8 ± 1.5
Total Dissolved Solids (TDS)	mg/L	1,518 ± 45
Chloride (Cl^-)	mg/L	245 ± 7
pH		8.1 ± 0.4
Electrical Conductivity (EC)	mS/cm	2.56 ± 0.05
Salinity	‰	1.14 ± 0.05

* There was no SS when it was prepared for the first time. When it wasprepared at high volumes, a precipitate was formed depending on time.

4.3 The Characteristics of Domestic Wastewater

The real wastewater sample taken from Akhisar WWTP as explained in Chapter 3 was exposed to the characterization studies. The characteristics of the domestic wastewater was given in Table 4.2 .

Table 4.2 The characteristics of the wastewater

Parameter	Unit	Value
SS	mg/L	150
VSS	mg/L	130
COD	mg/L	422
pH	-	7.82
EC	mS/cm	1.51
Salinity	‰	0.6
Cl	mg/L	280
Alkalinity	$mgCaCO_3/L$	406
TN	mg/L	50
NH_4-N	mg/L	44,4
TP	mg/L	6.5
SO_4	mg/L	154

4.4 Operation of Sequencing Batch Reactor (SBR)

SBR had several basic operational modes or periods for biological treatment of synthetic or domestic wastewater. The periods were filling, reaction, settling, drawing, and idle in a time sequence. These operational modes can be modified depending on the operational strategies desired (Al-Rekabi et al., 2007). However, in this study, the same operational cycle was applied to the both synthetic and domestic wastewater as given in Table 4.3. The working conditions of the SBR unit were determined based on the calculations as given in Metcalf & Eddy (2013). In accordance with the C/N/P ratios of the wastewater, in order to ensure nutrient removal, anoxic zone was created for 1 hour while fully aeration for 3 hours and then settling for 1 - 1.5 hours were applied. Total cycle time of the operation was about 5.5 hours.

Table 4.3 Operation of SBR

SBR Properties	(h)
Total cycle time (t_t)	5.5
Fill (t_f)	0.25
React/aerate (t_a)	3
Settle (t_s)	1.5
Decant (t_d)	1
Idle (ti)	-

4.4.1 The Characteristics of Sludge used as Inoculum for SBR

Activated sludge samples to be used as an inoculum were supplied from Çiğli WWTP as detailed in Chapter 3. The characteristics of these sludges are given in Table 4.4. A significant difference was observed on EC, salinity, CST, and SVI parameters of both sludges. However, SS and VSS results were found as very close to each other. The sludges were taken before and after pandemic lockdown period. This situation was reflected in the operating results from time to time. The changes in the sludge during the operation process were monitored as given the later parts of this chapter.

Table 4.4 Characteristics of Çiğli WWTP sludges (07.02.20 & 22.06.20)

Parameter	Unit	07.02	22.06
SS	mg/L	11,516	10,580
VSS	mg/L	8,916	8,575
COD	mg/L	10,090	10,870-
pH		6.93	6.91
EC	mS/cm	11.33	4.39
Salinity	‰	6.1	2.2
CST	s	18.8	23.6
SVI	mL/g	114	85

Particle size analysis (PSA) was carried out on the inoculum sludge as shown in Figure 4.1. The detailed information about the PSA results is given in Table 4.5.

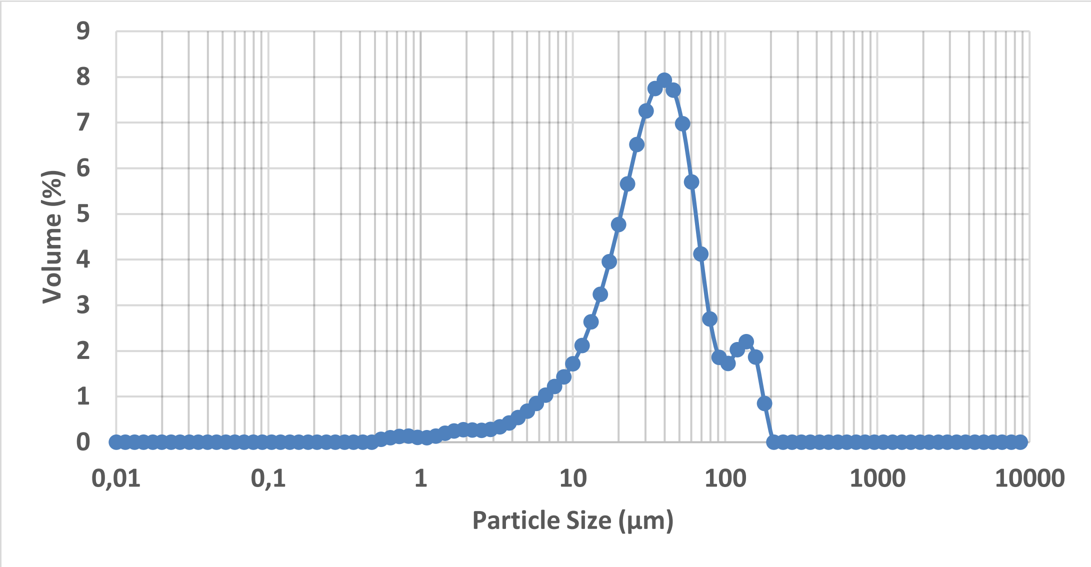


Figure 4.1 Particle size distribution of different activated sludge

Table 4.5 Detailed information on particle size distribution of inoculum sludge

D [4, 3] - Volume weighted mean (µm)	21.569
D [3, 2] - Surface weighted mean (µm)	7.952
Specific surface area (m^2/g)	0.0319
d(0.1) (µm)	11.082
d(0.5) (µm)	36.862
d(0.9) (µm)	94.380

4.5 Filtration System Performance

The filtration unit was operated at each 5-flow level system by adjusting via the flowmeter for an hour. Each of them was denoted as “set” in this chapter. During the research period, a total of 8 sets were applied for synthetic wastewater treatment as follows:

[1] One Layer each side Cotton textile fabric (TF),
[2] Four Layer each side Cotton textile fabric (TF),
[3] One Layer each side Metal Braided Textile Fabric (MBTF),
[4] Four Layer each side Metal Braided Textile (MBTF),

[5] SBR + Four Layer Metal Braided Textile Fabric (MBTF)

[6] SBR + Four Layer Metal Braided Textile Fabric (MBTF)+ a layer S1 each side,

[7] SBR + Four Layer Metal Braided Textile Fabric (MBTF) + a layer S3 each side

[8] SBR + Four Layer Metal Braided Textile Fabric (MBTF) + a layer AC each side

Subsequently, the best performing set as 8^{th} were applied for the real wastewater treatment. The results belonging to the experimental series were given in detail in the following subsections.

4.5.1 Performance of One Layer each side Cotton Textile Fabric (TF) Filtration

Cotton Textile Fabric (TF) that having 20µm pore size was selected as first textile material used in the filtration cassette. The first set was carried out to measure the filtration efficiency of TF. Synthetic wastewater was transferred from influent tank to the cassette system by a submersible pump with control by flowmeter. The flow rates over five stages from 1 to 5 as 13, 37, 61, 80, and 90 mL/min were applied in all sets. pH, EC, Salinity, and COD parameters were analyzed. The results of the first set are given in Figure 4.2.

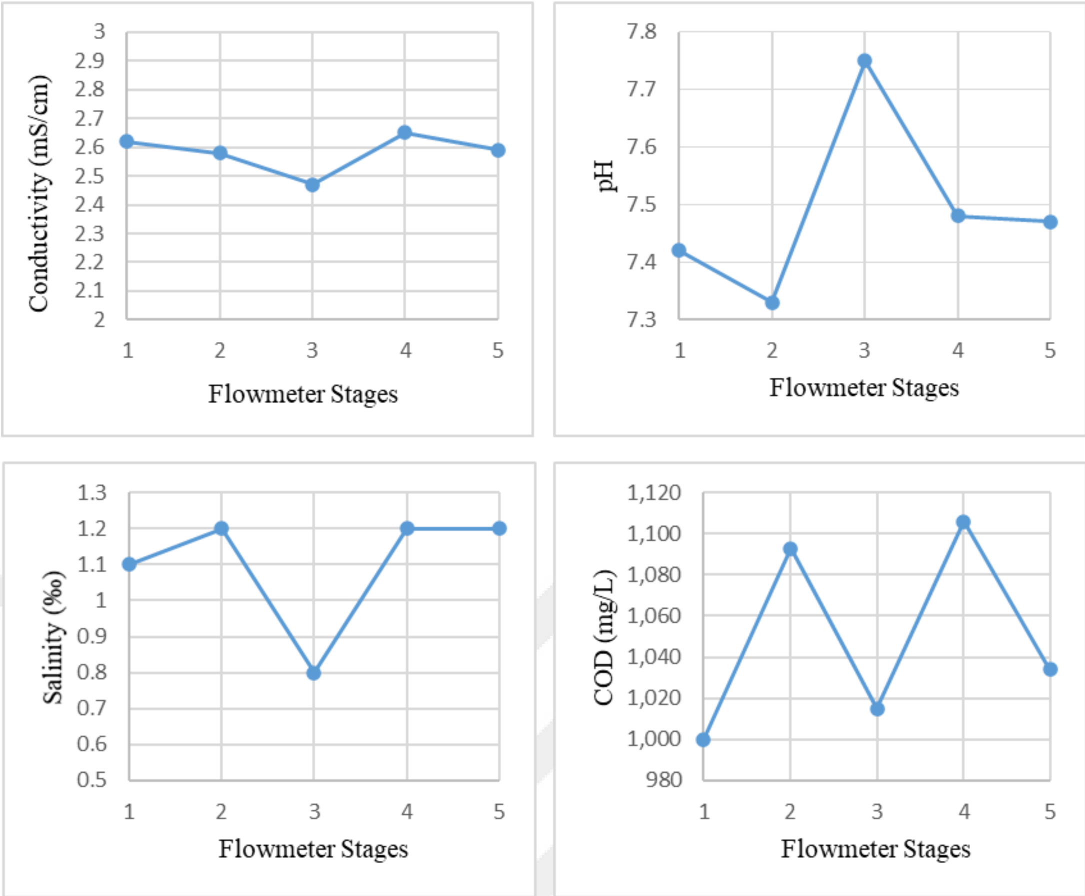


Figure 4.2 The variations of EC, pH, Salinity, and COD parameters in the effluent as a function of applied flowmeter stages for 1st Set (TF)

Wastewater temperature varied between 18 °C and 20 °C during the operation. After the synthetic wastewater was fed to the filtration unit, fluctuations were observed in the filtrate, and there was no stabile behavior. The pH ranged between 7.3-7.8. This range is known as the appropriate filtration range (Adin & Elimelech, 1989). The salinity only experienced a significant decrease in the 3rd stage, this decrease was also reflected in the electrical conductivity, but the system would have compensated itself in other flow rate stages. Those results have pointed out that this filtration material was inefficient to decrease conductivity and salinity values. The COD values in filtrate samples were obtained as 1,000 mg/L, 1,093 mg/L,1,015 mg/L, 1,106 mg/L and 1,034 mg/L, respectively, depending on the flowrate stages. As a result of the first set operation, the single-layer Cotton textile fabric (TF) filter system could not reach sufficient efficiency on the COD parameter alone. Therefore, it was decided to increse the number of TF layers for next trials.

4.5.2 Four Layer each side Cotton Textile Fabric (TF) Filtration

After the first set as the 2nd set, TF material was mounted on each surfaces of the cassette system as 4 layers. The system was operated under the same conditions as in the 1st Set. The wastewater temperature varied between 19 ºC and 20 ºC. During the 2nd set, no significant difference was observed on the pH, EC, and salinity values in the effluent streams compared to the influent wastewater as shown in Figure 4.3. Multilayer application of TF material did not also affect the parameters.

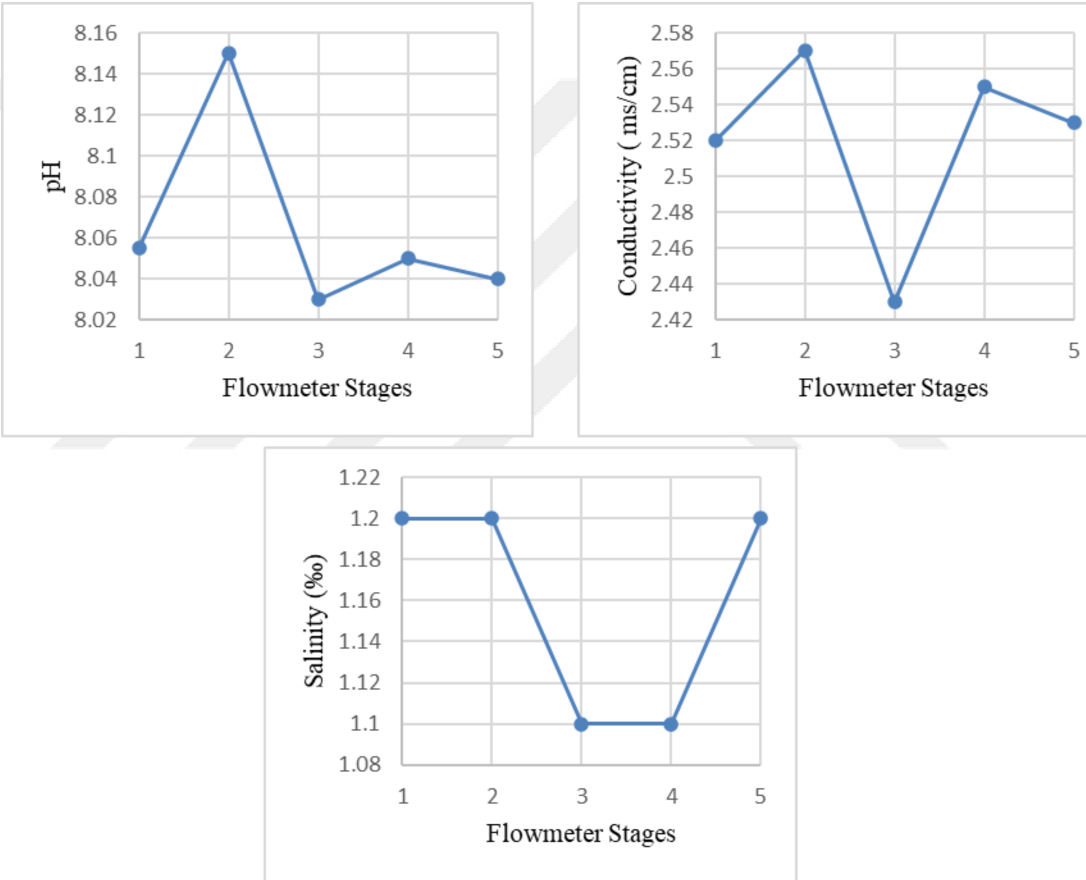


Figure 4.3 The variations of EC, pH, and Salinity in the effluent as a function of applied flowmeter stages for 2nd Set (4-layer TF)

In this set, the increase in the layer in the filtration material on the COD parameter led to slightly positive effect, but the removal efficiencies in the relevant system were not capable of overriding existing technological systems. Considering that options such as increasing the number of layers of the textile material in question did not cause a remarkable change on the efficiency, it was planned to test the metal braided textile fabric, which was selected as 2nd material, as a single layer and to shape the study depending on the result of this set. After a total of 5 hours and five days of operation, the change in each layer of filter materials can be seen from Figure 4.4. It has been observed that the pollution in the material's surface decreases as it was moved from the first contacting layer to the outer surface.

Figure 4.4 Photographs of the TF material from 1st to 4th layer end of 2nd set (Personal archive, 2019)

The effect of the 2nd set operation on COD parameter increased with the increased number of the layers. As a function of flow stages, COD values were measured as 1,023 mg/L, 1,031 mg/L, 1,025 mg/L, 997,and 1,020 mg/L respectively, as plotted in Figure 4.5. As a result of the operation, it was observed that the efficiency increased compared to the 1st set, but the desired removal efficiency could not be achieved.

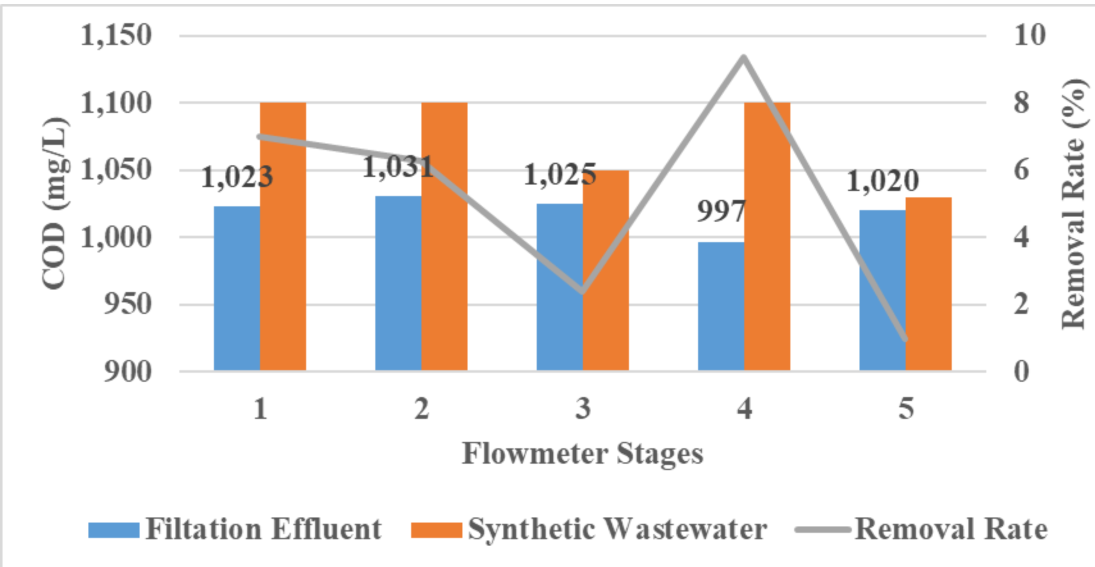


Figure 4.5 Effect of 4-layer cotton textile fabric (TF) on COD parameter

During the operation, no clogging problem was observed in the second set. More efficiency was obtained from a single layer use. However, it was about 10% levels, which was very poor to eliminate pollution.

4.5.3 One Layer each side Metal Braided Textile Fabric Filtration

MBTF was mounted on each surfaces of the cassette system as one layer. It was operated for a total of 5 hours, 1 hour each flow rate for five days. Wastewater temperature varied between 18 °C and 19.5 °C. pH, EC, and salinity values in the effluent streams were depicted in Figure 4.6. There was no more changes in the values except for the highest feed rate 90 mL/min flowrate which had a significant effect on salinity and electrical conductivity.

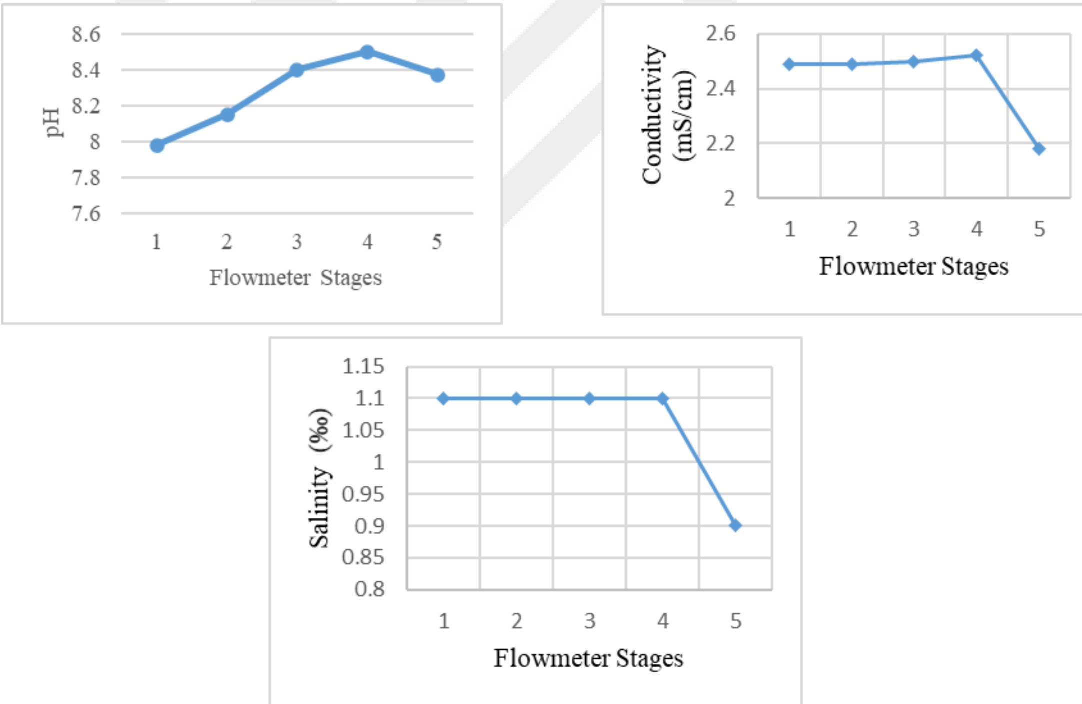


Figure 4.6 The variations of EC, pH, and Salinity in the effluent as a function of applied flowmeter stages for 3rd Set (one-layer MBTF)

The photographs of the used filter material were given in Figure 4.7. COD values for each flowmeter stage were found as 970, 920, 959, 963 and 826 mg/L, respectively. COD removals were about 20% as shown in Figure 4.8 for this trial. One-layer MBTF showed better treatment performance than one-layer TF filtration. However, the treatment level was not at the desired level for the COD parameter. So, for the next trial, four-layer MBTF filtration was applied. For this set, it can be said that the filtration efficiency increases as the input flow rate increases.

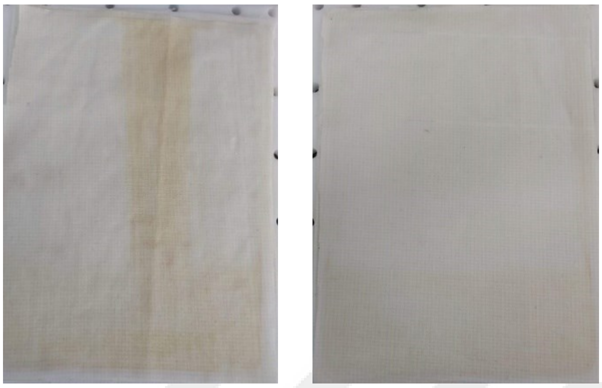
Left Side  Right Side

Figure 4.7 Photographs of the one-layer MBTF used for the filtration (Personal archive, 2019)

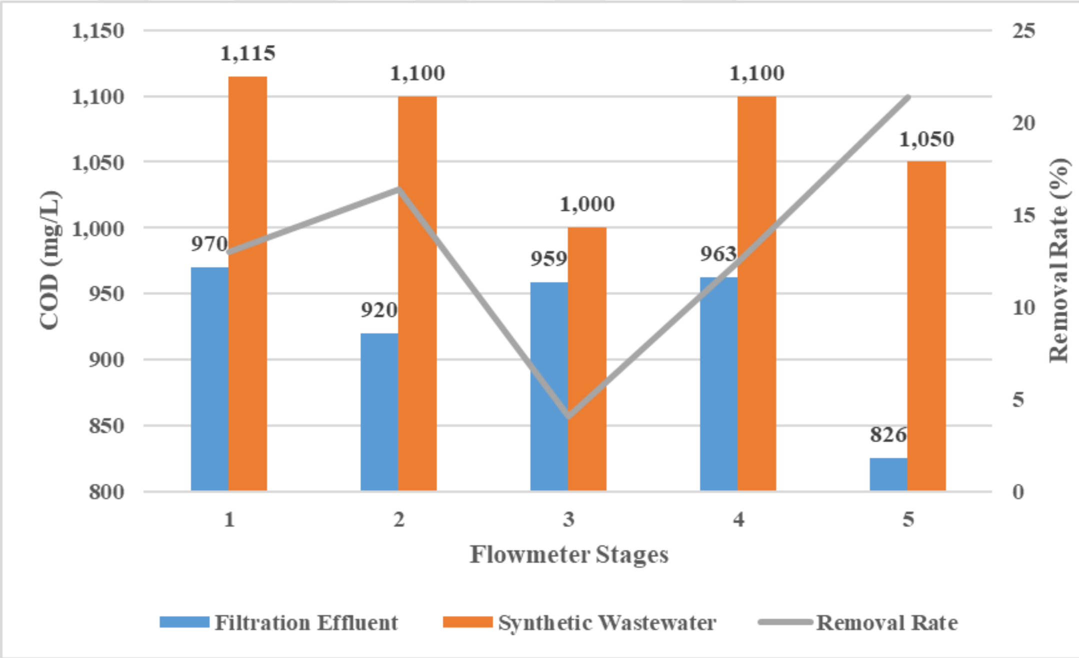


Figure 4. 8 Effect of one-layer MBTF filtration on COD parameter

4.5.4 Four Layer each side MBTF Filtration

The changes in pH, COD , conductivity and salinity parameters were given in Figure 4.9 for the fourth set of the operation done by four layers MBTF. There was no significant change for all parameters. Wastewater temperature varied between 18.8 °C and 17.3 °C during the filtration. The four-layer MBTF material were shown in Figure 4.10. It was observed that the pollution in the material's surface decreased as it was moved from the first contacting layer to the outer surface. While working the 4th set, COD values were obtained as 727, 739, 721, 777 and 796 mg/L respectively, for each stage, as depicted in Figure 4.11. The removal efficiencies ranged between 25% to 35%. Figure 4.12 showed some images of synthetic wastewater and filtration effluent.

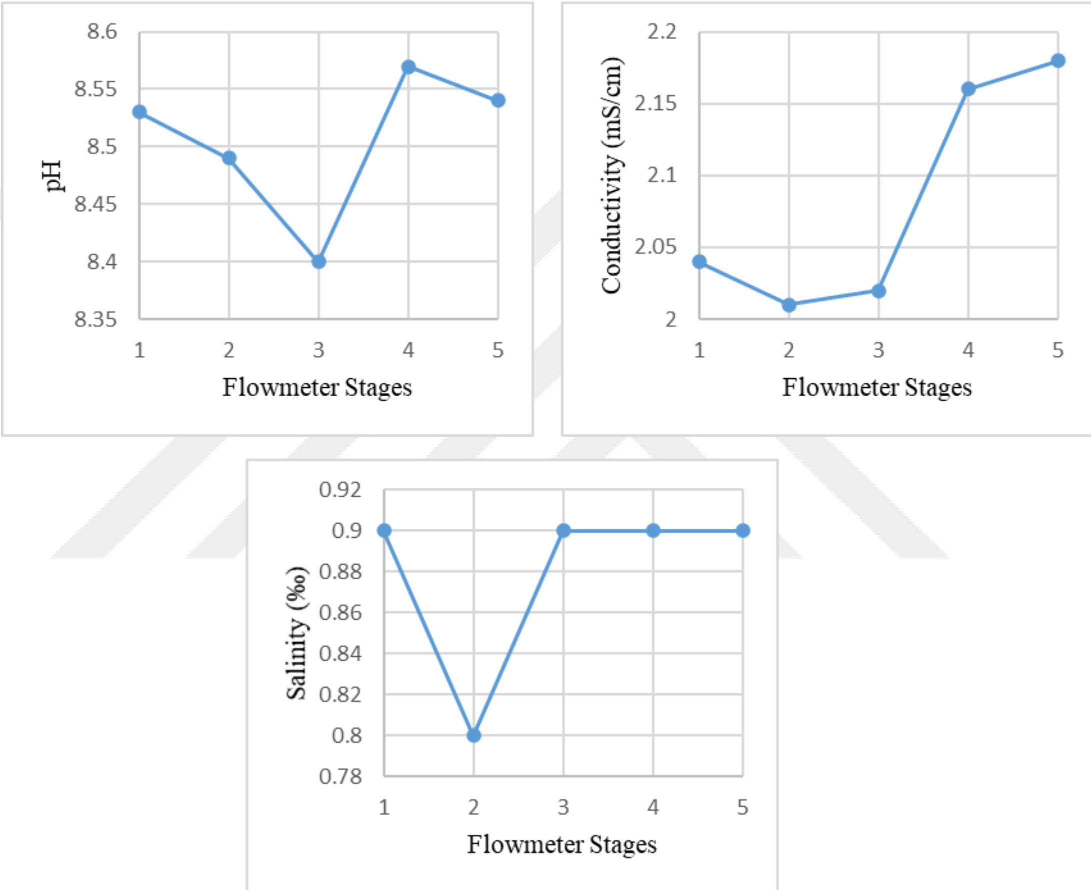


Figure 4.9 The variations of EC, pH, and Salinity in the effluent as a function of applied flowmeter stages for 4th Set (four-layer MBTF)

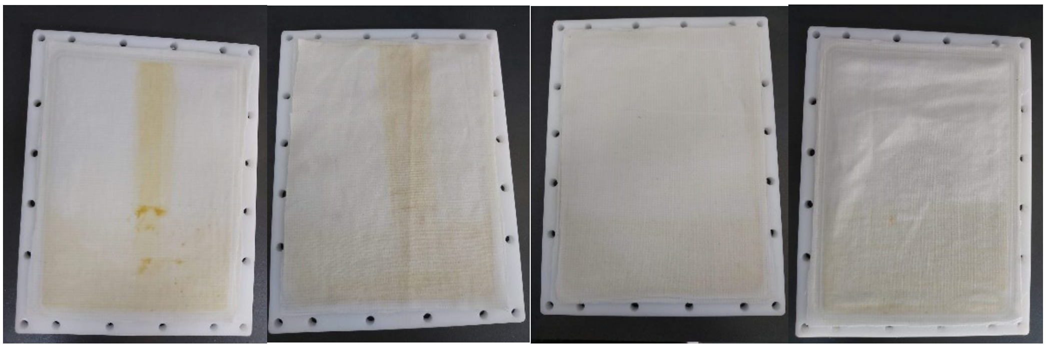


Figure 4.10 Photographs of the MBTF material from 1st to 4th layer end of 4th set (Personal archive, 2019)

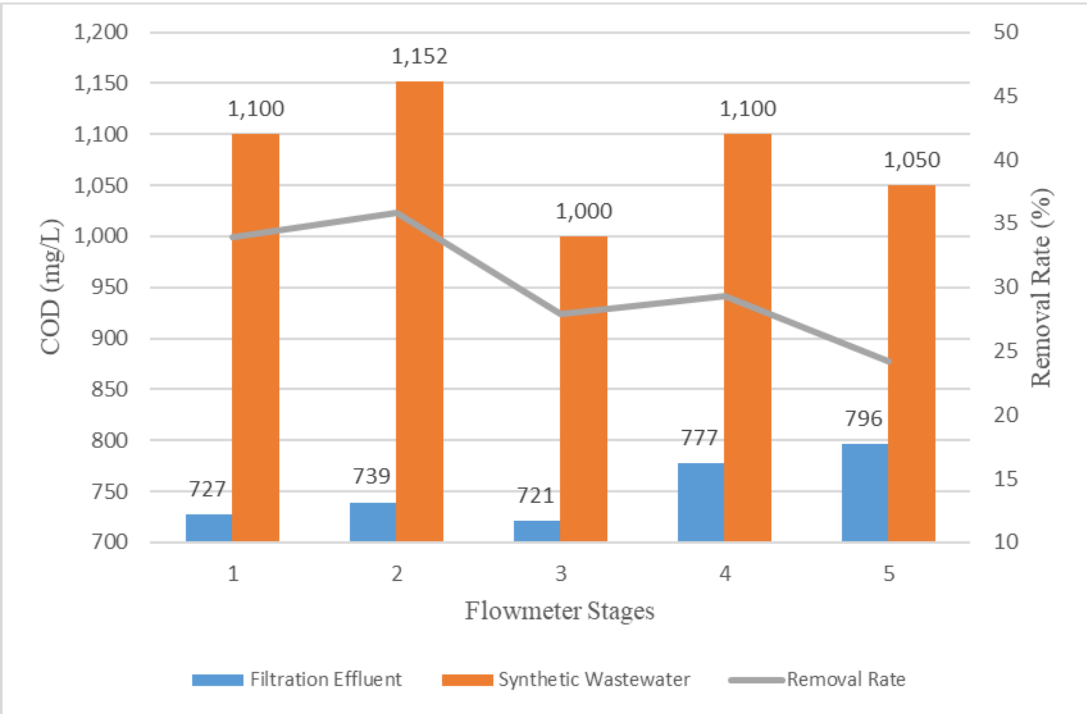


Figure 4.11 Effect of 4 Layer stainless steel mesh fabric on COD parameter

Figure 4.12 Visuals of Synthetic Wastewater (L) and Filtration Effluent (R) (Personal archive, 2019)

4.6 Comparison of Filtration Performance of TF and MBTF Materials

The experimental results belonging to the first fourth series were depicted in between Figure 4.13 and Figure 4.16. During the operating period, the lowest temperature was measured as 17.3 °C in 4 layers MBTF filtration system. However, the highest temperature belonged to TF with 20.4 °C. Temperature is an important environmental parameter affecting the filtration efficiency by changing the viscosity (Sutherland,2008b; Sutherland,2008a). Comparing 4 separate filtration studies, MBTF showed an increase effect on COD and BOD removals. For TF, four layers TF, MBTF and four layers MBTF series, BOD removal efficiencies reached 8.3%, 15.4%, 30% and 50%, respectively, while COD removal were obtained as 7%, 8%, 14% and 30% respectively.

As mentioned in the Filter and Filtration Hanbook (2008), fabrics will probably be preferred filter sizes or where actual absorption as well as mechanical is required for larger screening. Fabrics can be enhanced with a wide variety of materials, knitted and non-woven materials, whose properties can be further modified by impregnation with synthetic resin or a similar process.

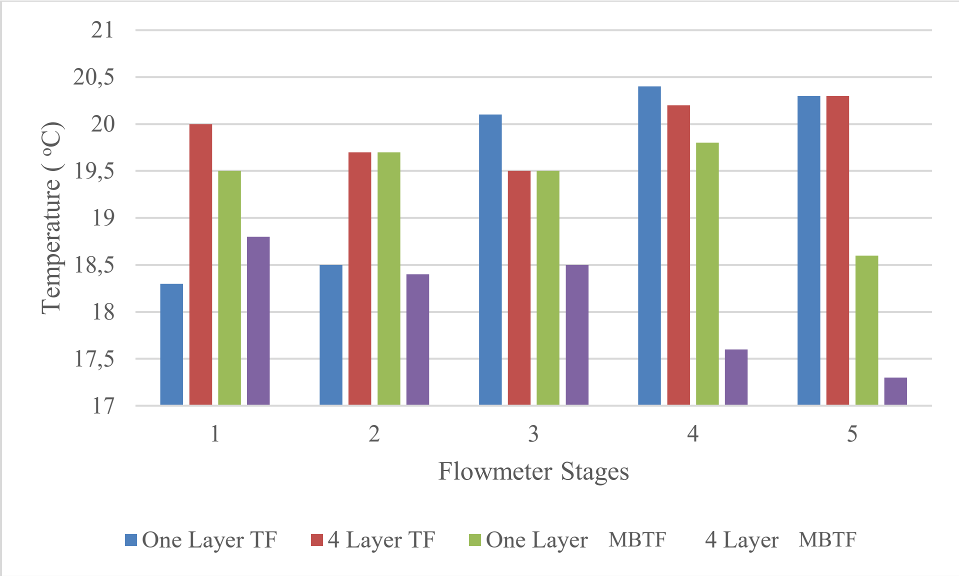


Figure 4.13 The changes in temperature values

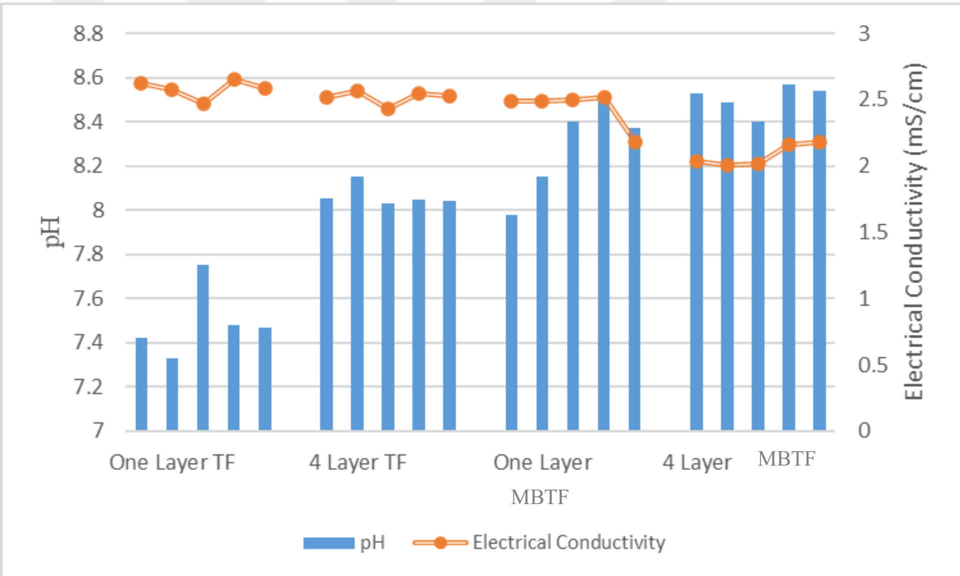


Figure 4.14 The changes in Electrical Conductivity and pH values

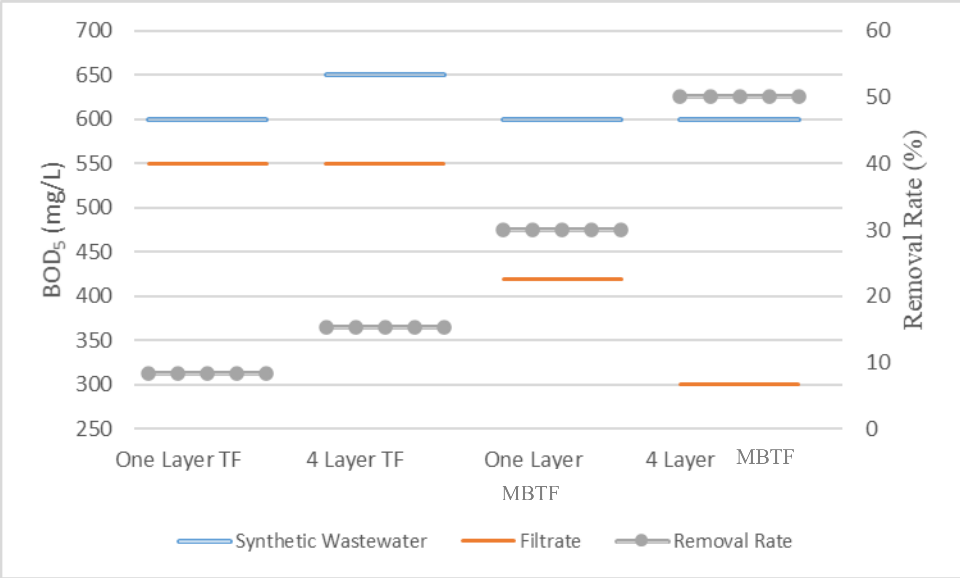


Figure 4.15 The changes in BOD5 values

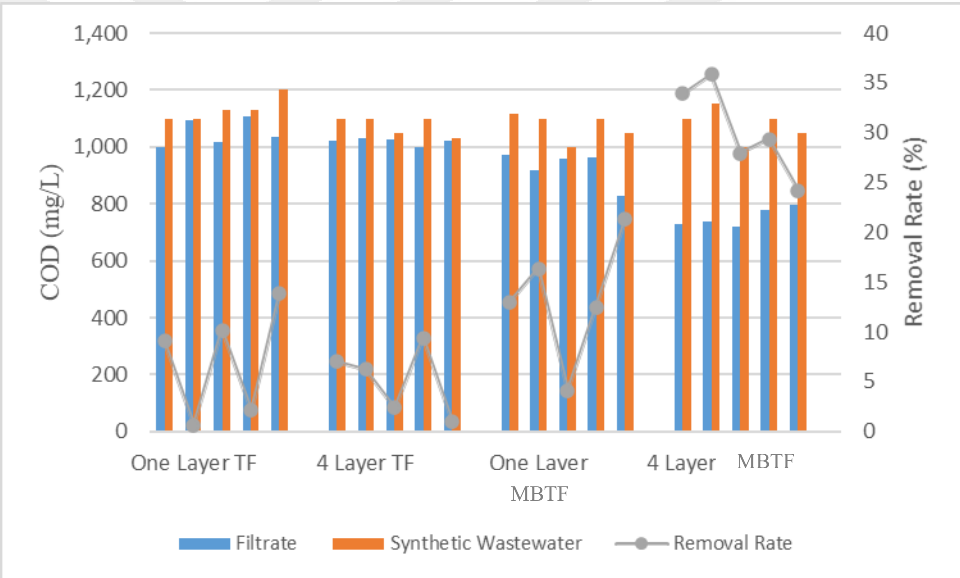


Figure 4.16 The changes in COD values

4.7 SBR Implementation

Regarding the lower organic matter removal in first fourth series, SBR was integrated to the filtration unit. It was suitable for the final effluent through the physical filtration process, and the system currently needs a biological treatment system. The flow scheme of the operated system is given in Figure 4.17.

SBR's volume was 40 liters in total and 35 L volume was actively used. During SBR operation, inoculum activated sludge was supplied twice from İZSU Çiğli Municipal WWTP as mentioned in Chapter 3. Operating conditions of the system were first set as 4 hours of effective reaction as one hour anoxic, and 3 hours aerobic conditions. In anoxic cycle, dissolved oxygen value was kept as lower than 1mg/L, and in aeration cycle, it was kept as higher than 3mg/L. After the synthetic wastewater was fed to the reactor, the reaction time had been provided and about 1.5 hours settling period was allowed. The liquid remaining on the upper part of the SBR was transferred to the filtration unit by a diaphragm pump and the filtration unit was operated approximately one hour.

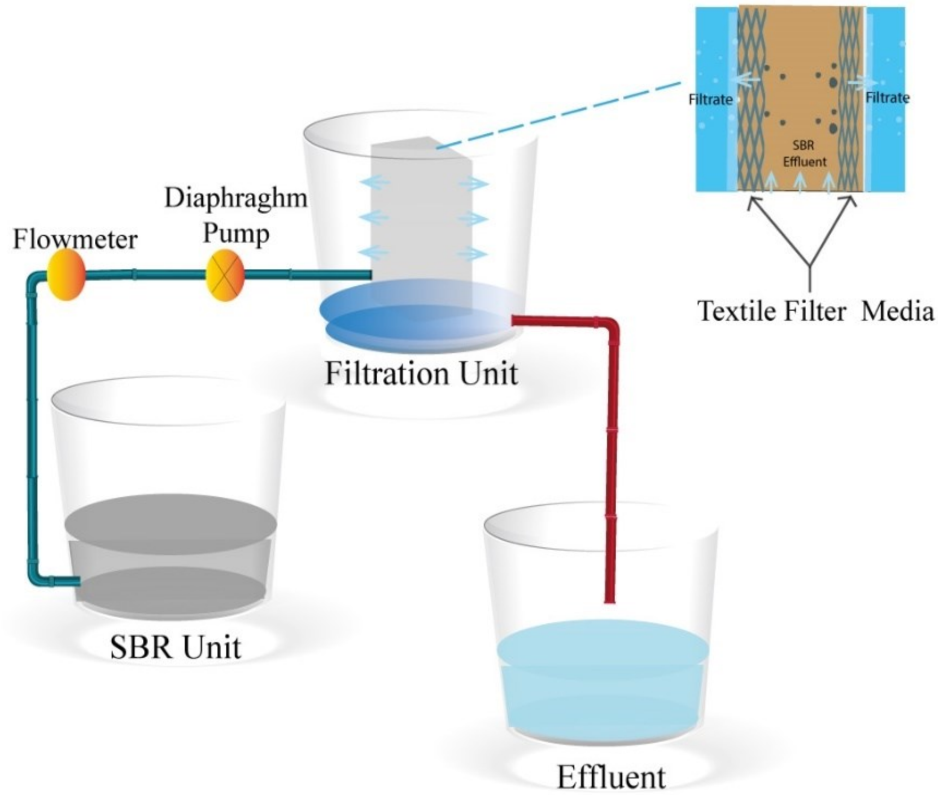


Figure 4.17 Schematic diagram of SBR + Filtration System used in the experimental studies

4.7.1 SBR + Four Layers MBTF Filtration

This study was carried out by connecting the 4-layer MBTF filter material. The SBR effluent was fed to the filtration unit under predetermined conditions for approximately 16 days of operation. Initially, MLSS value was determined as 5,000mg/L. Throughout the study, balance between the SBR effluent and feed water to filtration unit has been checked to protect the MLSS value.

In the first experiment with SBR improvement, the measured pH, EC, Salinity, and ORP values were plotted in between Figure 4.18 and Figure 4.21 for SBR effluent, filtrate, and sludge inside of the reactor. Reactor temperature varied between 10 °C and 12 °C. A slight increase in pH was observed in SBR effluent and filtrate. While the conductivity and salinity parameters experience a certain decrease compared to the sludge, no significant change was observed between SBR effluent and filtrate. It is also known that the inrease of salinity parameter negatively affect the COD removals (Wang et al., 2013).

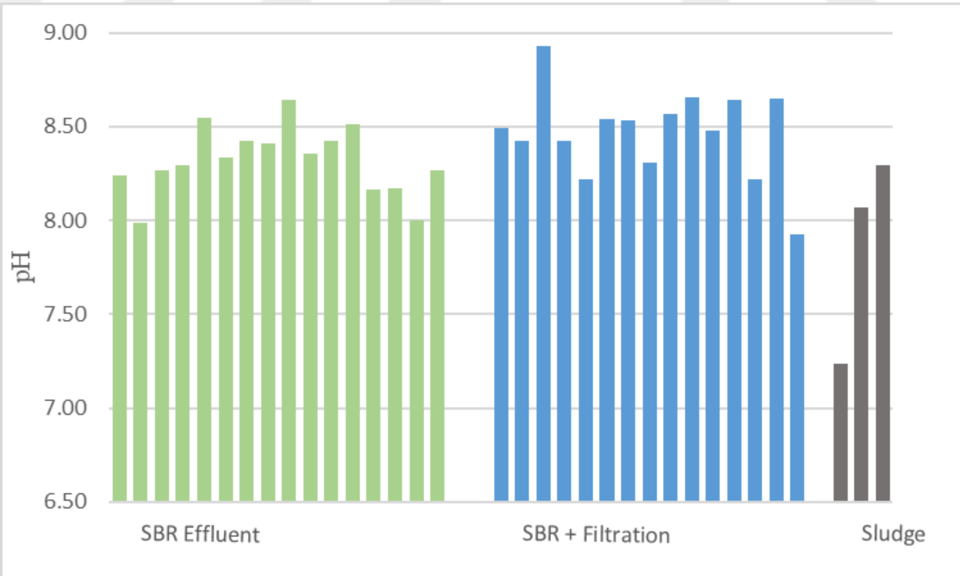


Figure 4.18 Daily changes in pH values

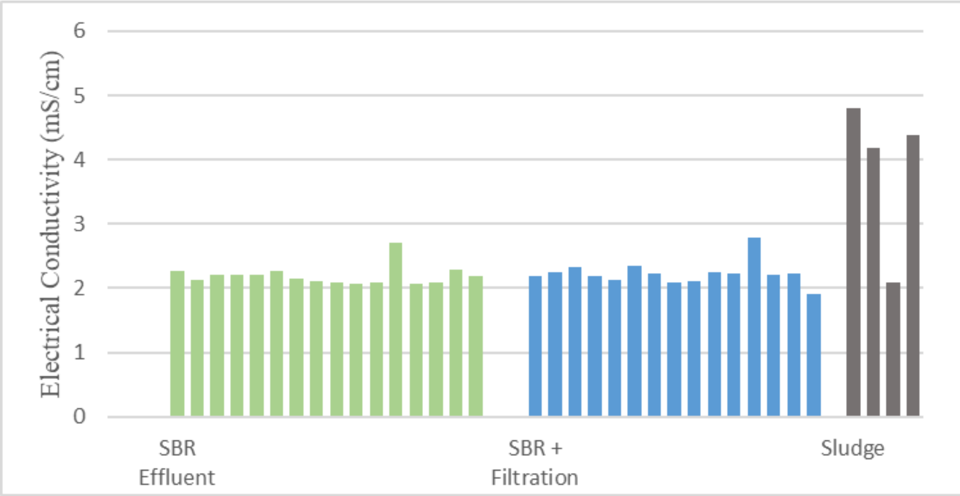


Figure 4.19 Daily changes in Electrical Conductivity values

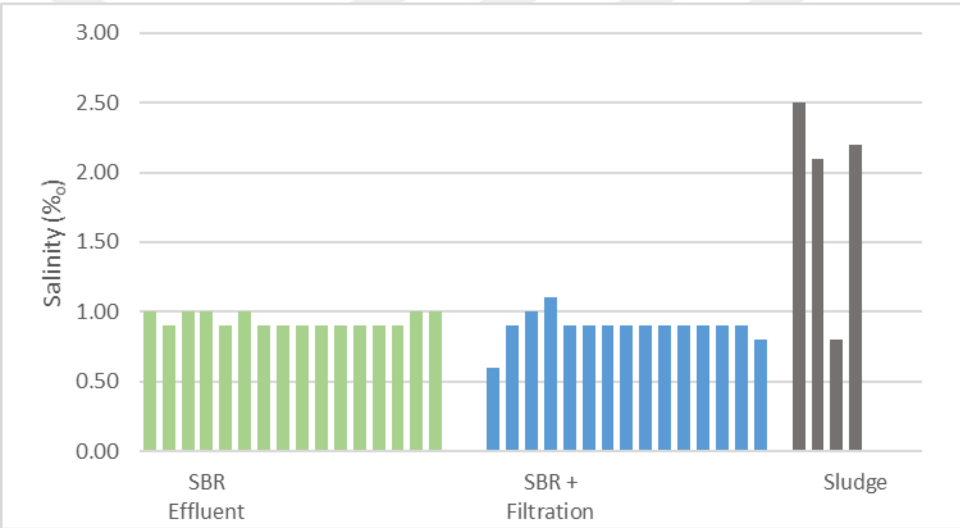


Figure 4.20 Daily changes in Salinity values

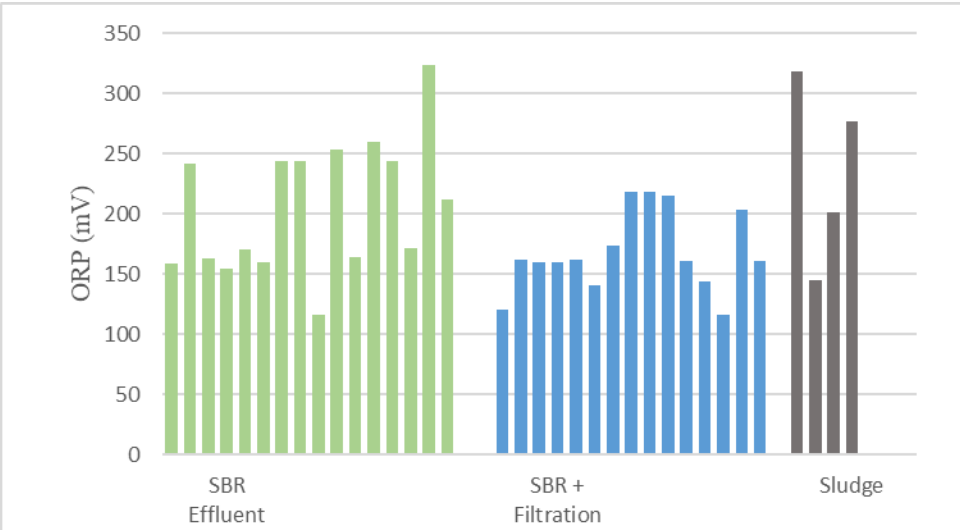


Figure 4.21 Daily changes in ORP values

The change on the COD parameter was observed for each stage during the study. While operating the system, the COD removal efficiencies were measured inscope of the SBR effluent and filtrate samples.

Syntethic wastewater with a COD value about 1,000 mg/L was fed to the SBR. The average COD values for SBR effluent ranged between 35 mg/L and 286 mg/L, while they ranged from 17 mg/L to 112 mg/L for filtrate samples. Average COD value in filtrate samples was 73.93 mg/L. The COD values were plotted in Figure 4.22. The COD removal efficiency did not exceed 30% with only the filtration system; however, it reached to 90% at the SBR effluent and a final 96-98% removal in terms of total treatment efficiency as shown in Figure 4.23. Filtration efficiency after SBR increased to 50% due to the increase influent water quality. Al-Rekabi (2007), reported that the effluent wastewater qualities as 92-118mg/L and 80-105 mg/L of COD in the comparison of two SBR systems that fed with synthetic wastewater with 1,096mg/L COD concentration.

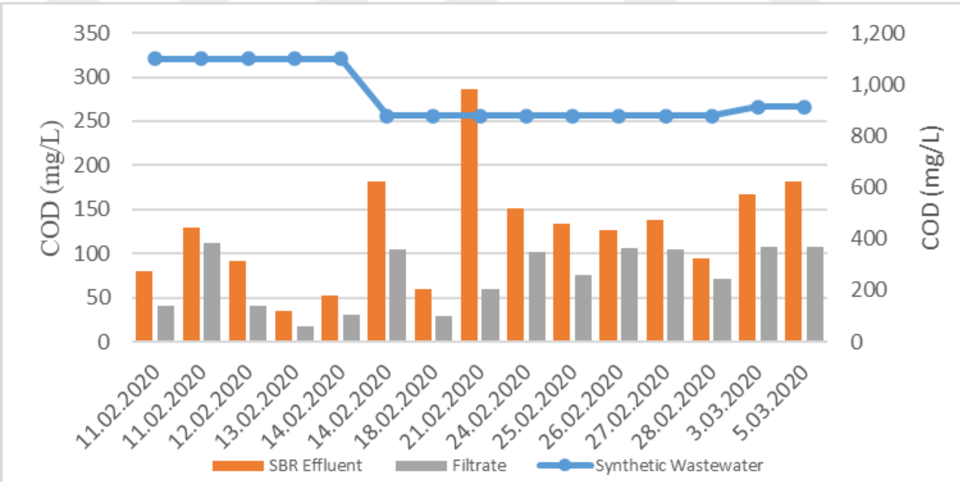


Figure 4.22 Daily changes in COD values

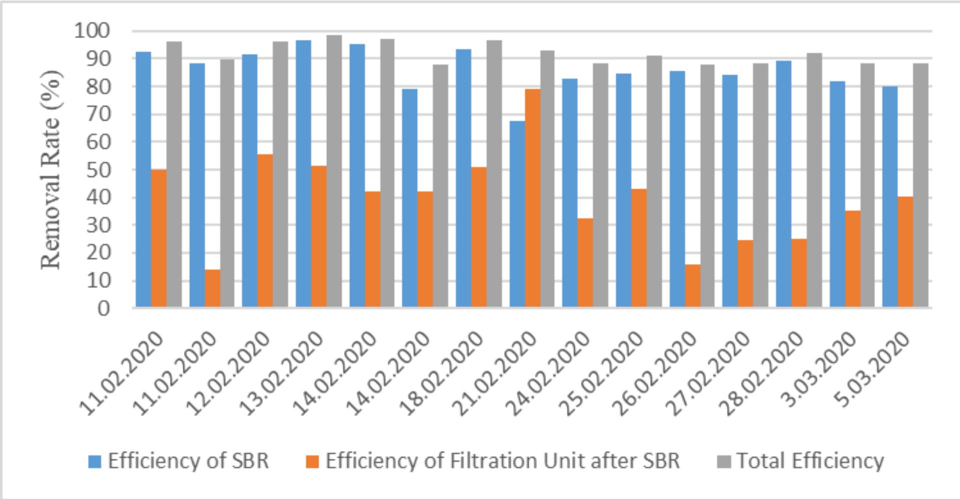


Figure 4.23 COD removal efficiencies

Total BOD_5 removal efficiency in the system after SBR improvement reached up to %98.3. Filtration systems did not reached higher efficiency rates with SBR implementation itself as shown in Figure 4.24.

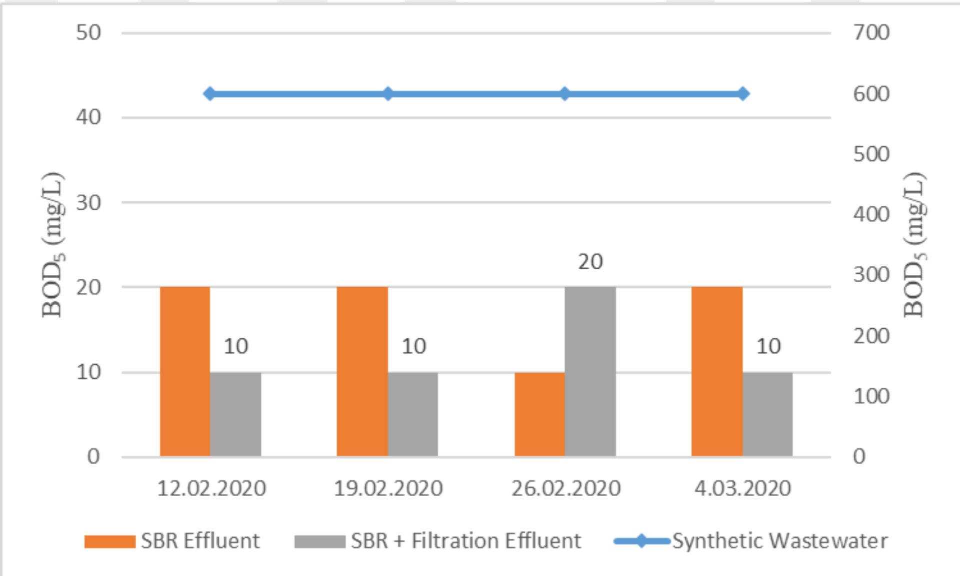


Figure 4.24 Effect of time on BOD_5

Particle size distributions is necessary in determining the effectiveness of filtration, as in all solid / liquid separation processes (Darby et al., 1991). Particle size of solids plays a vital role for formation. Larger particles promote the formation of layer and contribute to accumulating biosolids on the supporting material with a shorter time. Small particles may penetrate support material in early formation stage resulted with high permeate concentration. Particle size distribution of filtrate was shown in Figure 4.25. While volume weighted mean D[4,3] and surface weighted mean D[3,2] of SBR+ + layers MBTF filtration sample was analyzed as 10.045 µm and 5.739 µm. Particle size distribution of the SBR sludge , SBR effluent was analyzed. The volume weighted mean of SBR sludge was 48.898 µm SBR effluent was 29.674 µm, while this value for SBR+4 layers MBTF filtrate was measured as 10.045 µm. There were changes in particle size distribution between SBR and filtration effluent .

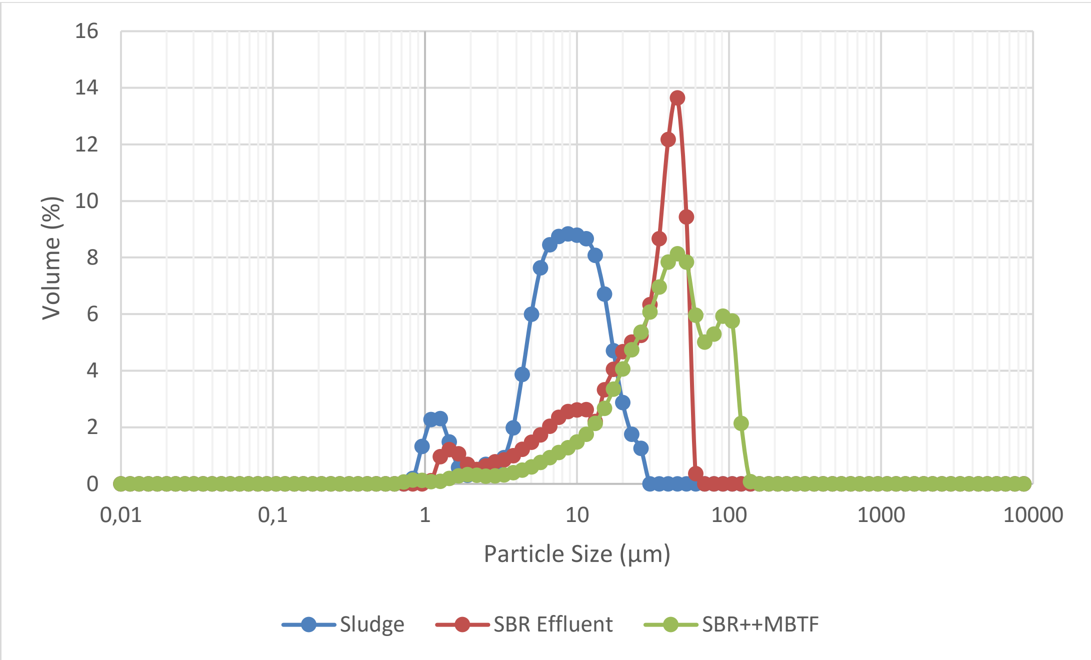


Figure 4.25 Particle size distribution between SBR Effluent- SBR +F and Sludge

The sludge and sludge properties in the SBR system were monitored in certain periods. Activated sludge was in the range of 120-140 mL/g Sludge Volume Index (SVI) showing reasonable sludge property. SBRs with MLSS range higher than 3,000mg/L lead to better treatment performance. In the light of this information, SBR system was started to operate at higher MLSS concentrations. Figure 4.26 showed the effluent suspended solids results and MLSS-MLVSS values in the SBR system. SVI and Zeta Potential values measured in the MLSS were plotted in Figure 4.27. MLSS concentration varied between 2,560 mg/L and 3,267 mg/L during operation. Average

MLVSS/MLSS ratio was found as 72.3%. Almost no change observed in CST and SVI values. The surface charge of sludge was measured with zeta potential to see its influence on solids retention in the filter. ZP values were found as very negative values.

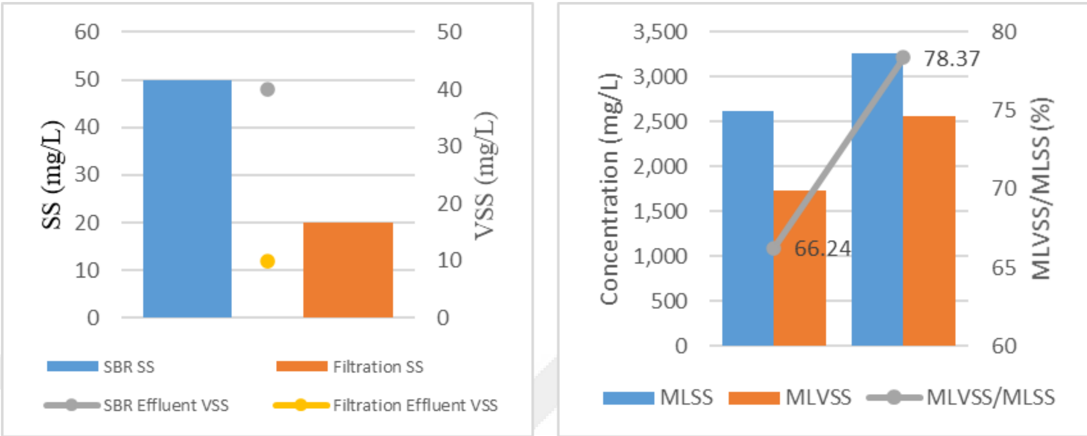


Figure 4.26 SS-VSS values of the samples taken from different treatment stages and MLSS MLVSS values in the reactor sludge

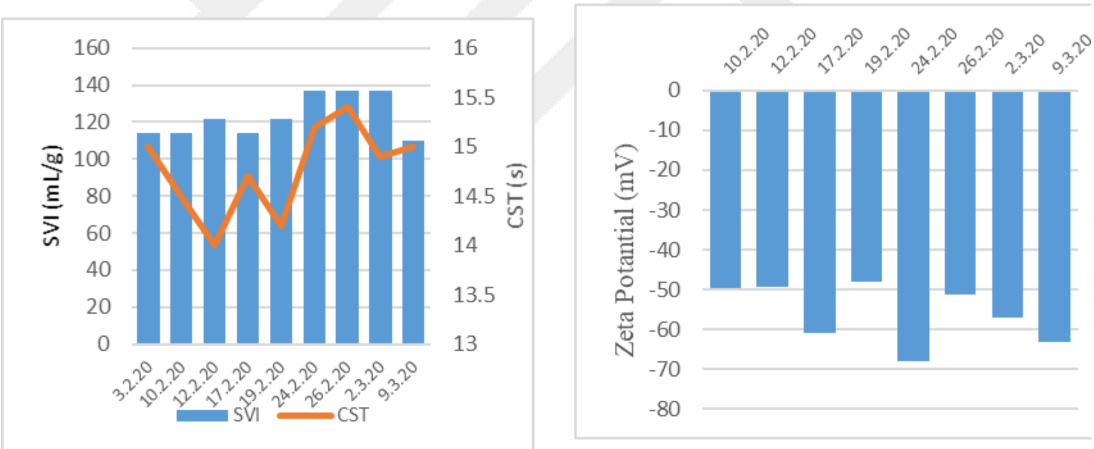


Figure 4.27 Changes in SVI and ZP values in the SBR sludge

The changes in TN and TP parameters during the operation were shown in Figure 4.28. They reached total removal efficiencies as 73% and 80%, respectively. Table 4.6 showed the changes in SO_4^{-2} parameter having almost 53.8% removal rate. The photographs of the used filter materials were given in Figure 4.29.

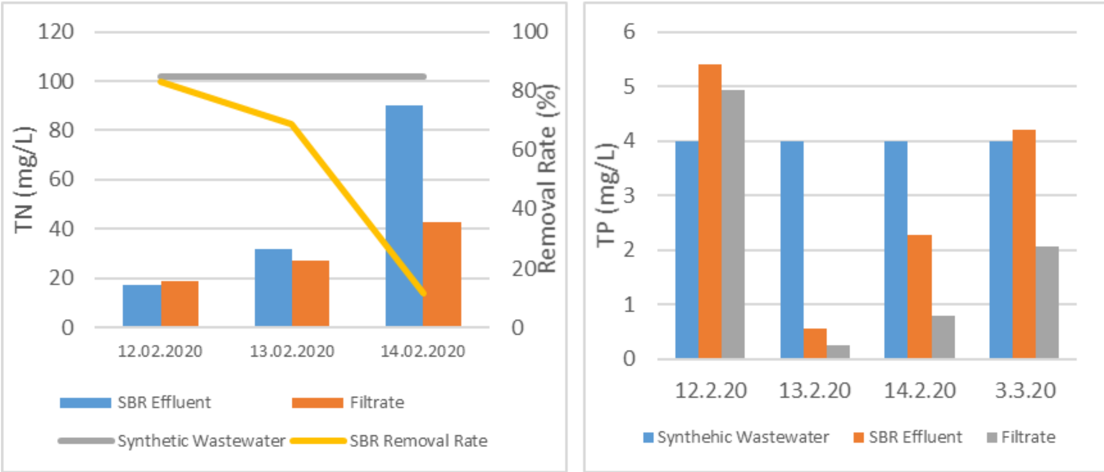


Figure 4.28 TN and TP changes during the operation

Table 4.6 Sulphate Concentrations

Sample	Unit	Value
Sludge	$mgSO_4^{=}/L$	130
SBR Effluent	$mgSO_4^{=}/L$	407
Filtrate	$mgSO_4^{=}/L$	188

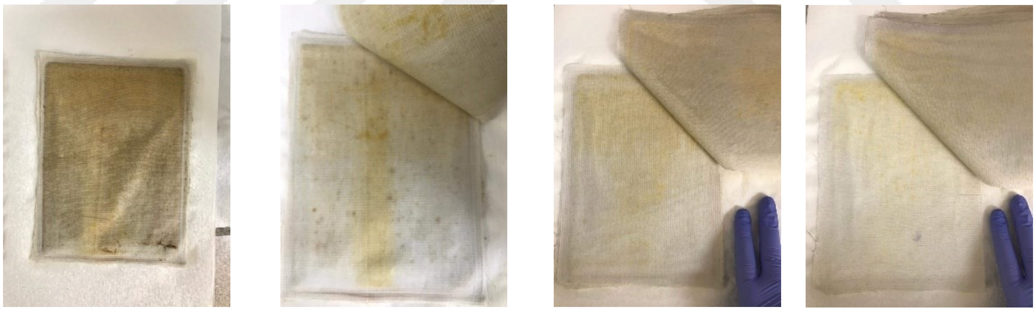


Figure 4.29 Photographs of filter materials used in the study from 1st to 4th layers (Personal archive, 2020)

4.7.2 Operation Problems Living in the Covid-19 Pandemic Break

In study, after the first Covid-19 cases were seen in Republic of Turkey on 11 March 2020. The operation of the reactor systems were stopped because of the legal lock down process until 1 June 2020. During the activated sludge in the inoculum reactor was kept alive by feeding synthetic wastewater once a week with continous aeration. However, this elapsed time had left various negative effects on the activated sludge. Various optimization studies were carried out to achieve the removal efficiencies obtained before the pandemic lockdown. Since the behavior of the Corona virus in wastewater and sludge was not fully known, it was seen as a priority to recover and use the existing "clean" sludge. However, activated sludge was also obtained from the Çiğli WWTP. These optimization studies were summarized in this subsection.

Various studies have been carried out on MLSS parameter for the recovery of the SBR treatment efficiency between 1 June 2020 and 2 July 2020. During the period, COD removal efficiencies were investigated. The changes in pH, EC, Salinity, ORP, dissolved oxygen (DO), COD, SS, VSS, MLSS, MLVSS, TN, TP, Alkalinity, Ammonium, and Nitrate parameters were given in between Figure 4.30 and Figure 4.37.

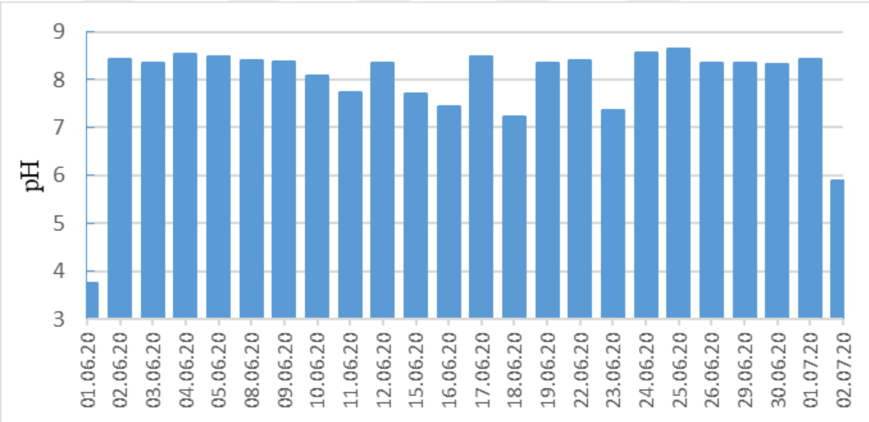


Figure 4.30 Changes in pH during optimization period

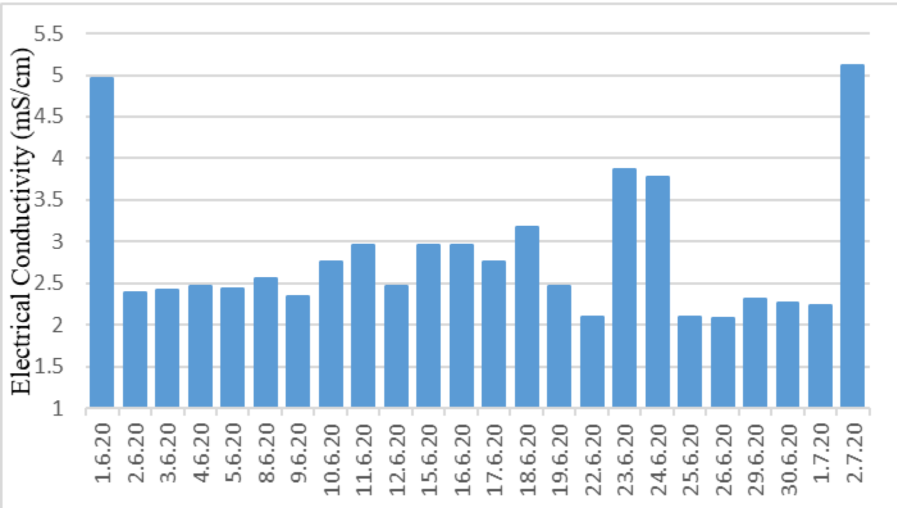


Figure 4.31 Changes in EC during optimization period

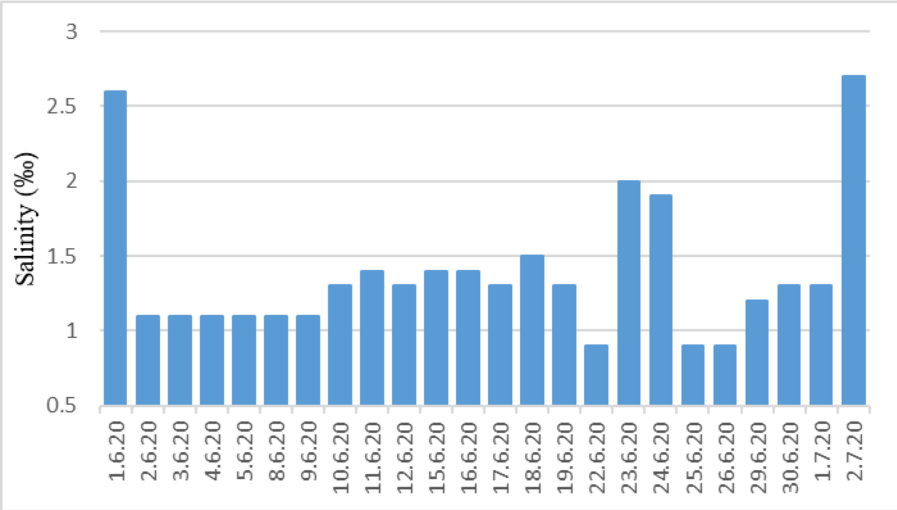


Figure 4.32 Changes in Salinity during optimization period

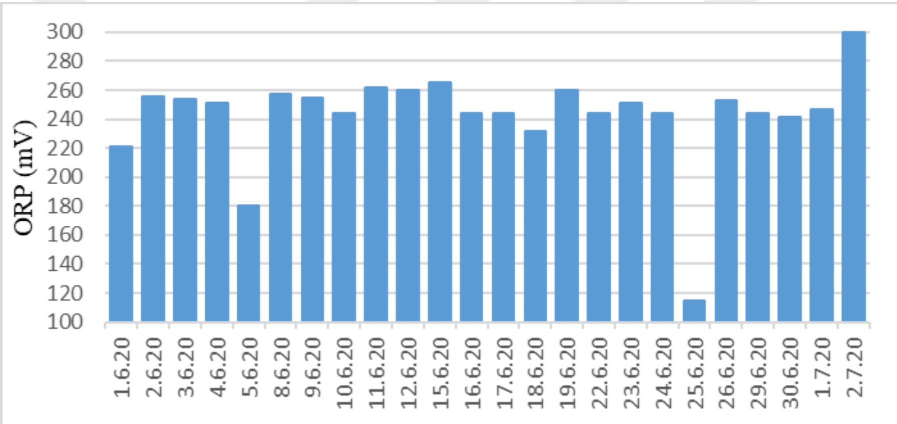


Figure 4.33 Changes in ORP during optimization period

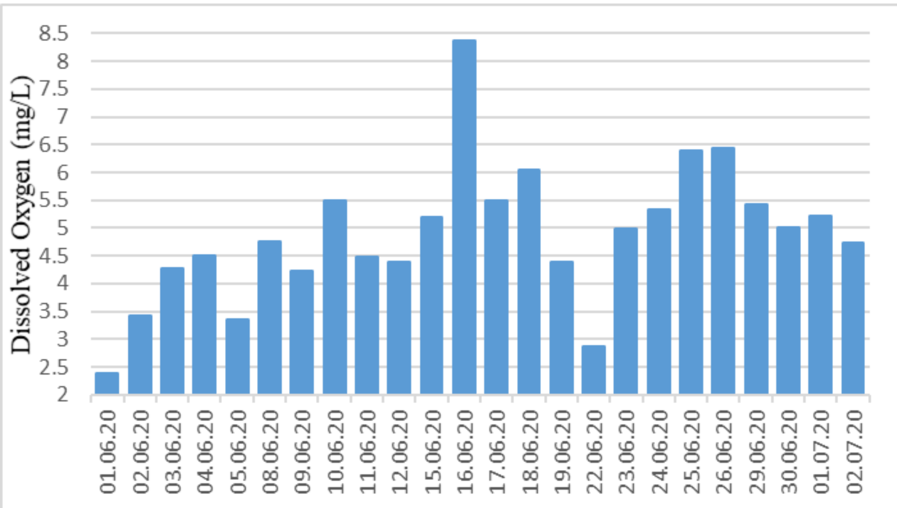


Figure 4.34 Changes in DO during optimization period

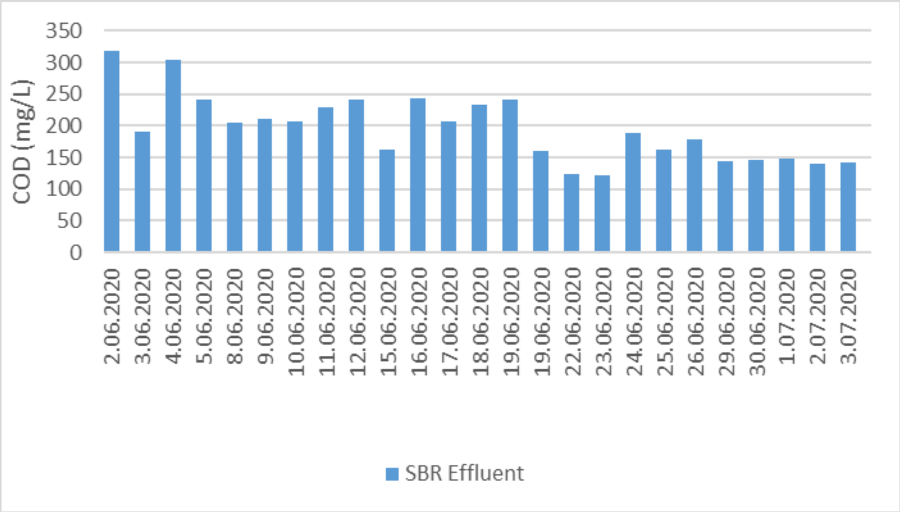


Figure 4.35 SBR Effluent's COD values during optimization

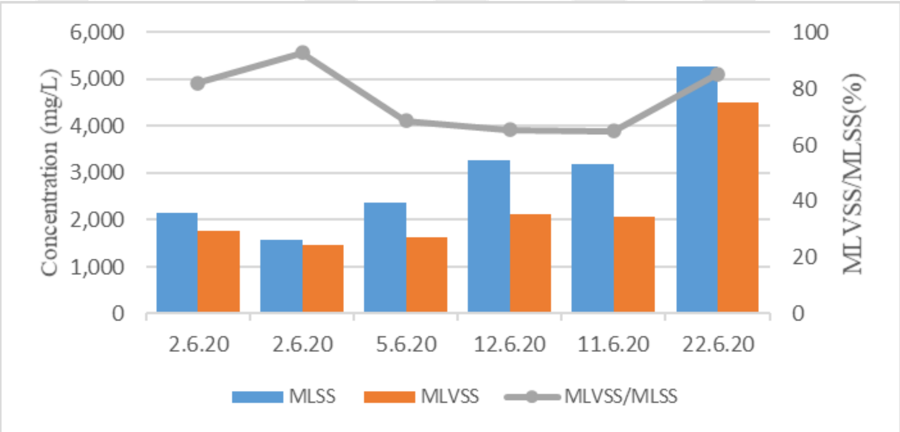


Figure 4.36 MLSS and MLVSS values during optimization period

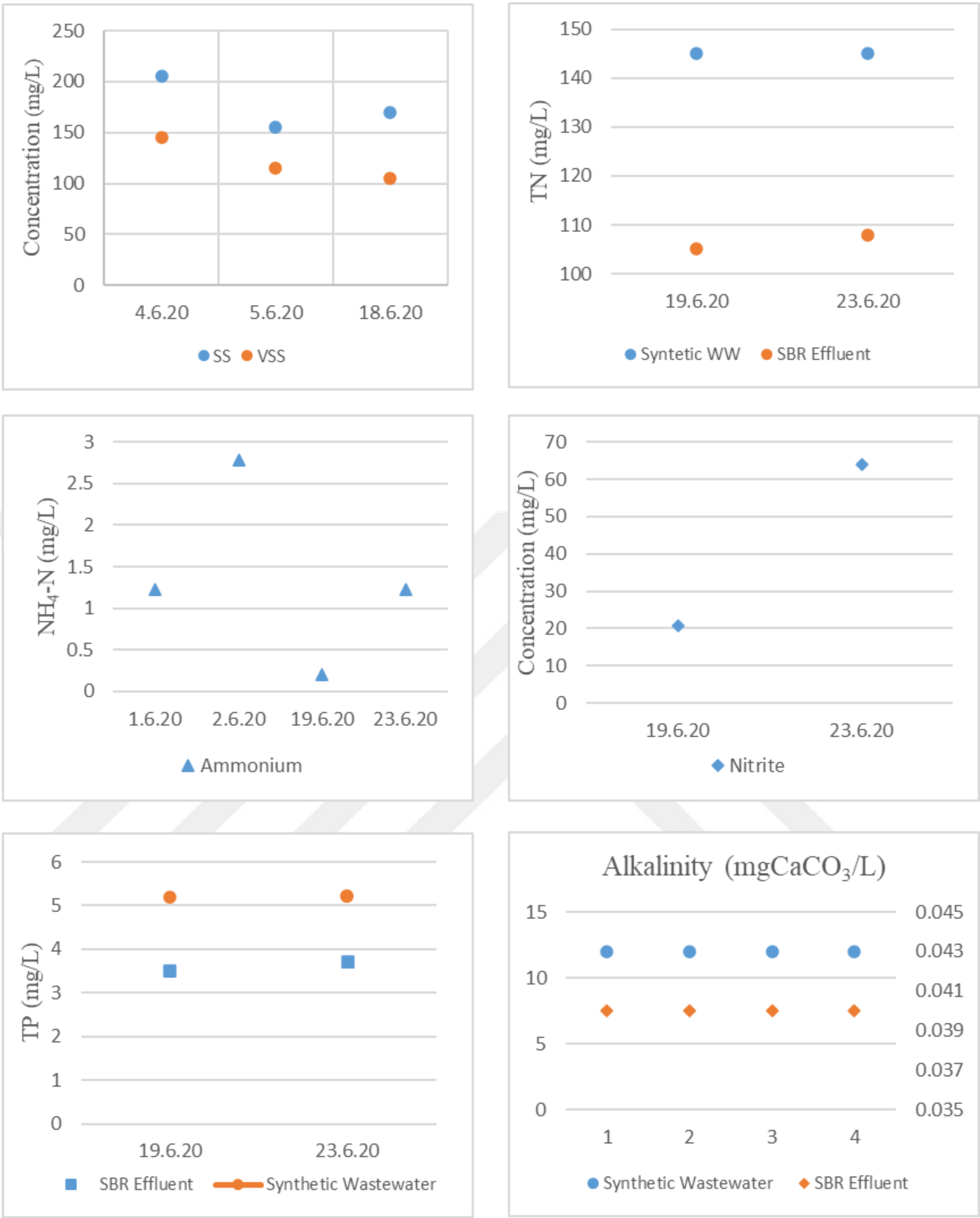


Figure 4.37 Changes in different parameters during the optimization of SBR system operation

During these studies, it was observed that the pH decreased considerably, however, the electrical conductivity and salinity increased. ORP remained at average values, but the sludge's oxygen fell below the desired values. First of all, DO level was increased and improvements were initiated for the sludge.

Subsequent analyzes were on MLSS, MLVSS, SS and VSS parameters. SS, which was around 50 mg/L on average before the break, increased four times up to 200 mg/L, while the MLSS value decreased to 1,500mg/L levels due to the lack of water withdrawal while feeding with the order. This decrease in the MLSS value directly reflected on the COD value, which was double of the pre-pandemic value around 250 mgCOD/L. However, the SBR effluent had lost its clarity and the particle size ratio varied greatly. In addition, sludge was provided on 22 June 2020, which could not reach its pre-pandemic efficiency despite all physical improvements . Although existing sludge mixed with this new sludge showed a better decrease in COD, it was close to reach previous levels.

Activated sludge flocs cannot be uniquely defined because of the irregular geometry of the floc, however particle size distribution helps to understand filtration behaviour. Particle size of the effluent was measured by the Malvern Mastersizer 2000, which works on the principle of laser diffraction and is capable of measuring the particles in size range of 0.02 µm to 2,000 µm (Wu & Wheatley, 2009). While the volume based PSD showed fluctuated results for effluents sampled on different dates, there was notable differences among number based PSDs as shown in Figure 3.38. The peak particle size for volume distribution is about 1,000 µm, whereas in number distribution the majority of particles are in the range of 100–1,000 µm, These results in the particle distribution coincided with the turbidity in SBR effluent.

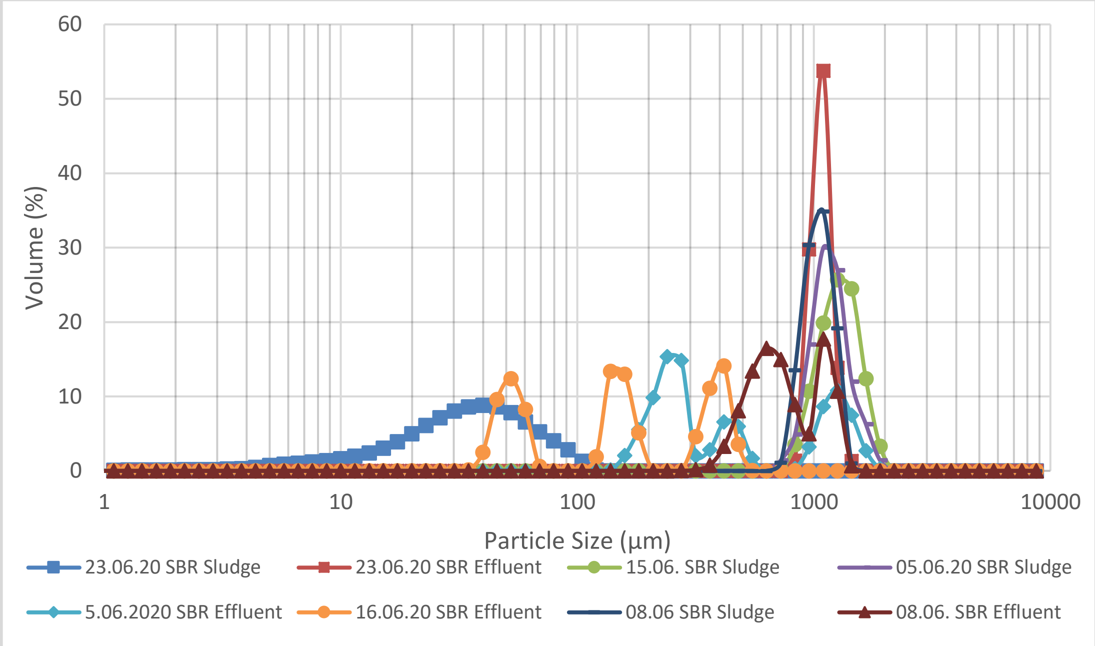


Figure 4.38 Particle size distribution during optimization studies

The composition of EPS fractions especially protein is very important for the filtration (Wang et al., 2013). Therefore, EPS fractions were also measured in the new sludge as given in Figure 4.39.

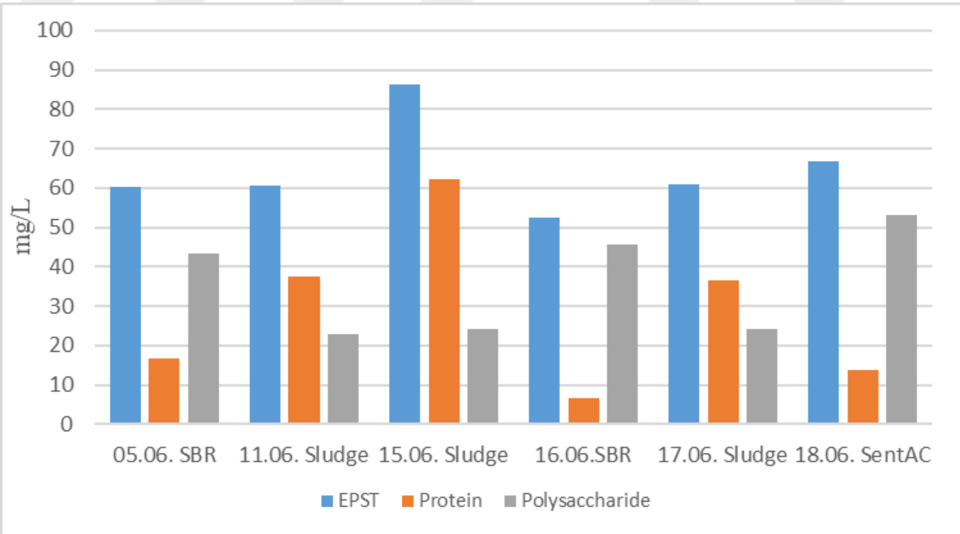


Figure 4.39 EPS results

After the system improvement, the filtration system was also commissioned. In this new series, SBR was then attached to the filtration unit with four layers of MBTF and different final fabric materials like S1 or S3. These studies were detailed in following subsections.

4.7.3 SBR + Four Layer MBTF + one layer S1 each side

After the optimisation studies as the 5th set, S1 + MBTF filter material was mounted on each surfaces of the cassette system. It was operated for a total of 5.5 hours. SBR temperature varied between 18 ºC and 19 ºC. The changes in pH, DO, ORP, conductivity and salinity parameters were given Figure 4.40. While pH value increased in the filtrate, conductivity and salinity values had almost the same as in the effluent. Likewise, salinity value behaved the same in different flowmeter stages. Those results have pointed out that MBTF with S1 addition was inefficient to decrease conductivity and salinity values.

In this set, the system continued to be fed with synthetic wastewater with a COD of 1,000 mg /L. As a result of COD analysis, even if the SBR system did not reach its pre-pandemic efficiency, the efficiency of the system, including filtration was 90% as depicted in Figure 4.41. In addition, after the addition of S1 material between the SBR outlet and the filtration outlet, the filtration efficiency reached 57% more treatment levels.

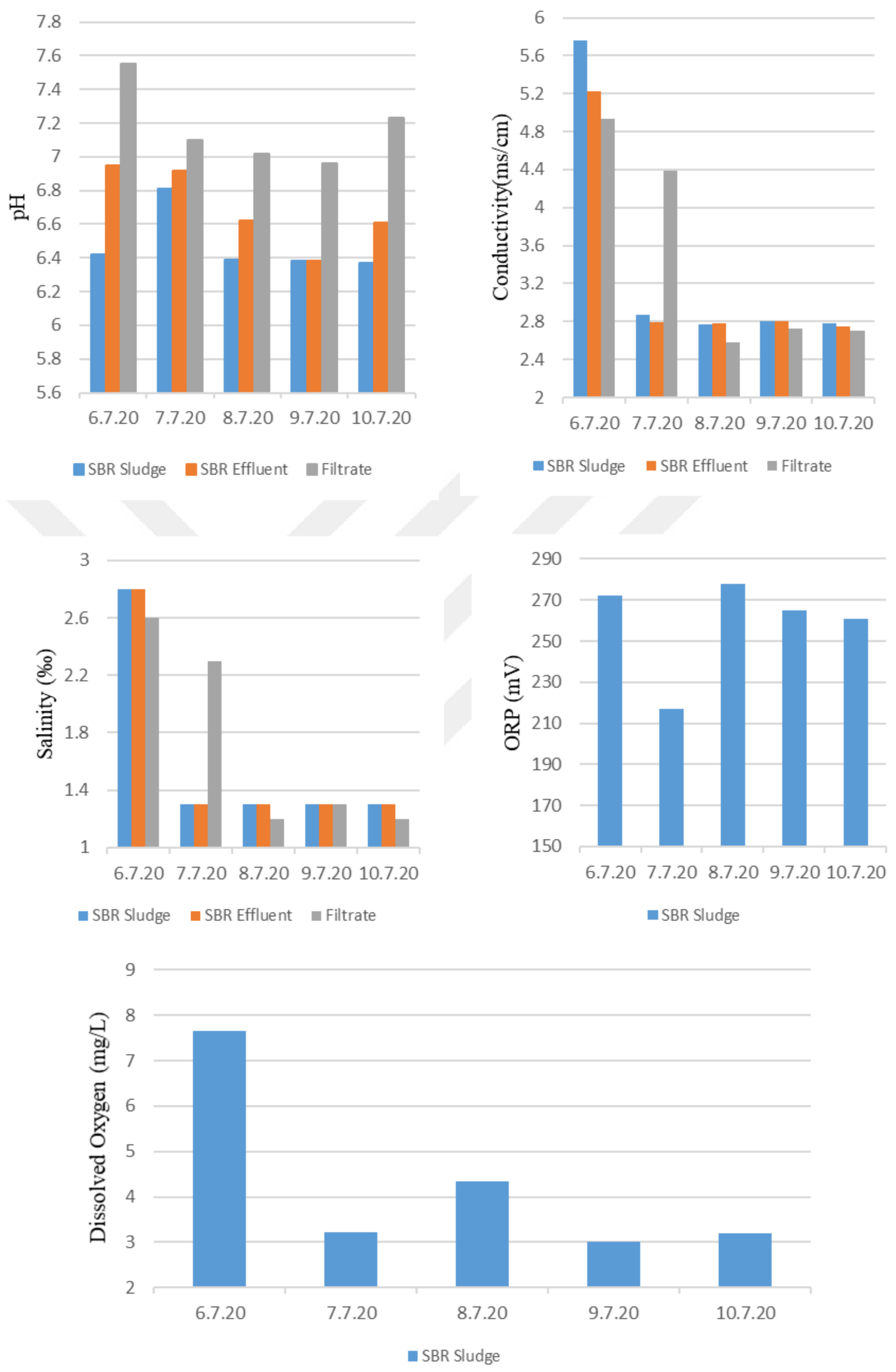


Figure 4.40 Variations in different operational parameters for SBR + 4-layer MBTF + S1 as 5th set

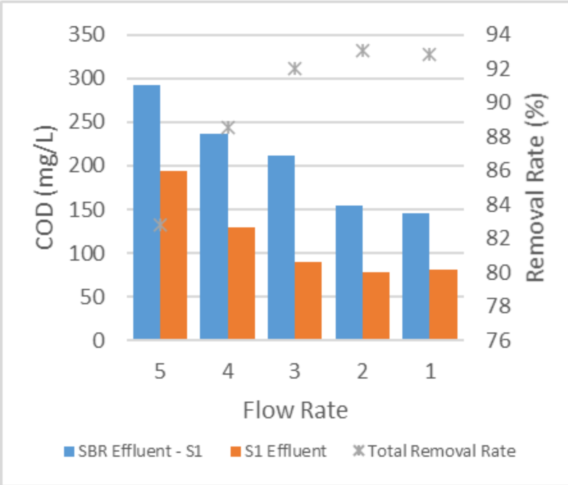


Figure 4.41 Change on COD parameter

Removal efficiencies continued at high rates throughout the entire operation in terms of Nitrite and NH_4^+-N. Efficiencies reached 90% and 96%, respectively. Compared to other experimental studies, there was a slight increase in TP removal rather than TN removal efficiencies of TN and TP reached 29% and 31%, respectively. Sulphate removal was not remarkable reaching only 6%. There was slight chloride removal, which was about 6.01 %. Those results showed that S1 addition into cassette system increased COD while there was not sufficient efficiency on chloride removal. Influent alkalinity concentration was generally higher than effluent alkalinity concentration. The results were presented in Figure 4.42.

Figure 4.42 Variations in different parameters for SBR + 4-layer MBTF + S1 as 5th set

Particle size distribution of the SBR effluent and filtrate was analyzed. The volume weighted mean of SBR effluent was 21.560 µm, while it was measured as 11.551 µm in the filtrate. There were partial changes in particle size distribution between SBR and filtration effluent. Figure 4.43 showed the particle size distribution of SBR effluent and filtrate. Also, detailed information on the analysis was given in Table 4.7.

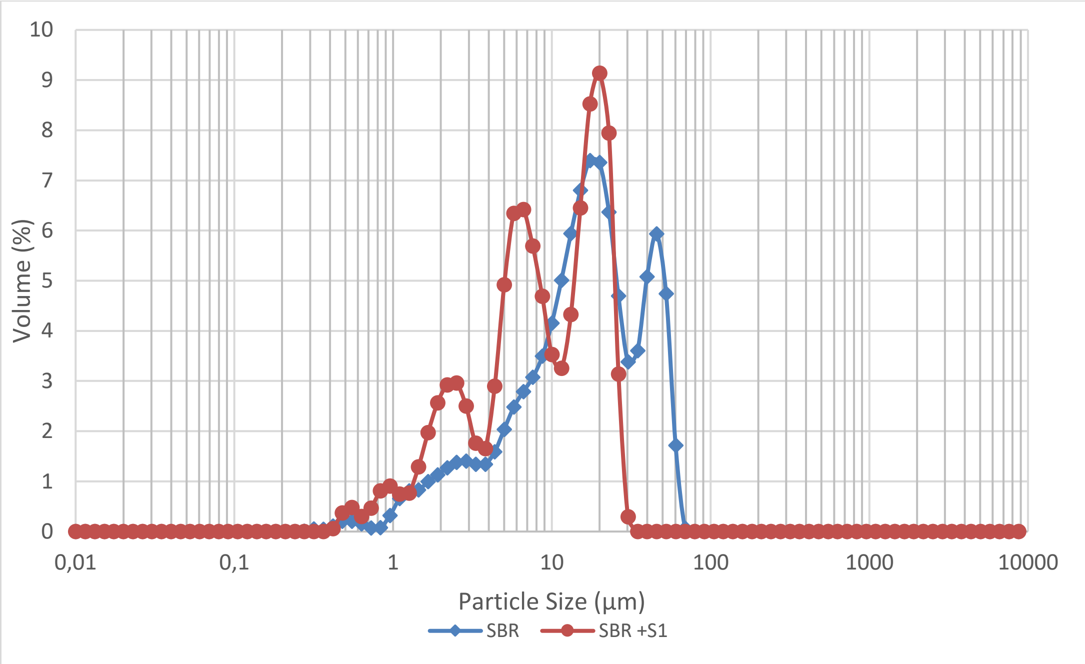


Figure 4.43 Particle size distribution S1 filtrate and SBR effluent

Table 4.7 Detailed information on particle size distribution of SBR and SBR+ MBTF-S1

	SBR	SBR+S1
D [4, 3] - Volume weighted mean (µm)	21.569	11.551
D [3, 2] - Surface weighted mean (µm)	7.952	4.946
Specific surface area (m^2/g)	0.754	1.21
d(0.1) (µm)	3.425	2.112
d(0.5) (µm)	17.483	9.012
d(0.9) (µm)	48.388	23.411

Rheological properties of SBR effluent and SBR- MBTF+S1 filtrate were given in Figure 4.44. It is clear that samples exhibited non-Newtonian flow behavior from the rheograms. There is no remarkable change in viscosity of SBR effluent, filtrate showed more change according to incresed level of shear rate.

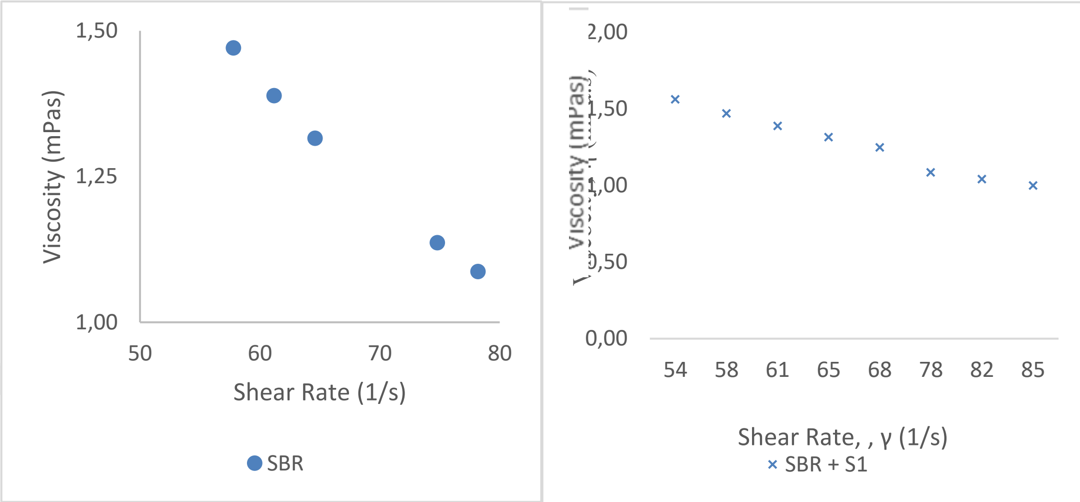


Figure 4.44 Viscosity of SBR Effluent and MBTF+S1 Filtrate as a function of Shear Rate

When the effluent samples were compared, it was observed that there was a turbidity difference in SBR and MBTF+S1 effluents as shown in Figure 4.45. This result was also consistent with the particle size distribution results. Another way to achieve high filtration efficiencies at low particle sizes is to coat the filter medium with a fine powder – the precoat – to build up a thin cake on which the main filtration can then be undertaken without loss (Sutherland, 2008a). From this information, it can be said that the S1 textile material led to better performance than the uncoated textile material. Figure 4.46 showed the S1 textile material before and after its use.

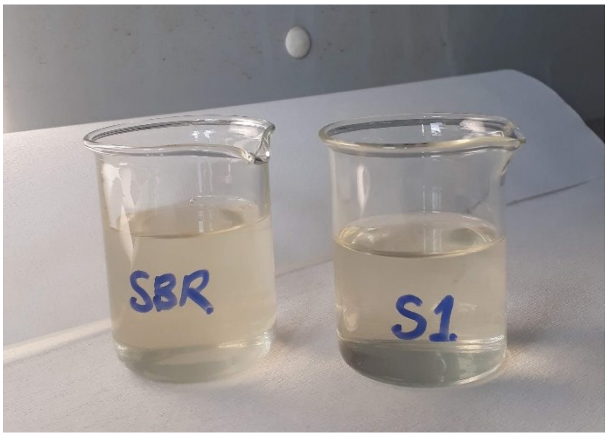


Figure 4.45 Images of SBR effluent (L) – SBR- MBTF+S1 Effluent (R) (Personal archive, 2020)

Before After

Figure 4.46 Images of S1 textile material before and after used (Personal archive, 2020)

4.7.4 SBR + Four Layers MBTF + One layer S3

As a 6th set, S3 + four-layer MBTF was mounted on each surfaces of the cassette system. It was operated for a total of 5.5 hours. The difference between S1 and S3 was only activated carbon coating percentage. The effect of this difference between them was examined on the parameters without changing the operating conditions. SBR operational conditions were also the same in previous experimental serial. The changes in pH, conductivity, salinity, and ORP parameters were given Figure 4.47.

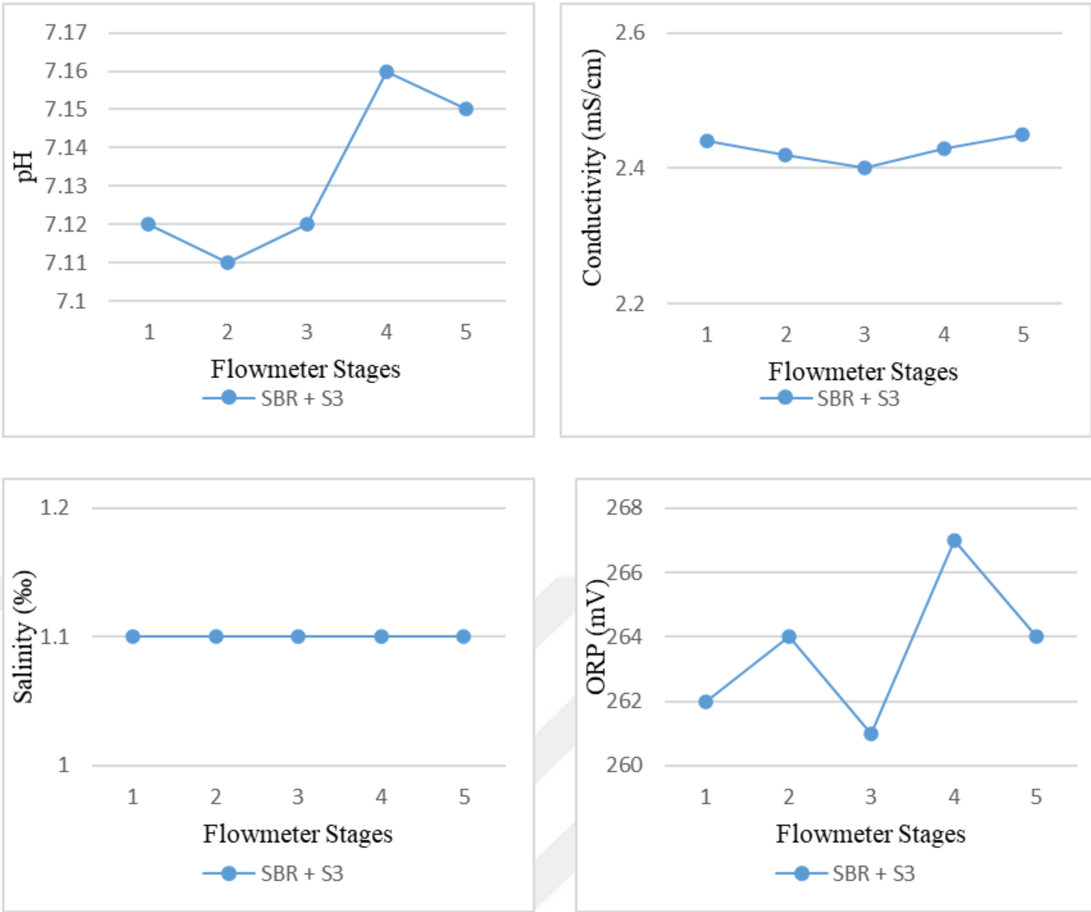


Figure 4.47 Variations in different operational parameters for SBR + 4-layer MBTF + S3 as 6th set

Removal efficiencies continued at high rates throughout the entire operation in terms of COD and BOD removal efficiencies and reached to 92.73% ±0.33 and 93.33%, respectively. In addition, only the S3 material achieved a 49,40% ±1.57 additional removal efficiency on COD while operated with SBR effluent as depicted in Figure 4.48. Compared to other experimental studies, there was an increase in TN removal; however, slight decrease in TP removal was obtained rather than other removal efficiencies. TN and TP reached 74.84% and 12.36%, respectively. Sulphate removal was not remarkable reaching only 5%. There was almost no chloride removal with 1.61% rate. Those results indicated that S3 addition into filtration unit led to increases in COD, BOD_5, and TN removals as in S1 addition. Influent alkalinity concentration was generally higher than effluent alkalinity concentration. The results were presented in Figure 4.49.

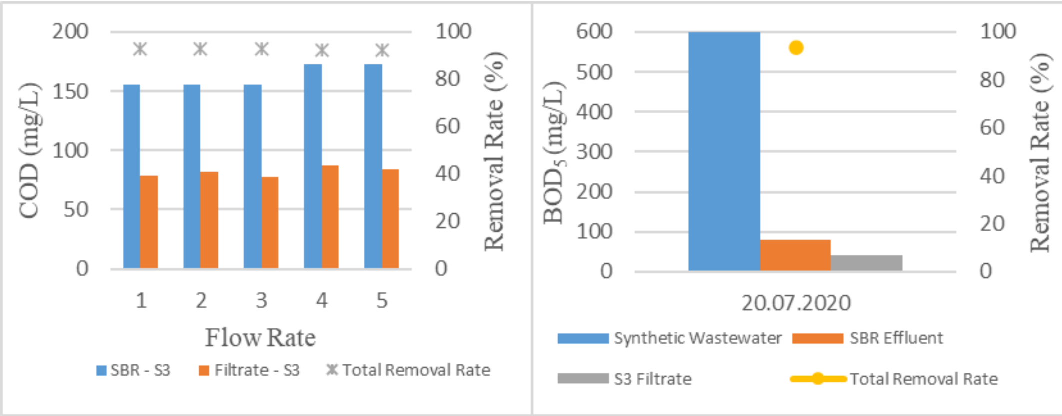


Figure 4.48 Changes in COD and BOD5 parameters during the operation

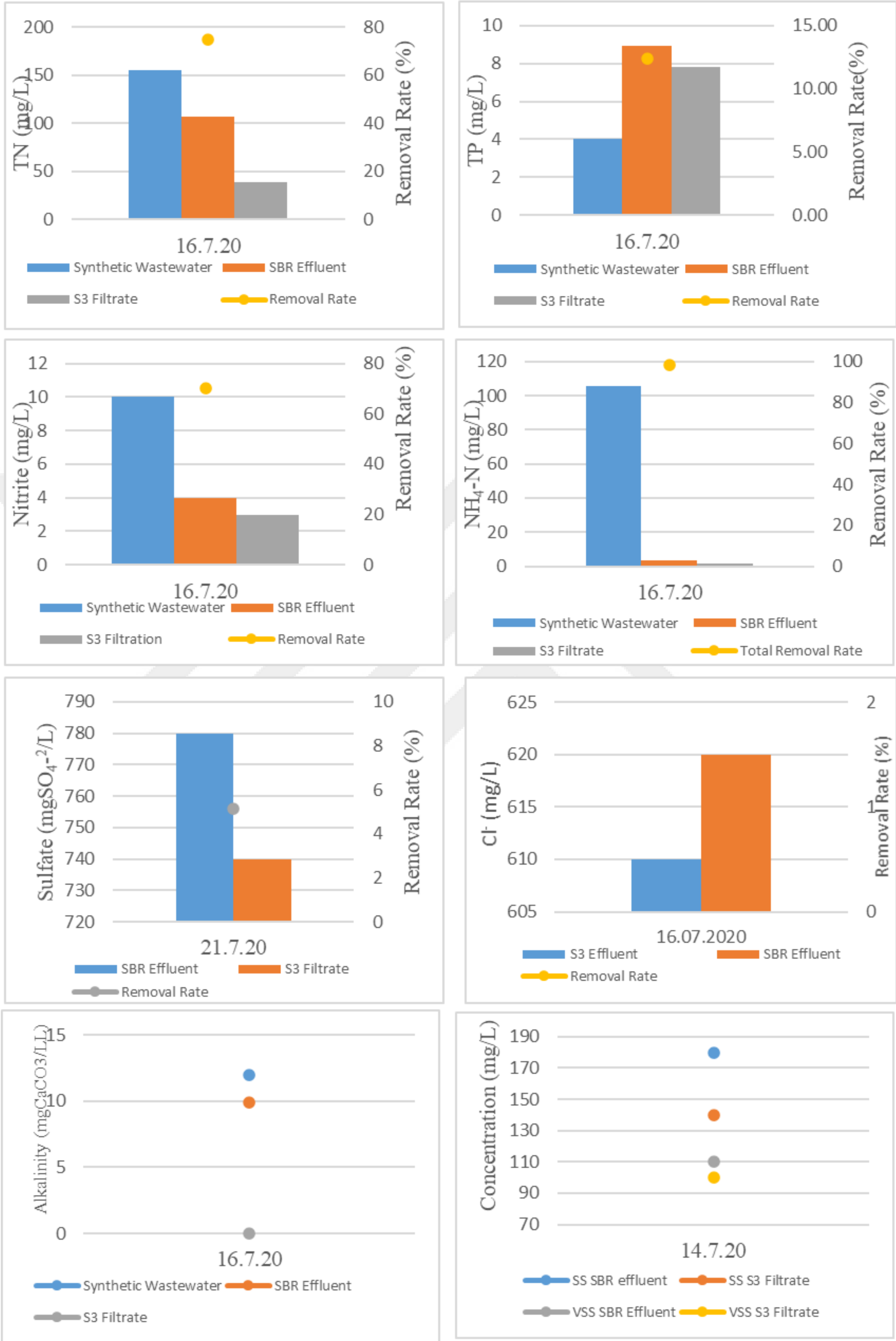


Figure 4.49 Variations in different parameters for SBR + 4-layer MBTF + S3 as 6th set

Particle size distribution of the SBR effluent and SBR+4- layers MBTF+S3 filtrate was analyzed. The volume weighted mean of SBR effluent was 64.442 µm, while it was measured as 22.455 µm in filtrate sample. There were change in particle size distribution between SBR and filtration effluent. Figure 4.50 showed the particle size distribution of SBR effluent and filtration effluent. The detailed information about particle size distribution analysis was also presented in Table 4.8.

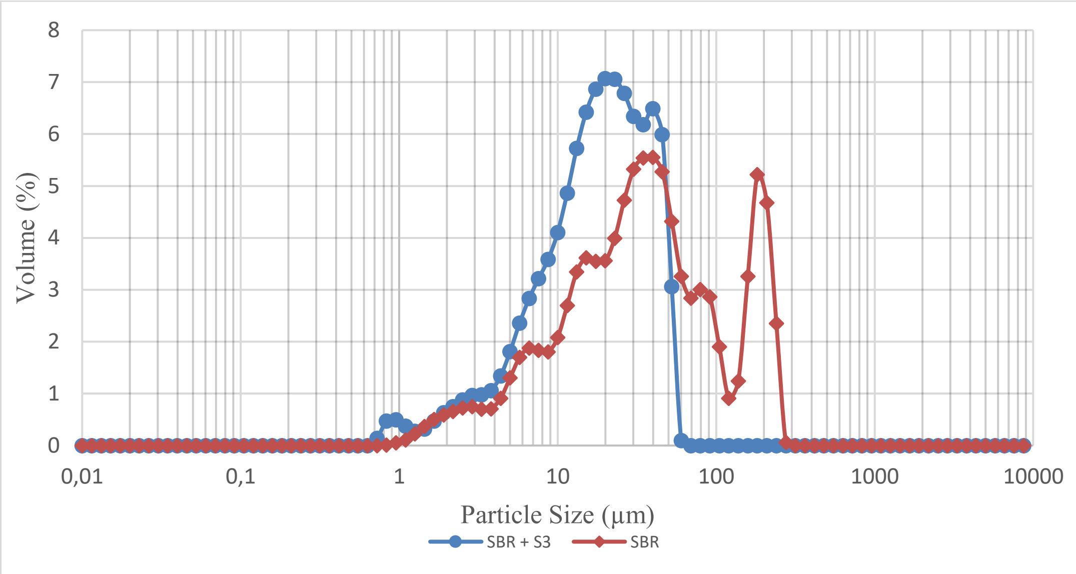


Figure 4.50 Particle size distribution S3 filtrate and SBR effluent

Table 4.8 Detailed information on particle size distribution of SBR and SBR+ 4-layer MBTF+ S3

	SBR	SBR+S3
D [4, 3] - Volume weighted mean (µm)	64.442	22.455
D [3, 2] - Surface weighted mean (µm)	16.286	10.332
Specific surface area (m^2/g)	0.368	0.581
d(0.1) (µm)	6.953	5.374
d(0.5) (µm)	36.716	19.589
d(0.9) (µm)	193.871	44.897

Rheological properties of SBR effluent and SBR- MBTF+S3 filtrate were given in Figure 4.51. It is clear that samples exhibited non-Newtonian flow behavior from the rheograms. There is no remarkable change in viscosity values of both samples. The viscosity values decreased as a function of shear rate.

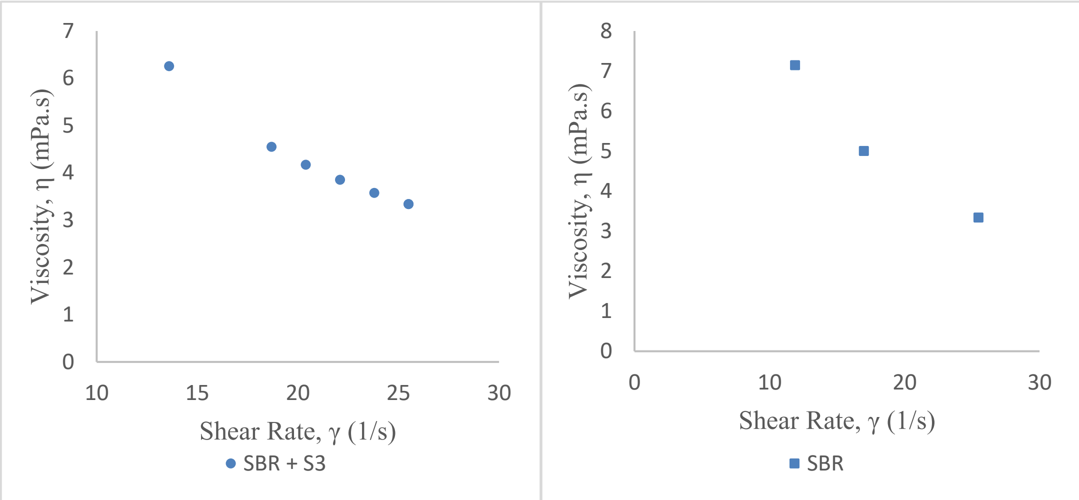
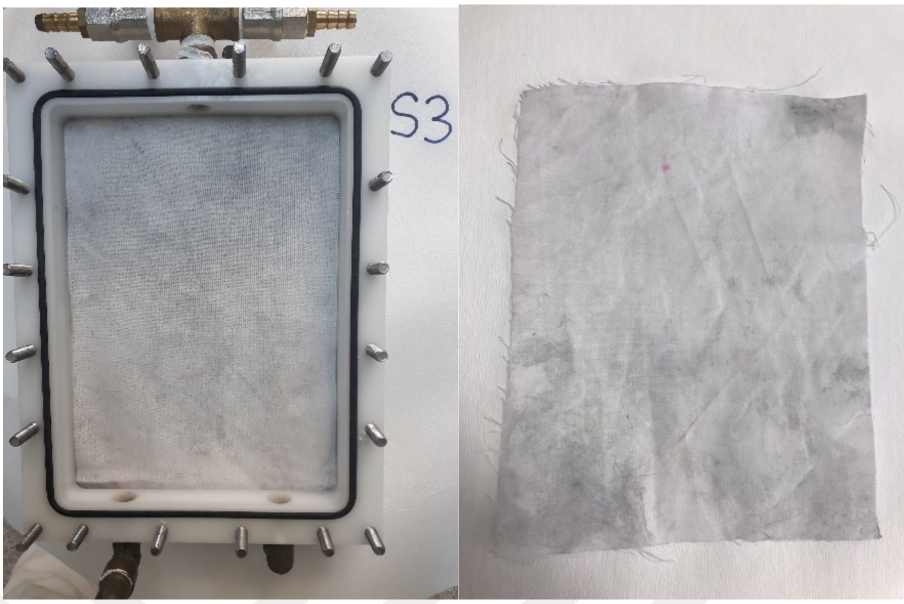


Figure 4.51 Rheological properties SBR and SBR + 4-layer MBTF+S3

When the effluent samples were compared, it was observed that there was a turbidity difference in SBR and MBTF+S3 effluents as shown in Figure 4.52. This result was also consistent with the particle size distribution results. Figure 4.53 presented the S3 textile material before and after its use.

Figure 4.52 SBR effluent (L) – SBR+MBTF+S3 Effluent (R) (Personal archive, 2020)



Before After

Figure 4.53 Images of S1 textile material before and after used (Personal archive, 2020)

4.7.5 *SBR + Four Layers MBTF + One layer AC each side*

As a 7th set, AC + four-layer MBTF were mounted on each surface of the cassette system. It was operated for a total of 5.5 hours. The difference between S1 and S3 was only activated carbon coating percentage; however, AC was made from pure activated carbon. The effect of this difference between them was examined on the parameters without changing the operating conditions. The operation of SBR was also the same as in the previous series. The changes in pH, conductivity, salinity, and ORP parameters were given Figure 4.54.

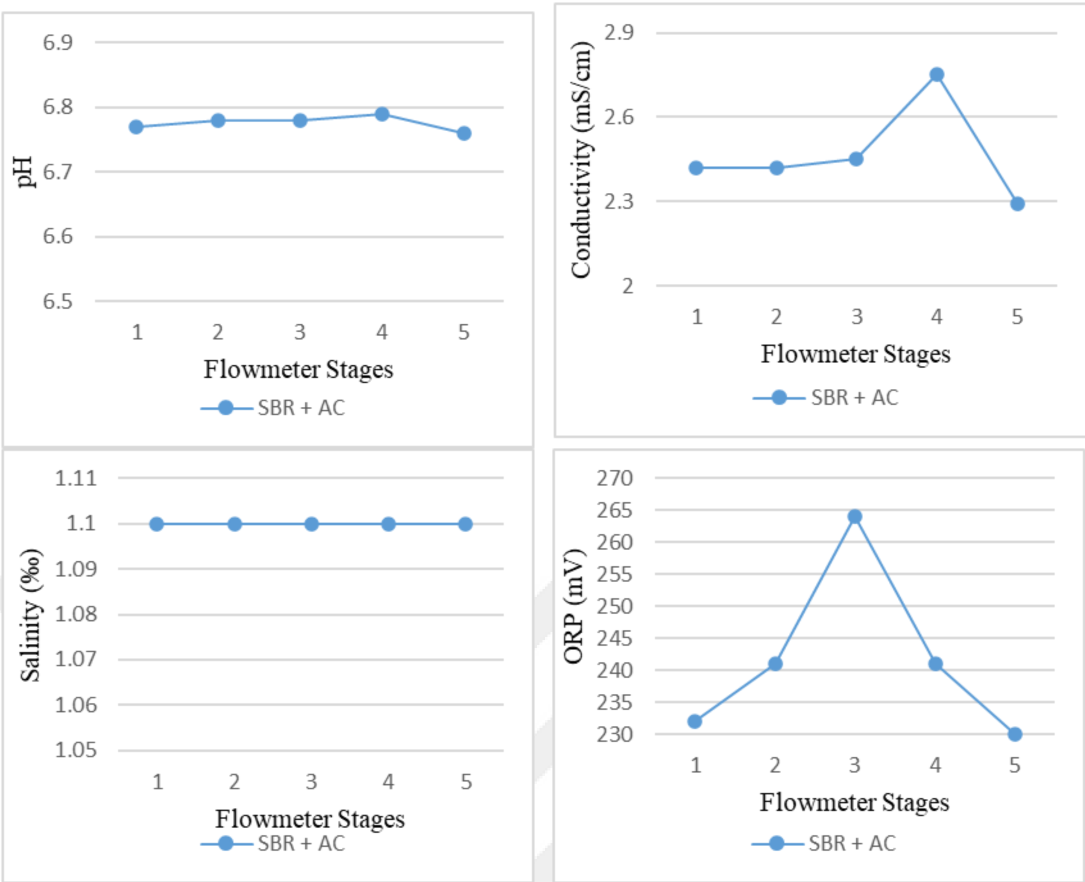


Figure 4.54 Variations in different operational parameters for SBR + 4-layer MBTF + AC as 7th set

Removal efficiencies continued at high rates throughout the entire operation in terms of COD and BOD removal efficiencies and reached to 92.95% ±0.3 and 95%, respectively. In addition, only AC material achieved a 49.92% ±3.03 additional removal efficiency on COD while operated with SBR effluent as depicted in Figure 4.55. Compared to other experimental studies, there was an increase in TN and TP removals as 67% and 51.75%, respectively. Sulphate removal triplicated efficiency reached to 15.39%. There was not remarkable chloride removal as 11.76%. The results indicated that AC addition into filtration unit led to increases in COD, BOD_5, TN, TP, sulphate, and chloride parameters. Influent alkalinity oncentration was generally higher than effluent alkalinity concentration. The results were depicted in Figure 4.56.

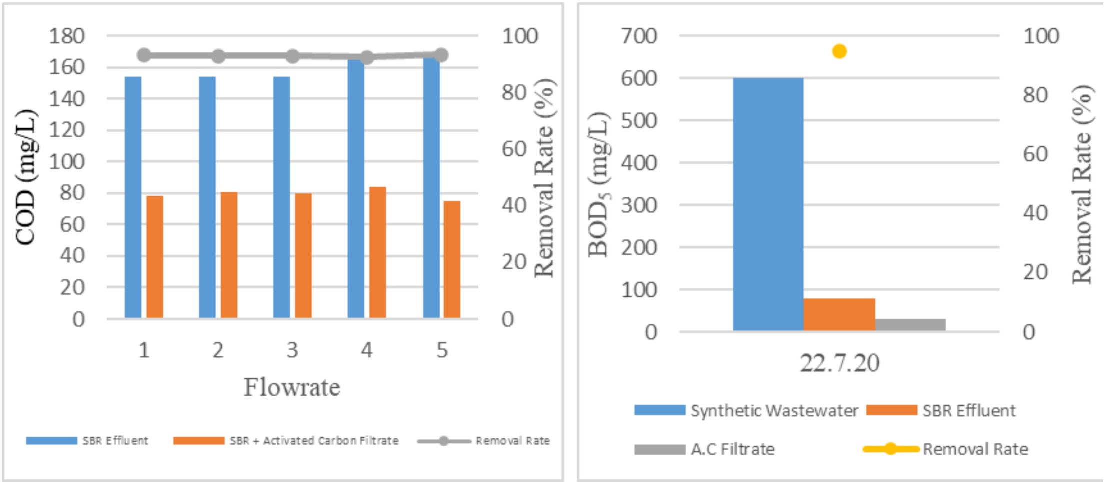


Figure 4.55 Changes in COD and BOD5 parameters during the operation

Figure 4.56 Variations in different parameters for SBR + 4-layer MBTF + AC as 7th set

Particle size distribution of the SBR effluent and SBR+MBTF+AC filtrate was analyzed. The volume weighted mean of SBR effluent was 23.554 µm, while this value for SBR+MBTF+AC filtrate was measured as 6.098 µm. There were changes in particle size distribution between SBR and filtration effluent . Figure 4.57 shows the particle size distribution of SBR effluent and filtration effluent. The detailed information about particle size distribution analysis was presented in Table 4.9.

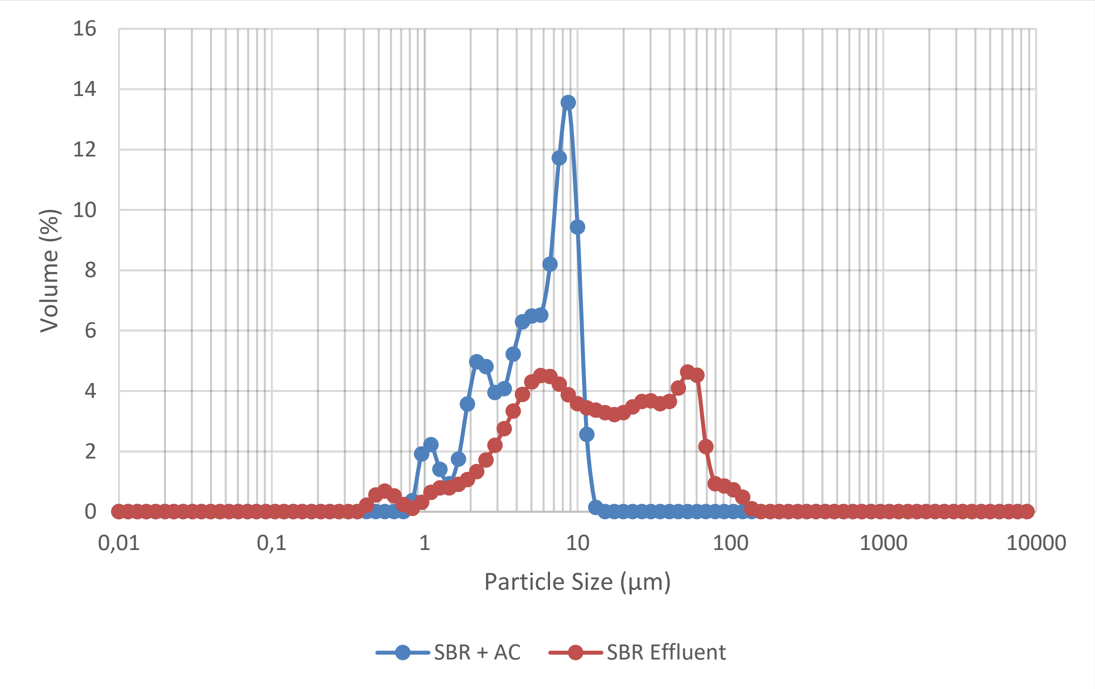


Figure 4.57 Particle size distribution of SBR effluent and filtrate samples

Table 4.9 Detailed information on particle size distribution of SBR and SBR+MBTF+AC

	SBR	SBR+AC
D [4, 3] - Volume weighted mean (µm)	23.554	6.098
D [3, 2] - Surface weighted mean (µm)	6.045	4.019
Specific surface area (m^2/g)	0.002	1.49
d(0.1) (µm)	2.918	2.034
d(0.5) (µm)	12.982	6.024
d(0.9) (µm)	59.821	10.239

Rheological properties of SBR effluent and SBR+MBTF+AC filtrate were given in Figure 4.58. It is clear that samples exhibited non-Newtonian flow behaviour from rheograms. There is remarkable change in viscosity of SBR effluent and filtrate sample showing lower values as a function of shear rate.

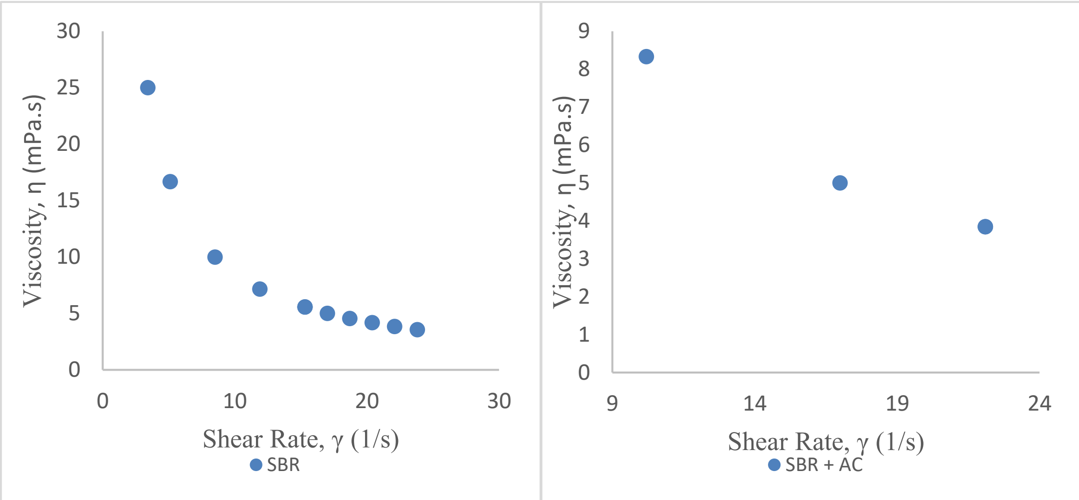


Figure 4.58 Viscosity values of SBR effluent and SBR + MBTF+AC filtrate as a function of shear rate

Figure 4.59 The photographs of SBR+S3 Effluent (L) and SBR effluent (R) (Personal archive, 2020)

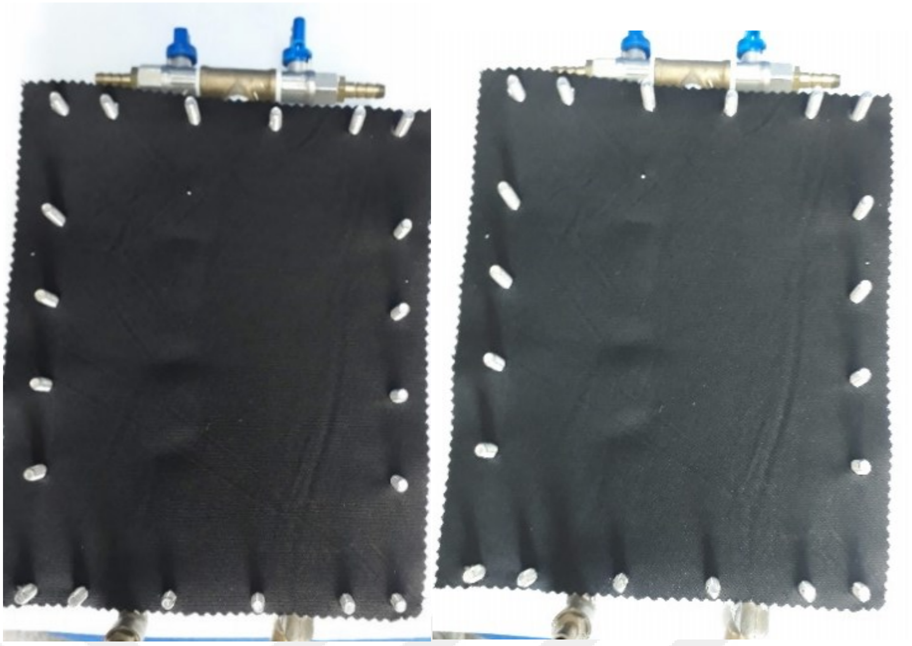


Figure 4.60 Images of AC textile material before and after used (Personal archive, 2020)

4.8 Comparison of the performance of Filter Materials

The proper selection of filter material is the most important factor in achieving efficient filtration. An appropriate filter material should be capable of retaining the particles in any suspension, providing a high amount of filtrate in high quality, having minimum resistance to flow, easy cleaning for the deposited cake, having resistant to chemicals, temperature changes and the pressure applied in the filter, not swelling during the filtration or backwashing process, being capable of preventing particles from wedged in the pores (Rushton et al., 2008). Regarding these requirements, the certain parameters such COD, BOD_5, TN,TP particle size etc. have been monitored in the studies as explained above subsections. 4 layers of MBTF either with S1, S3, and AC additions were evaluated in this section. Figure 4.61 shows the photographs of the SBR effluent and filtrate samples obtained from the experimental series. Figure 4.62 presented the EPS variations at different series. EPS values decreased in filtrate samples.

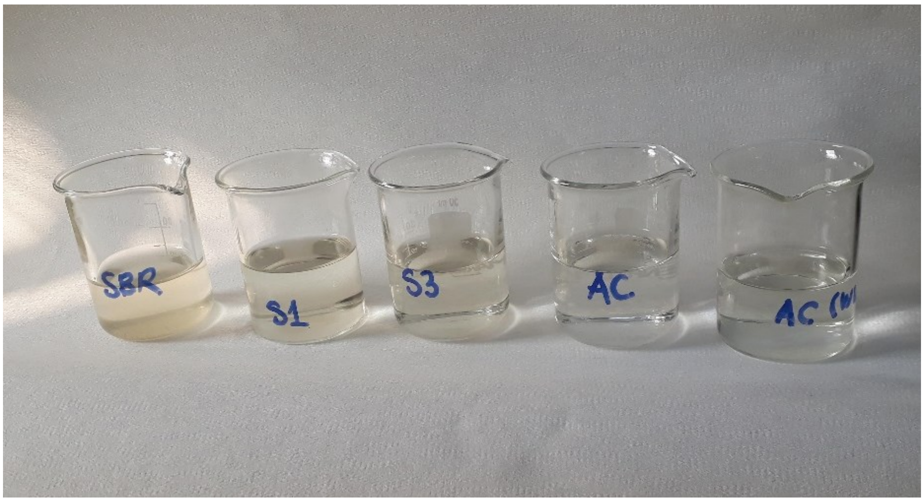


Figure 4.61 Photographs of the effluent streams obtained from experimental series (Personal archive, 2020)

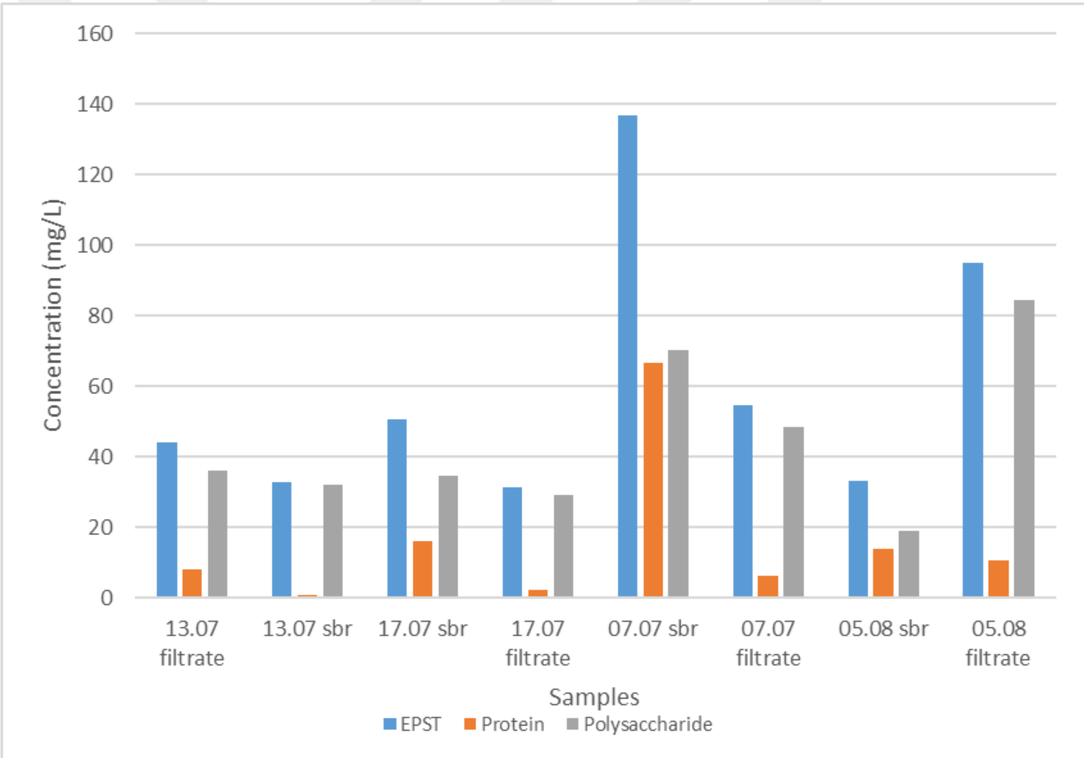


Figure 4.62 EPS results of SBR and filtration effluents with details of protein and polysaccharides

Although there were fluctuations in SBR effluent, AC addition led to high treatment efficiencies in many parameters when tested 4 layers MBTF plus S1, S3, and AC materials, respectively. Color and turbidity reduction in effluent streams occurred in all materials, but AC filtrate was observed to be the clearest water. Particle size distribution of the effluents taken from 4-layer MBTF plus S1, S3, and AC filters after

SBR application was given in Figure 4.63. The volume weighted mean of effluents varied between 304.984 µm and 1.734 µm. The detailed information on the results of particle size distribution analysis was given in Table 4.10. The comparison belonging series done by synthetic wastewater was summarized in Table 4.11. Al-Ajalin et al. (2020) reported that the planted reed system consisted of three sand layers with different size distribution provided the treatment performances up to 99% for TSS, 99.7% for BOD, 96.6% for COD, 100% for ammonium, and 99.6% for phosphate. In this study, very good removal efficiencies were obtained in an integrated treatment system consisting of SBR and filtration unit having very low space requirement when comparing to septic tanks and the constructed wetlands. This developed system was also found applicable to small settlements.

After 7 sets of experimental studies with synthetic wastewater, it was concluded that the AC added filtration application showed the best performance. This system was considered as a feasible and efficient system for small settlements in terms of ease of operation, economic constraints, and need for qualification. Depending on these results, the operation of system as in the 7th set by using a real wastewater was decided as explained in the following subsection.

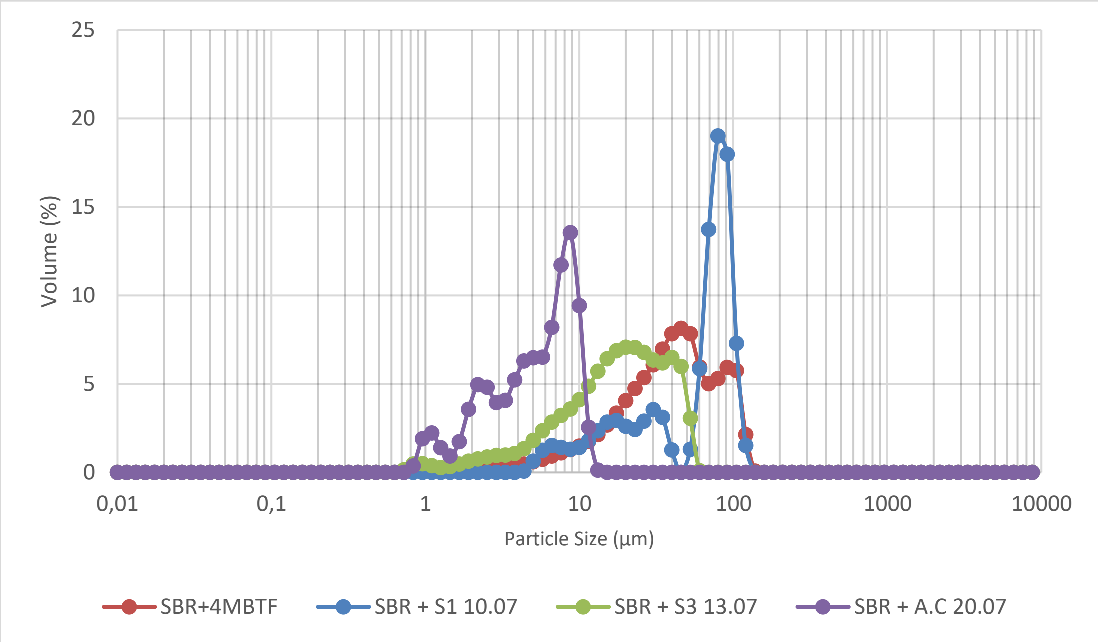


Figure 4.63 Particle size distribution variations after different filtration application following the SBR Effluents

Table 4.10 Detailed information on the particle size distribution analyses

	4MBTF	S1	S3	AC
D [4, 3] - Volume weighted mean (µm)	10.045	65.562	22.455	6.098
D [3, 2] - Surface weighted mean (µm)	5.739	33.702	10.332	4.019
Specific surface area (m^2/g)	1.05	0.178	0.581	1.49
d(0.1) (µm)	3.121	13.732	5.734	2.034
d(0.5) (µm)	9.002	76.615	19.589	6.024
d(0.9) (µm)	17.839	103.560	44.487	10.239

Table 4.11 Efficiency values of filtration materials

Parameter	TF	4xTF	MBTF	4xMBTF	SBR +			
					4L MBTF*	S1	S3	AC
MLSS (mg/L)					2,627-5,270	2,220	1,700	3,575-4,850
COD Removal (%)	7.72	9.36	13.2	30.2	96-98	90	92	93
BOD_5 Removal (%)	-	-	-	-	98.3	93.33	93.33	95
TN Removal(%)	-	-	-	-	53.8	29	74.84	67.10
TP Removal(%)					80	31	12.36	51.75
Nirate Removal(%)	-	-	-	-	-	9.04	34.42-	5.73-
TDS Removal(%)						3.73	8.51	14.72
Nitrite Removal (%)					67.81	90	70	90
Ammonium Removal (%)					55.76	95.16	98.48	98.96
Sulphate Removal (%)						6.41	5.13	15.38
Cl^{-*} Removal (%)						6.01	1.6	49,69
VSS mg/L					145	60	100	10
SS mg/L					205	80	110	15

*=between SBR effluent and filtration

4.9 SBR + Four Layer MBTF + One layer AC Operation for Real Wastewater Treatment (Domestic Wastewater)

As the system with the best performance, the system was operated with real wastewater supplied from Akhisar WWTP after the primary treatment units. The wastewater feed amount after SBR unit was determined as 1 liter for each operation and HRT of the SBR was adjusted as 8.75 h. SBR was operated with this wastewater as 22 days of operation time. Since there was no clear relationship between flow rate and treatment efficiency, the flow rate stage for the filtration was determined as 2 corresponding to 37 mL/ min. The results of pH, EC, salinity, ORP, DO for only aerated cycle of SBR for the samples as SBR sludge, SBR effluent, and filtrate were plotted in between Figures 4.64 and Figure 4.68. Salinity and EC values were found lower in filtrate samples during the operation.

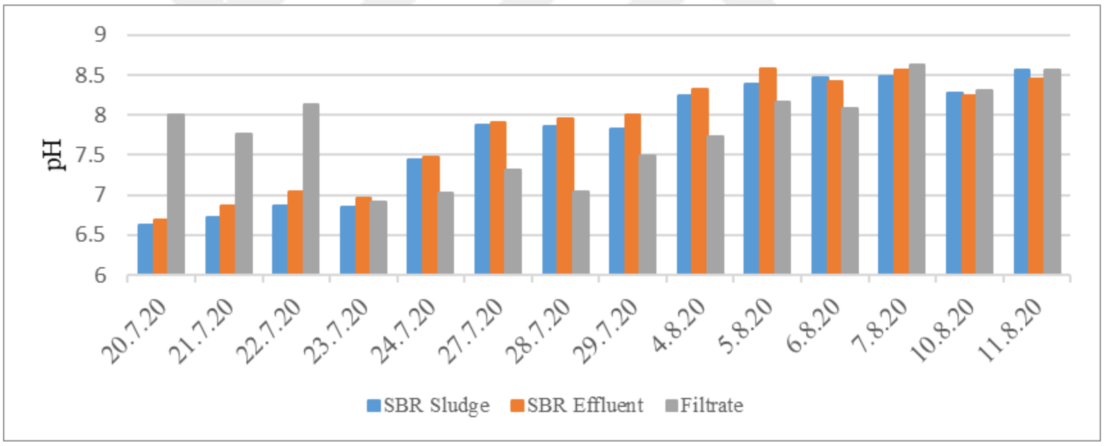


Figure 4.64 pH change during operation

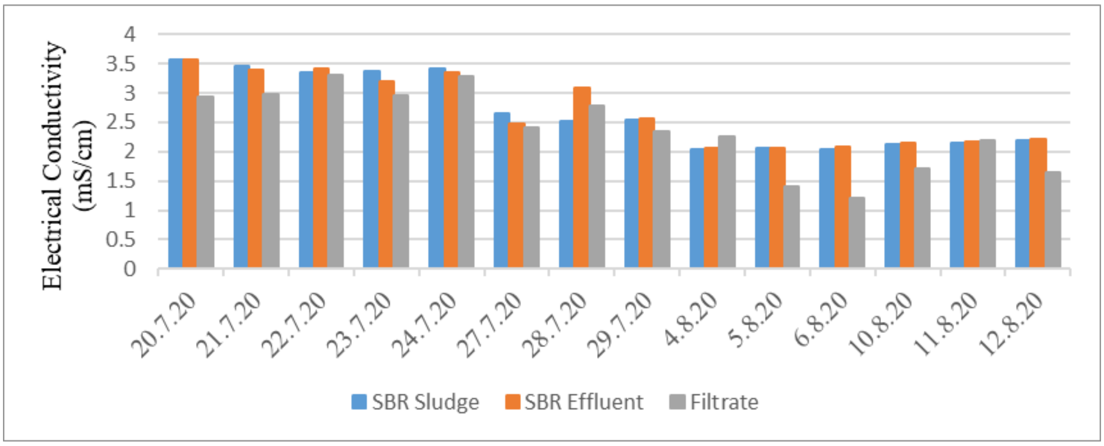


Figure 4.65 Electrical Conductivity variations during operation

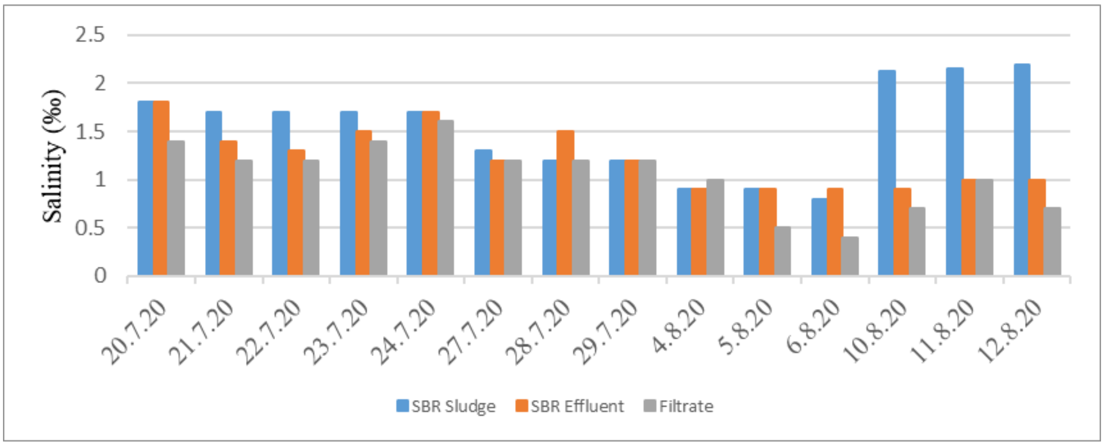


Figure 4.66 Salinity change during operation

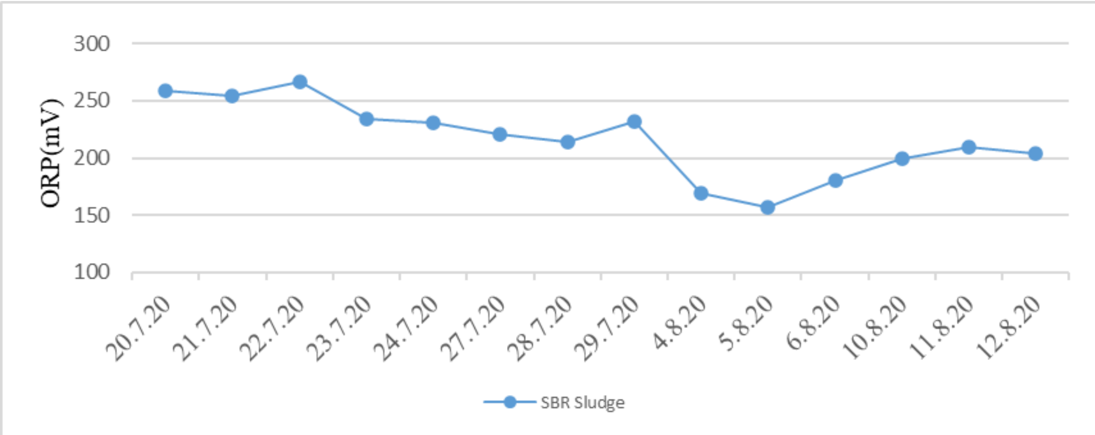


Figure 4.67 ORP change during operation

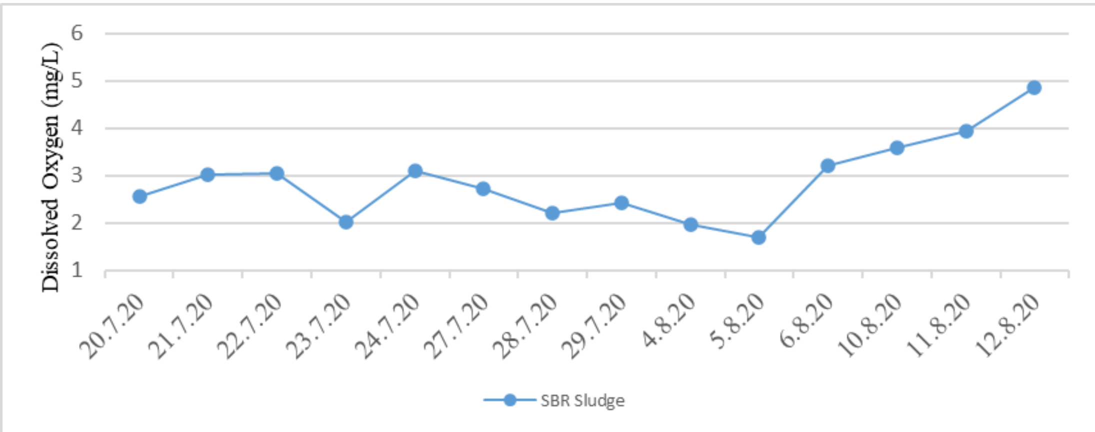


Figure 4.68 DO change during operation

Between measured parameters, no significant differences were observed at day 3 and day 22 in all sampled points of the system. Therefore, it was thought the system had the steady state at day 3 of the operation. COD and BOD removals can be seen from Figure 4.69 and Figure 4.70, respectively. Removal efficiencies continued at high rates throughout the entire operation in terms of COD and BOD. The maximum and minumum concentrations obtained from SBR and filtration system were 216 mg/L and 56 mg/L for SBR, 101 mg/L and 23 mg/L for filtrate, respectively, based on COD parameter. COD and BOD efficiencies reached upto 89.83% ± 5.98 and 84.45% ±3.85, respectively. In addition, only the filtration unit achieved a 57.65% ± 11.13 additional removal efficiency based on the COD. In previous studies with CW technologies removal efficiencies of COD were reported as 71%, 65% and 61% using plastic, gravel, and rubber media (Khalifa et al., 2020).

Compared to other experimental studies, there was a decrease in TN; however TP removals were also very good. TN and TP removal efficiencies were obtained up to 74% and 83.07%, respectively. Sulphate removal efficiency reached 11.19%. There was very good chloride removal up to 46.69%. Influent alkalinity concentration was generally higher than effluent alkalinity concentration. The results were depicted in Figure 4.71.

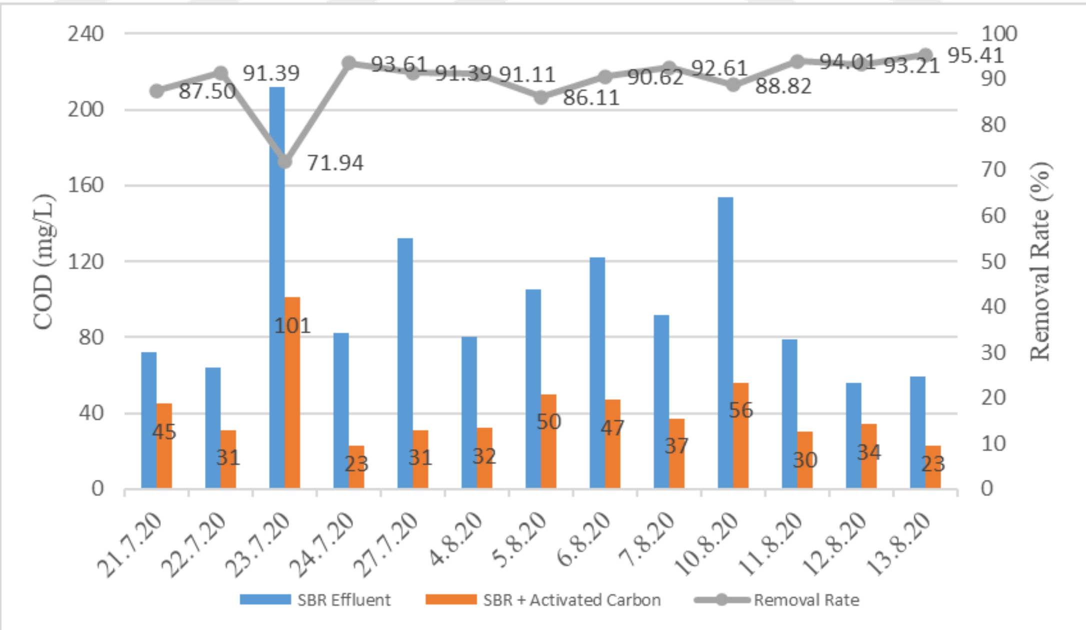
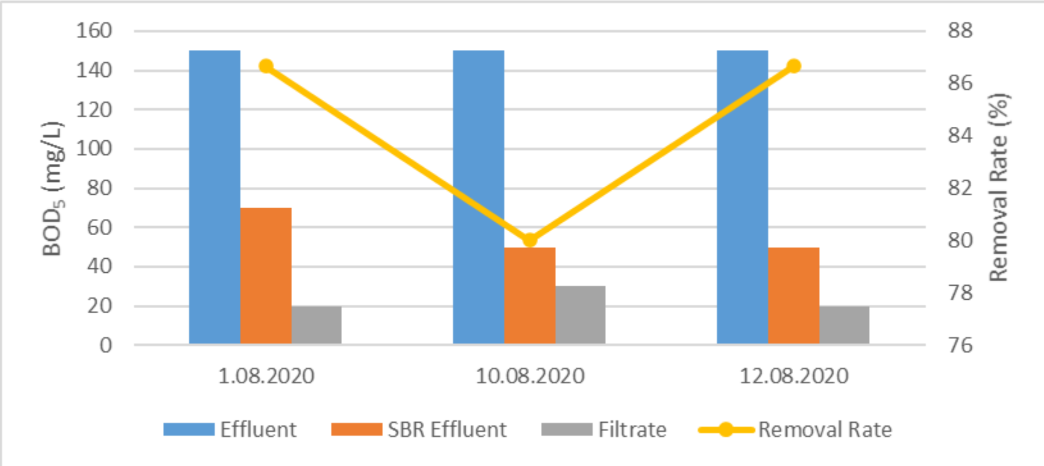


Figure 4.69 COD Removal Performance with real wastewater



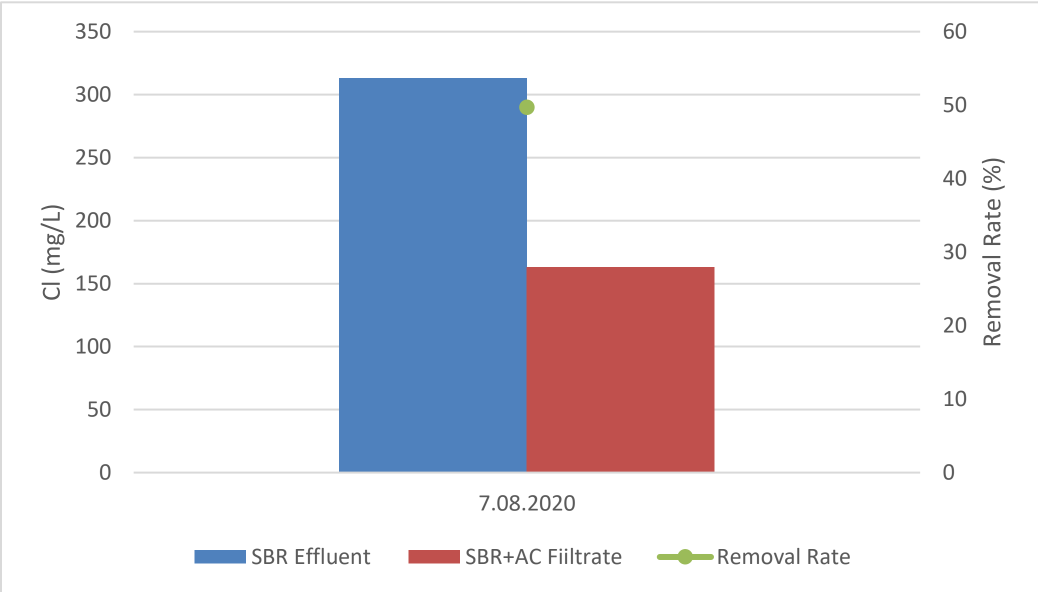


Figure 4.70 BOD - Cl Removal Performance with real wastewater

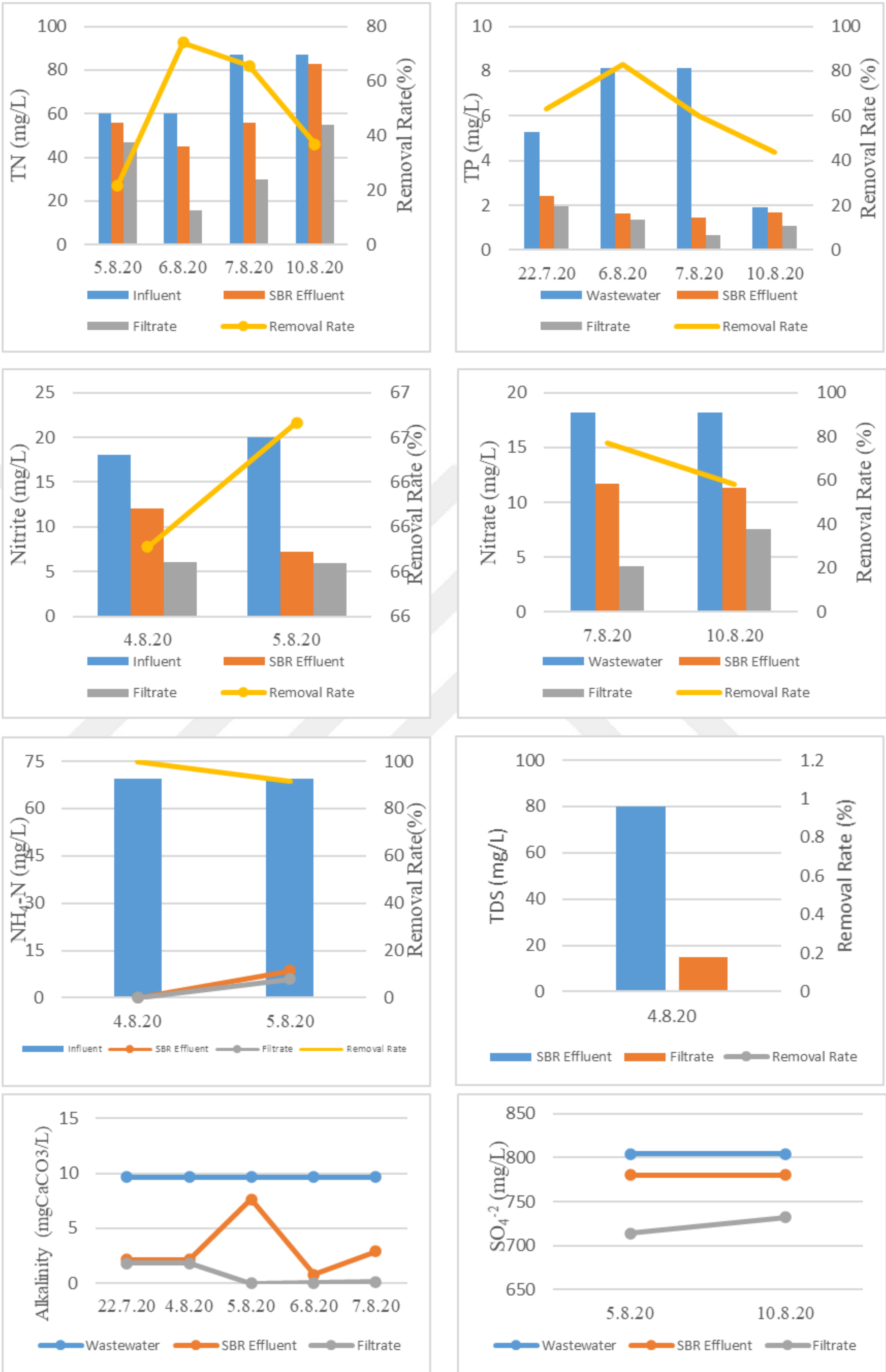


Figure 4.71 Graphical representation of system performance with real wastewater

Particle size distribution of the filtrate samples was plotted in Figure 4.72 and also summarized in Table 4.12. The volume weighted mean of effluents varied between 32.802 µm and 25.765 µm.

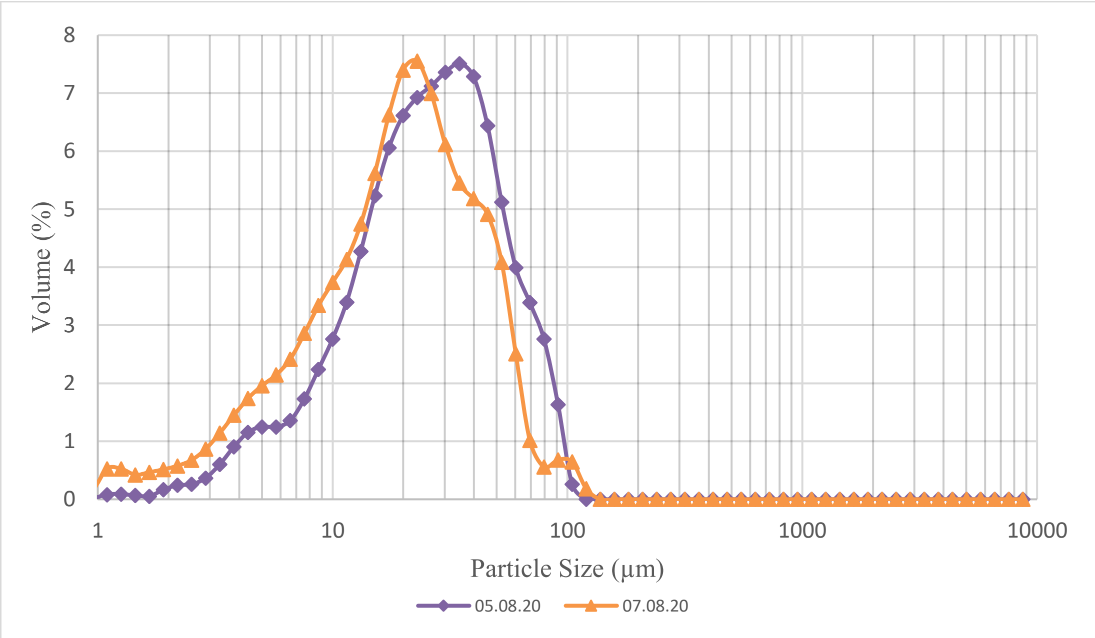


Figure 4.72 Particle size distribution after filtration with wastewater feed

Table 4.12 Detailed information on the particle size distribution of filtrate samples taken from at different operation days

	05.08	07.08
D [4, 3] - Volume weighted mean (µm)	32.802	25.765
D [3, 2] - Surface weighted mean (µm)	17.662	11.448
Specific surface area (m^2/g)	0.34	0.524
d(0.1) (µm)	8.949	5.348
d(0.5) (µm)	27.831	21.248
d(0.9) (µm)	64.422	51.986

Rheological properties of SBR sludge, SBR effluent and SBR+MBTF+AC filtrate were shown in Figure 4.73. It is clear that samples exhibited non-Newtonian flow behaviour from figures. There is remarkable change in viscosity of SBR effluent, filtrate showed lower change according to shear rate. For all effluents, material viscosity tended to decrease as shear rate increased. The photographs of the SBR effluent and filtration effluent were shown in Figure 4.74.

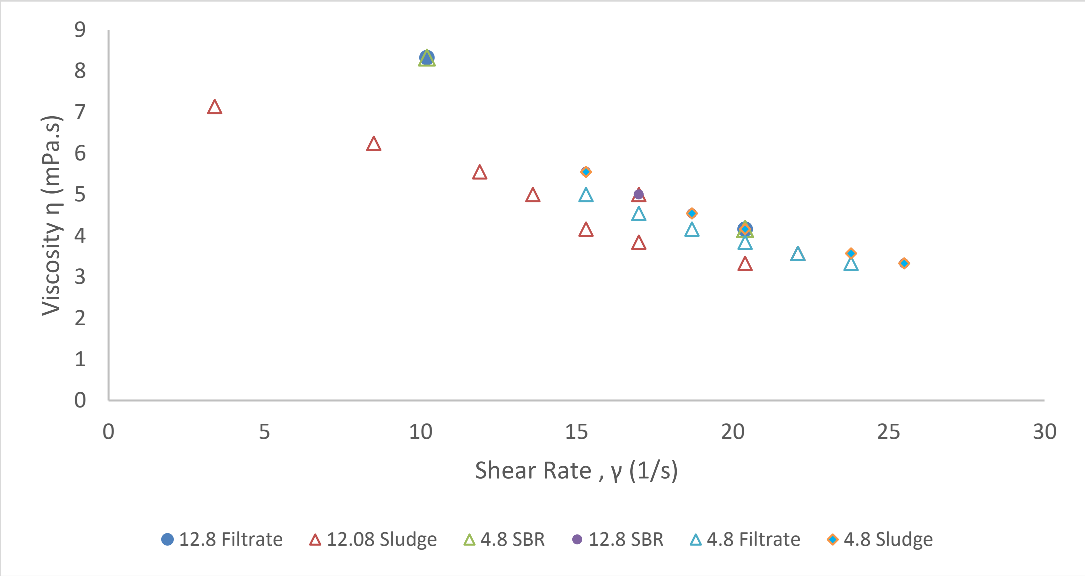


Figure 4.73 Rheograms of different samples

Figure 4.74 Photographs of SBR and Filtration Effluents (Personal archive, 2020)

4.9.1 Heavy Metal Analysis

Heavy metal analysis was carried out by using Perkin Elmer ICP-QMS (Perkin Elmer-Optima 2100DV) device. Table 4.13 shows the heavy metal concentrations for SBR sludge, raw wastewater and effluent sample following the filtration unit. Ncube et al. (2018) indicated that the typical treated wastewater also contains heavy metals such as chromium, copper, cyanide, cobalt, manganese, zinc and lead. The heavy metal results were compared to the limit values in Technical Communique on Wastewater Treatment Plant Procedures No. 27527 dated March 20, 2010 in Annex 7 regarding the use of treated wastewater for irrigation purpose. Consequently, all parameters except for molybdenum (Mo) remained below the limit values.

Table 4.13 Heavy metal analysis results

Parameters	SBR Sludge (mg/L)	Raw Wastewater (mg/L)	Effluent (mg/L)	Limit values in case of continuous irrigation (mg/L)
Aluminium (Al)	0.03	0.20	0.07	5.0
Arsenic (As)	0.01	<0.01	0.02	0.1
Beryllium (Be)	<0.01	<0.01	<0.000	0.1
Boron (B)	0.34	0.16	0.12	-
Cadmium (Cd)	<0.01	<0.01	0.00	0.01
Chromium (Cr)	<0.01	0,01	0.00	0.1
Cobalt (Co)	<0.01	<0.01	0.00	0.05
Copper (Cu)	<0.01	0.01	0.06	0.2
Iron (Fe)	0.02	0.29	0.06	5.0
Lead (Pb)	<0.01	<0.01	0.00	5.0
Lithium (Li)	0.01	0.01	0.01	2.5
Manganese (Mn)	0.02	0.06	0.00	0.2
Molybdenum (Mo)	<0.01	<0.01	0.02	0.01
Nickel (Ni)	0.01	<0.01	0.01	0.2
Selenium (Se)	<0.01	<0.01	0.00	0.02
Vanadium (V)	<0.01	<0.01	0.01	0.1
Zinc (Zn)	0.02	0.09	0.09	2.0

4.9.2 SBR Sludge Properties

During the study, MLSS, SVI, CST and Zeta Potential parameters were regularly monitored by using the SBR sludge. The monitoring frequencies and experimental results of these parameters were given in Figure 4.75.

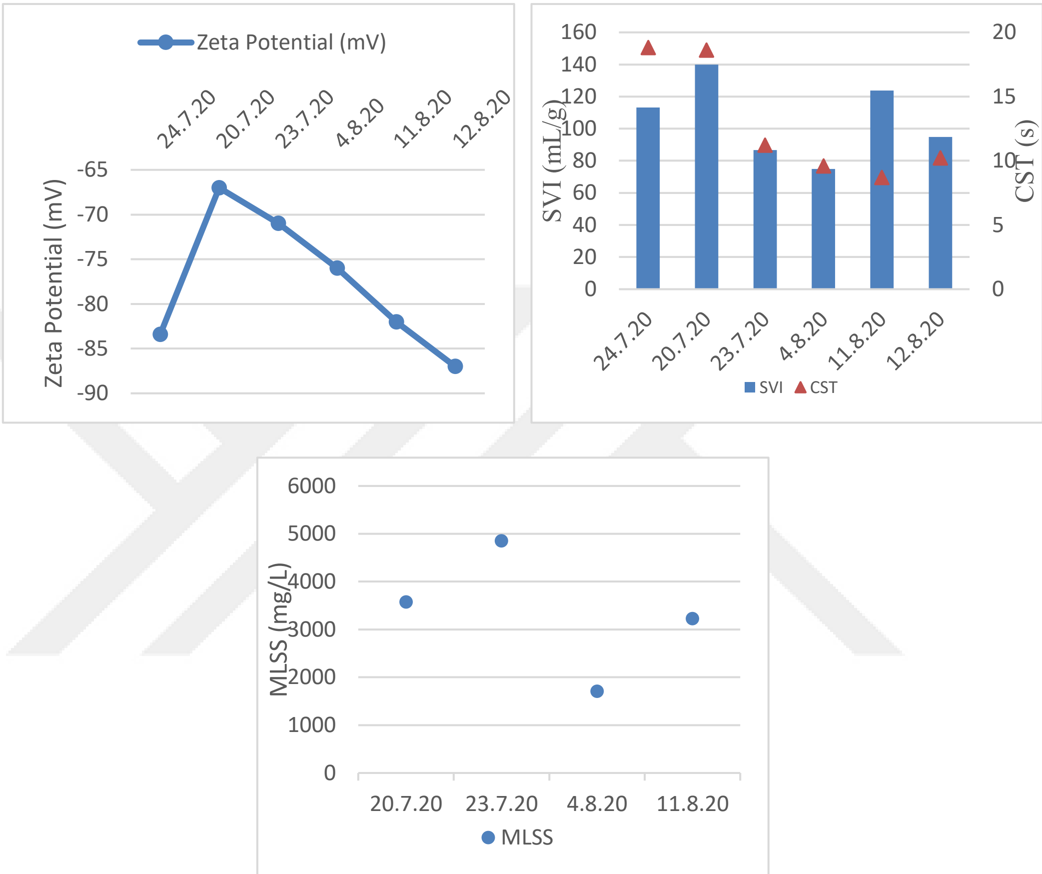


Figure 4.75 Graphical representation of SBR sludge properties

MLSS concentration varied between 5,000 mg/L and 2,000 mg/L during operation. MLVSS/MLSS ratio was generally around 75%. Capillary suction time (CST) and sludge volume index (SVI) values decreased slightly in the later days of operation. Therefore, the settling and dewatering properties of the sludge were very good. Zeta potential measured to determine the adsorption tendency of MLSS inside of the reactor varied between -67 mV and -87 mV. Studies reported that the flocculation balance factor decreased with the increase of EPS content and the decrease of zeta potentials (Huifang et al., 2020; Z. Li et al., 2016). Particle size distribution results of the SBR sludge were shown in Figure 4.76 and also summarized in Table 4.14.

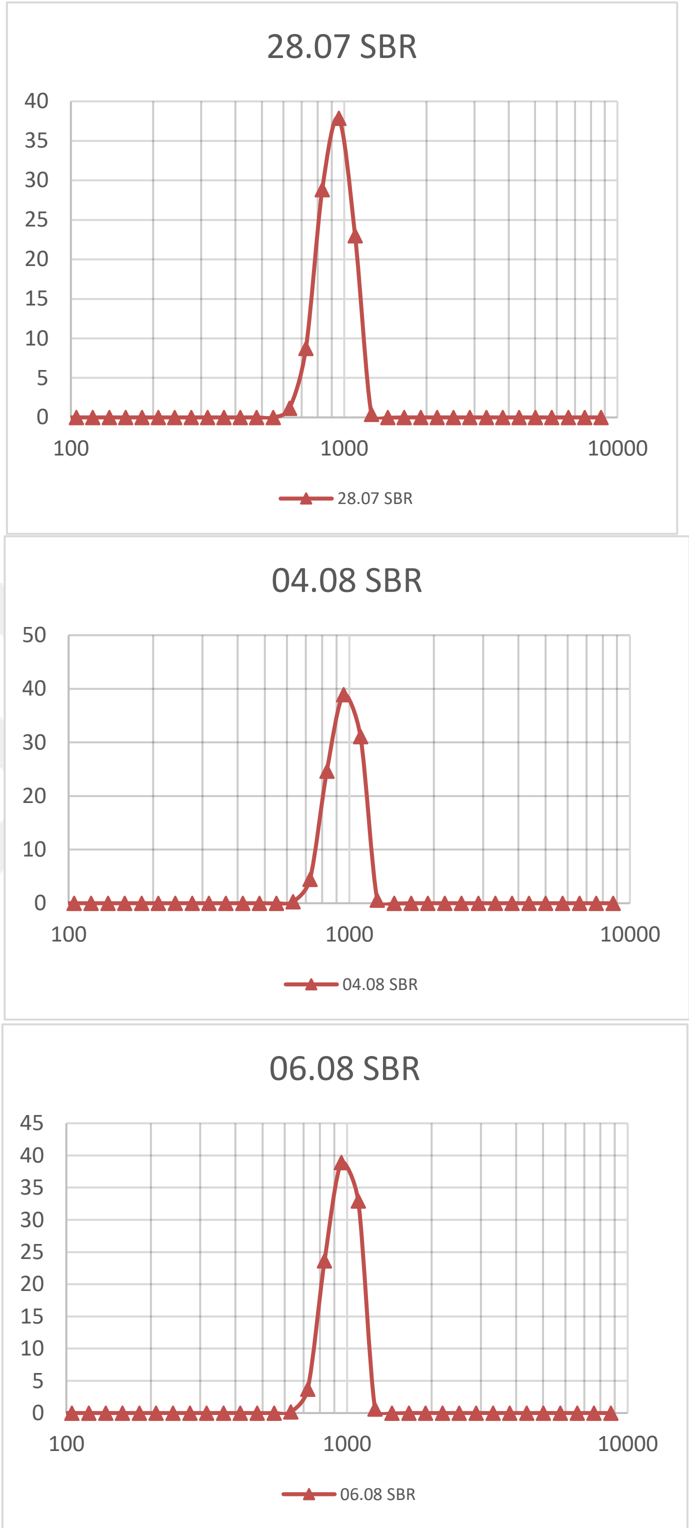


Figure 4.76 Particle size distribution of SBR sludge

Table 4.14 Particle size analysis results of SBR sludge

	28.07.2020	04.08.2020	06.08.2020
D[4,3], µm	995.802	1027.787	1034.344
D[3,2], µm	978.468	1012.428	1019.487
Specific Surface Area (m^2/g)	0.00613	0.00593	0.00589
D(0.1) µm	832.360	868.139	874.717
D(0.5) µm	995.046	1031.420	1039.341
D(0.9) µm	1163	1183.245	1187.004

EPS is an important parameter in terms of causing clogging problem. EPS results of SBR sludge were presented in Figure 4.77. Total EPS concentration fluctuated between 14.854 mg/L and 68.153 mg/L in SBR sludge. Low EPS concentration contributes to providing high filterability as EPS increases filtration resistance by affecting sludge that deposits on filtration surface (Mohan & Nagalakshmi, 2020). pH or salinity may be affected protein shape (Sutherland, 2008a).

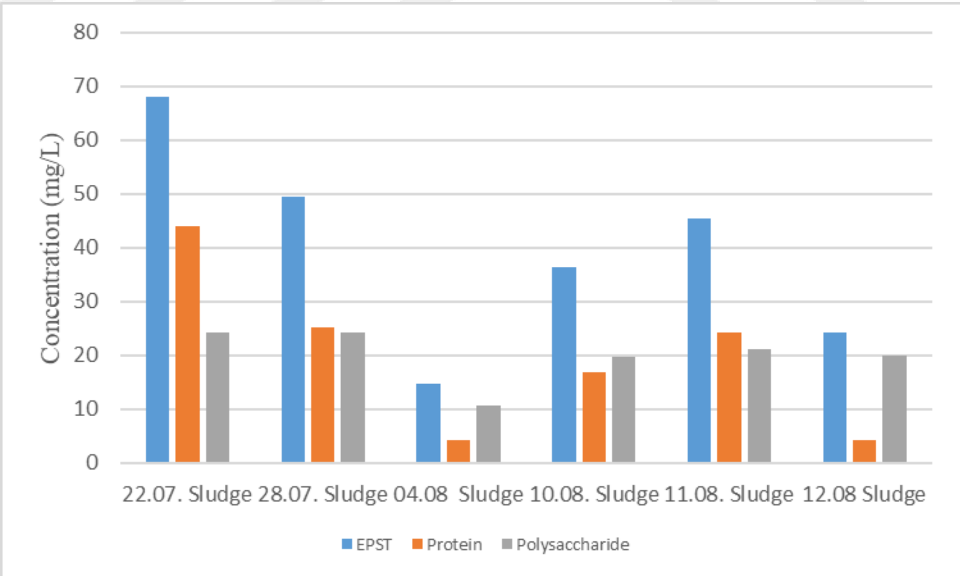


Figure 4.77 EPS results of SBR sludge

4.9.3 Fourier Transform Infrared Spectorphotometer- FTIR Analysis of Filtration Material Used

FTIR anaylsis were done to determine the organic composition of the filtration materials for the accumulation on the first layer of MBTF surface, which was the first contact with the wastewater. FTIR results were shown in Figure 4.78 and summarized in Table 4.15.

According to FTIR peaks, 3,282.29 cm^{-1} peak on IR spectrum equals to O-H vibration on filtrate's structure. The peaks between 2,921.65 cm^{-1} and 2,850.63 cm^{-1} refers to sp3 hybridization on sludge which means aliphatic C-H bound (Jawaid&Khan,2018). As a result of the FTIR analysis, a peak was formed at 9 different wavelengths. For each wavelength mentioned here 3,289.29, 2,920.82, 1,636.35, 1,546.08, 1,307.71, 1,314.30, 1,245.67, 1,027.69 and 602.20 cm^{-1} , gives information about the content of debris formed during filtration on the textile material.

Table 4.15 FT-IR results of the accumulation on the first layer of MBTF

Wavelength (cm^{-1})	Organic Groups
3,600-3,200	OH, Carboxyls, NH groups
3,100-2,800	Methyl and methylen aliphatic groups, =C-H, -C-H, -C-H aldehydic groups.
1,600-1,200	Carboxylic acids, ketones, aldehydes, phenyl and flouride (C-OH, C=C aromatic, C-O-C)
1,400-1,000	C-O carbohydrates, C-F bonding
800-600	C-Cl bonding, carboxyl functional groups

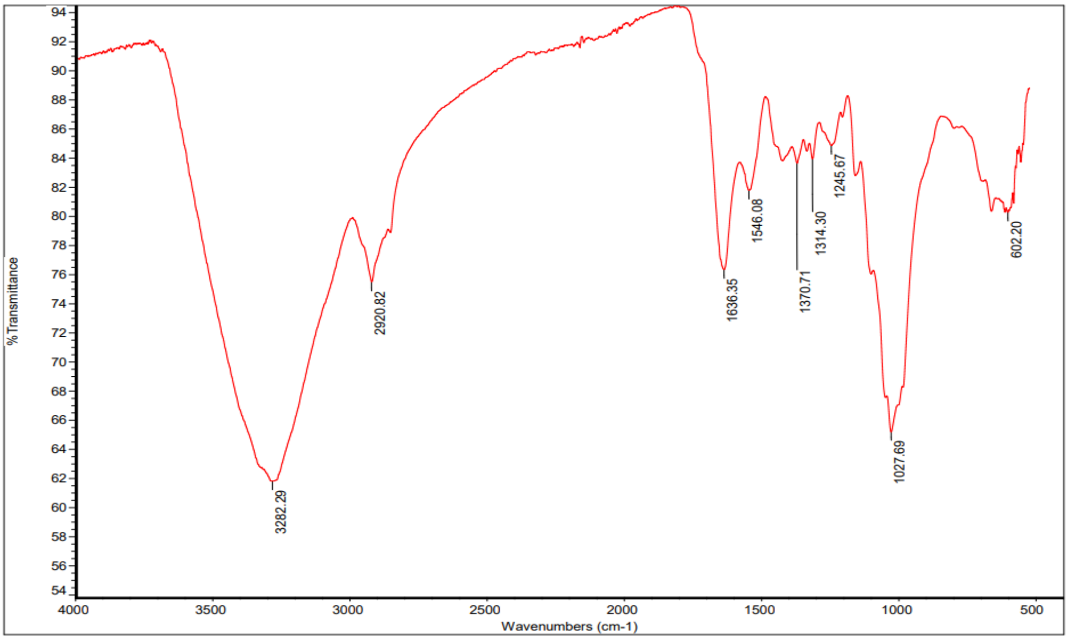


Figure 4.78 FTIR analysis of first layer of MBTF

4.9.4 SEM-EDS

The presence of inorganic substances in the mixed liquid such as Mg, Na Al, Si, P, Cl, K and S was determined on the MBTF textile material used. Iorhemen et al. (2016) reported that inorganic foulants such as Ca, Mg, Al, and SO_4 result in membrane fouling as inorganic foulants precipitate onto the membrane surface or into the membrane pores. Although the material used in this study was not a mebrane, this is important information considering clogging and backwashing.

When comparing SEM images of unused and used MBTF materials, the existence of a layer formed as a result of filtration cake on the surface was seen. SEM image was taken over the first layer contacted by the wastewater. The SEM images were shown in Figure 4.79 and Figure 4.80.

At the same time, Energy-dispersive X-ray spectroscopy (EDS) analysis was done on the MBTF. X-ray spectroscopy is an analytical technique used for elemental analysis or chemical characterization of a sample (Wang, Wagner, Ghosal, Bedi, & Wall, 2017). The C, O, Ca, Mg, Si, P elements were observed in the EDS analysis results as shown in Figure 4.81.

SEM images given in Figure 4.82 showed a very small amount of contamination on the activated carbon woven textile surface, despite having a very high adsorption capacity. It means that this activated carbon woven fabric, which has the highest cost in the system, can be operated for a long time without encountering problems such as clogging. EDS results of used AC textile material was also presented in Figure 4. 83.

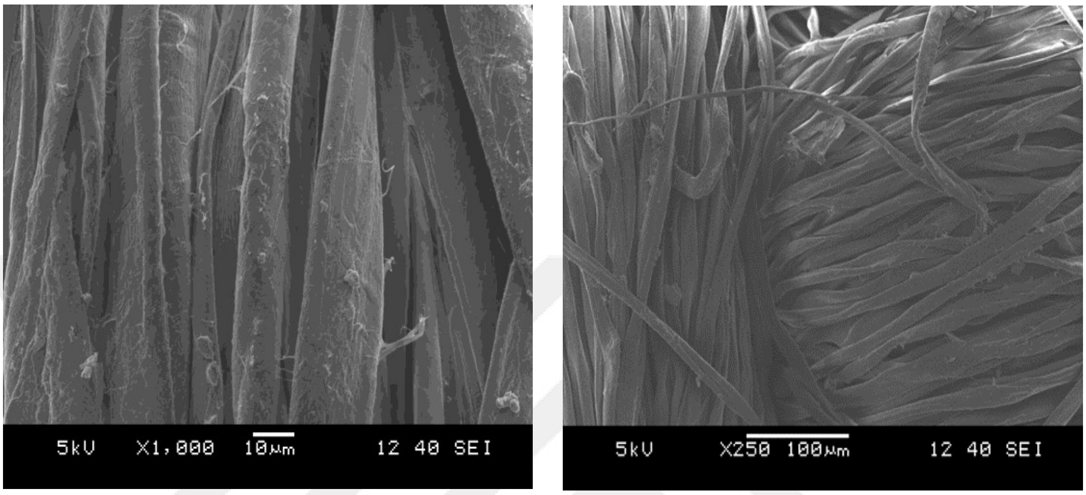


Figure 4.79 SEM Image of unused MBTF textile Material

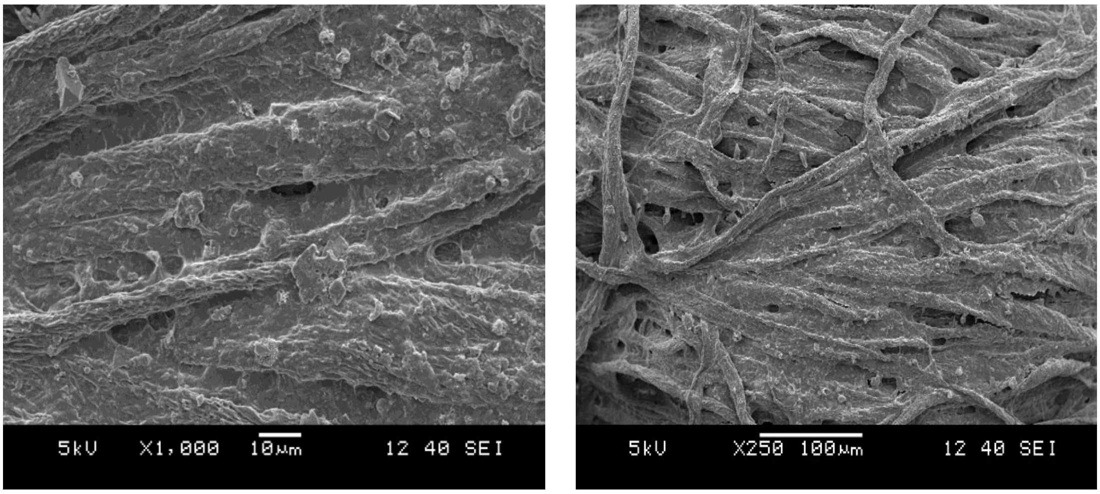
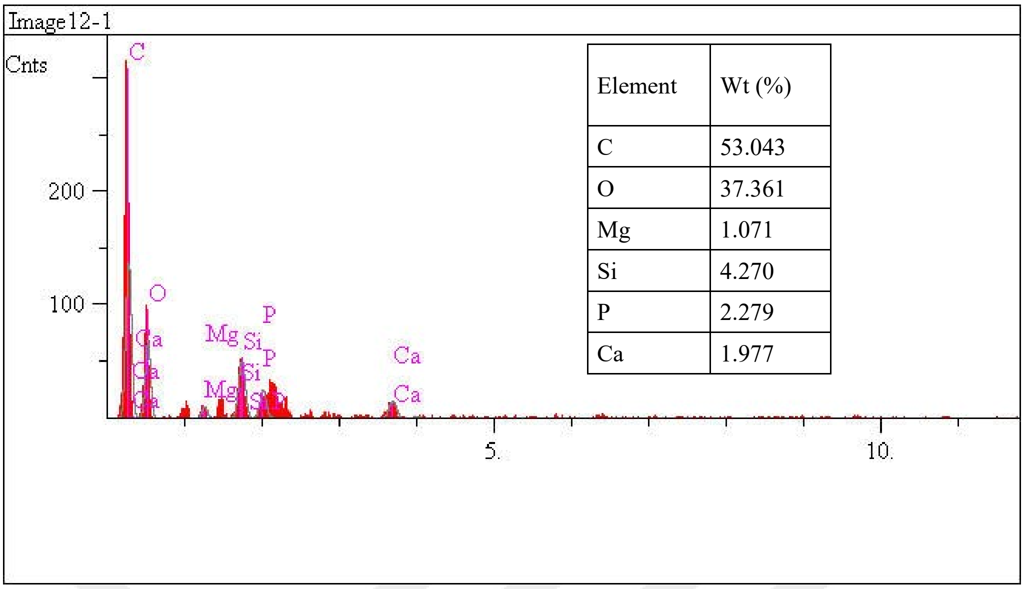


Figure 4.80 SEM Image of used MBTF textile material



Element	Wt (%)
C	53.043
O	37.361
Mg	1.071
Si	4.270
P	2.279
Ca	1.977

Figure 4.81 EDS results of used MBTF textile material

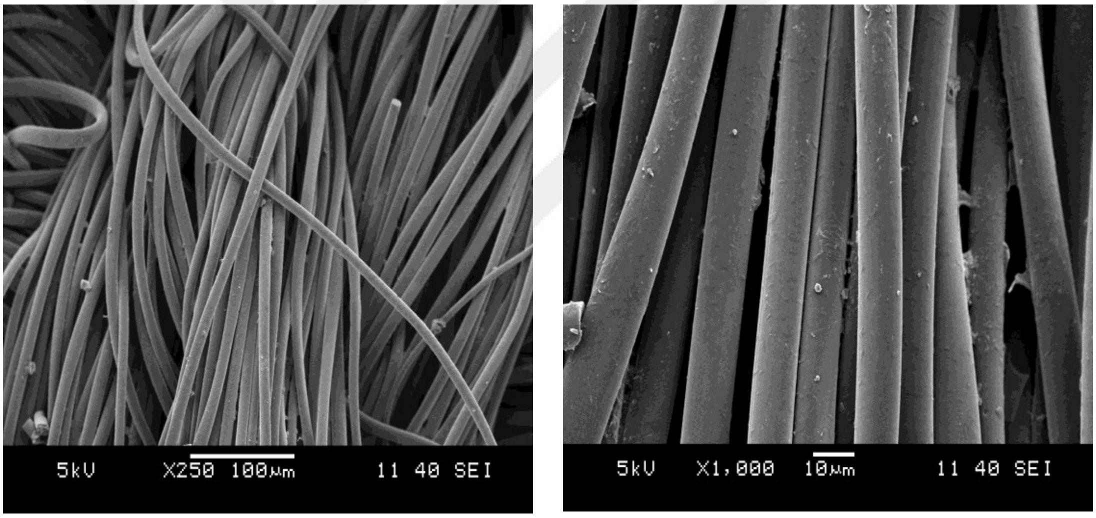
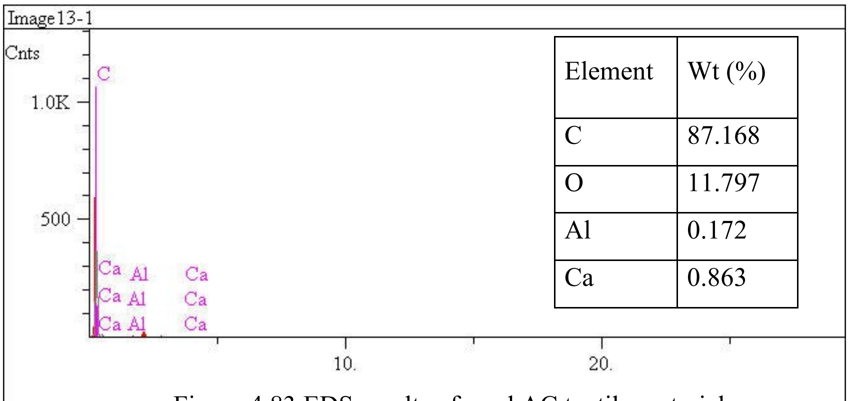


Figure 4.82 SEM image of used AC textile material



Element	Wt (%)
C	87.168
O	11.797
Al	0.172
Ca	0.863

Figure 4.83 EDS results of used AC textile material

4.10 The Applicability of the Treatment System for Rural Areas in Turkey

The choice of appropriate wastewater treatment technology with all its advantages and disadvantages is a highly complex process. The objective of the present study was to investigate an environmental and economically sustainable technic to treat domestic wastewater in rural areas of Turkey. Filtration processes has been gaining popularity as a low-cost, low-maintenance and effective alternative in vast rural areas. The concentrations of COD in effluent streams of SBR + Filtration system exhibited good removals. Also, some other parameters like nutrients can be removed by adjusting the operational conditions of SBR. This system can be appropriate for the rural aeras in Turkey. However, it needs the pilot scale and full-scale studies.

4.11 Evaluation of Manisa Province in Gediz Basin as a pilot area

Small settlements in the city of Manisa, which is within the borders of the Gediz River Basin, have been determined as pilot area. All settlements in the province with a population of less than 500 - this information was obtained from TURKSTAT (Turkey Statistical Institute)- were marked on the Google Earth program. In Manisa, General Directorate of Water and Sewerage Administration-MASKİ operated 19 domestic/municpal WWTPs having advanced biological treatment units as shown in Figure 4.84. The rate of commitment to the total treatment facility is 83.5%. However, the small settlements as the rural areas that are not connected to the sewerage system was asked from MASKİ. There are a total of 258 residential units with a population of less than 500 in 12 districts, which are not connected to the treatment plant. The system developed in this study can be implemented to these small settlements shown in Figure 4.85. However, as mentioned above, the pilot scale and full-scale studies should be applied regarding the technical and economical considerations.

Figure 4.84 Geographical locations of wastewater treatment plants in Manisa, Turkey

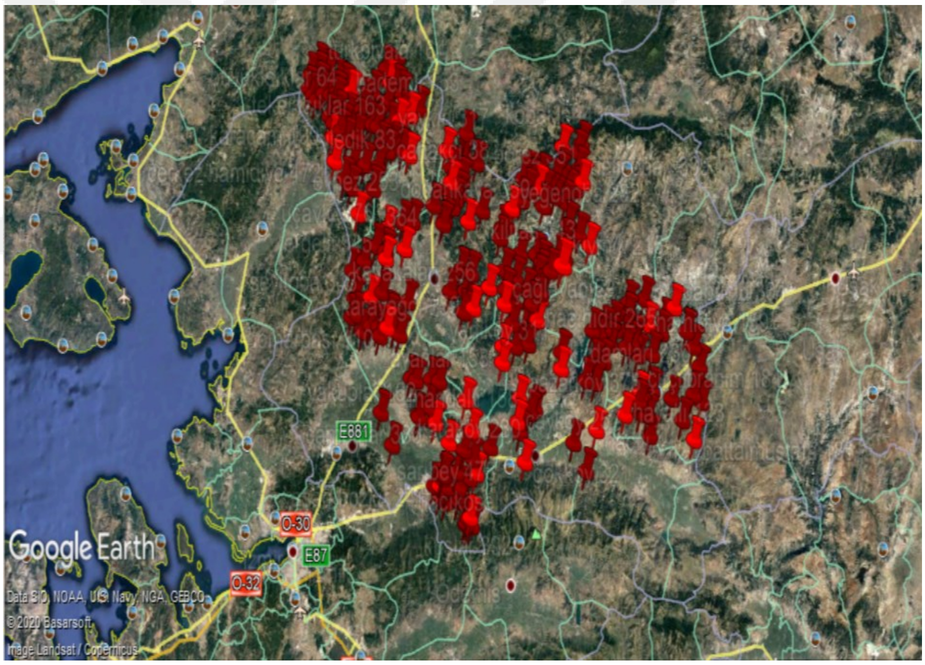


Figure 4.85 258 residential units which has the population less than <500 person

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this study is to apply a wastewater treatment system with a low-cost system such as filtration for small settlements. The research also focuses on the efficiency of the filtration unit with different filtration materials (such as activated carbon) applicable in wastewater treatment, in which the variable parameters were conducted to optimize the design of the unit and to investigate the most efficient configuration for the filtration unit. As a result of the study, four different textile materials were evaluated to be used as filtration media, and high efficiency was achieved as a result of the development of the system with biological treatment as SBR integrated with filtration unit.

Eight different sets tested with synthetic wastewater during the study. The operating conditions and technical equipment of the system were optimised to achieved the highest removal efficiency operated with real wastewater as well.

Some concluding remarks from the thesis are given as follows:

- Regarding the results done for determining the most suitable textile filtration material, MBTF achieved a better efficiency compared to the cotton-polyester blend fabric (TF).

- The filtration system alone can not achieve sufficient treatment efficiency. Therfore, the filtration system was integrated with a SBR system.

- Salinity and conductivity parameters changed depending on inlet wastewater and environmental conditions. The pH values of the treated water were observed between 7.5 and 8.5 units. Although there were various fluctuations in the inlet wastewater and environmental conditions, a high rate of organic matter reduction occurred in the sequencing batch reactor system.

- While working with only the filtration system, although the suspended solids retention was high, no clogging was observed in both fabric types. While this situation can be interpreted positively as it does not require backwashing.

- Although smaller the pore structure, the polyester-cotton blend textile material could not get upper hand the MBTF. This result can be attributed to the 50 micron-diameter stainless steel fibers that the textile material provided. Nevertheless, MBTF's efficiency on COD removal remained limited as 30% even when the number of layers was increased.

- After SBR implementation, MBTF filtration system operated by synthetic wastewater had 92% COD removal efficiency in the SBR system. The filtration unit also reached 50% removal efficiency more. Final BOD_5 values also decreased to 10 mg/L levels.

- The averages of COD concentrations in the influent were 1,000 ± 42.9 mg/L, and those of the effluent were 75.8 ± 2.38 mg/L for SBR and 35± 1.6 mg/L for SBR + Filtration, respectively. During the trials, the effect of 5 different input flow rates on system performance was also examined. Although a direct relationship was not observed between the hydraulic loading rate and treatment efficiencies, a trend was observed that the values of these parameters decrease as the values of the hydraulic loading rate increase in some stages.

- When operating with four different filtration materials, 4 layers of MBTF, S1, S3 and AC filters, the COD removal efficiencies were , 96-98%, 90%, 92%, and 93%, respectively. BOD_5 removal efficiencies varied as 98.5% , 93.99%, 93.33%, and 95%. TN removals achieved 53.8%, 29%, 74.84%, and 67.10%, respectively. TP removal efficiencies reached 80%, 31%, 12.4%, and 51.8%, respectively.

• After SBR implementation, there was partial nutrient removal in all sets. The aerobic operation of SBR unit and the presence of anaerobic/anoxic sections resulted nutrient removal. Considering only their filtration performance, S1 and S3 did not show a big difference, while AC showed high performance.

5.2 Recommendations

The proposed approach would be safer than the existing use of wastewater for irrigation of vegetables and other plants without any treatment often used in rural and peri-urban settings of developing countries.

It is known that high operating and maintenance costs and high energy consumption in wastewater treatment plants are considered as important factors. The full-scale applications of the system used in this study promise to avoid these constraints for small settlements.

It may be beneficial to develop the system with a disinfection unit in full-scale applications.

Turkey has prepared an Action plan for wastewater treatment for the years of 2015–2023 based on a previous action plan by Ministry of Environment and Urbanism. For the assessment of water quality and quantity in the river basins of Turkey, modeling techniques and some important pollutant parameters were emphasized in the action plan. Regarding the action plan, the developed system can be applicable for reusing of treated effleunts of small settlements. However, the pilot scale and full-scale studies should be applied regarding the technical and economical considerations.

Since AC vowen textile material application gave better removal results, this materialcan be regenerated via electrical current application or chemical methods for economical reasons in practice. So, the regeneration of AC vowen fabric should to be studied in future.

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