DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PERFORMANCE EVALUATION AND MASS BALANCE STUDIES ON MEMBRANE BIOREACTOR SYSTEMS

by
Gülce ÖZEL

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İZMİR

PERFORMANCE EVALUATION AND MASS BALANCE STUDIES ON MEMBRANE BIOREACTOR SYSTEMS

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by
Gülce ÖZEL

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İZMİR

M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"PERFORMANCE EVALUATION AND MASS BALANCE STUDIES ON MEMBRANE BIOREACTOR SYSTEMS"** completed by **GÜLCE ÖZEL** under supervision of **PROF.DR. NURDAN BÜYÜKKAMACI** 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. Nurdan BÜYÜKKAMACI

Supervisor

Prof. Dr. Ayşe FİLİBELİ

(Jury Member)

Yrd. Doç. Dr. Hasan SARPTAŞ

(Jury Member)

Prof.Dr. Ayşe OKUR

Director

Graduate School of Natural and Applied Sciences

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PERFORMANCE EVALUATION AND MASS BALANCE STUDIES ON MEMBRANE BIOREACTOR SYSTEMS

ABSTRACT

In this study, membrane bioreactor systems which are in competition with activated sludge systems are investigated. This system is being popular for both domestic and industrial wastewater treatment. In the scope of this thesis, treatment performance of a full-scale MBR system, which is placed in an industrial wastewater treatment plant, was evaluated and mass balance studies for this system were done considering some significant design and operational parameters and some kinetic parameters were calculated.

A full-scale industrial wastewater treatment plant, which is in İzmir Torbalı Organized Industrial Zone, was chosen as a pilot plant. The annual data for some significant operational parameters, such as pH, chemical oxygen demand, suspended solids, electrical conductivity, dissolved oxygen, and temperature, was obtained from the authorized person of the plant. The system performance was evaluated considering this data. In addition, samples were taken from the inlet of the aeration tank, inside of the aeration tank, and outlet of the membrane unit in consecutive five day for a week. Chemical oxygen demand (COD), suspended solids (SS), volatile suspended solids (VSS), total solids (TS), total volatile solids (TVS), total nitrogen, and total phosphorous analyses were performed. According to results, mass balances for these parameters were generated and some important kinetic coefficients were calculated by applying Monod model.

Keywords: Kinetic parameters, kinetic studies, mass balance, membrane bioreactor, membrane processes, yield coefficient.

MEMBRAN BİYOREAKTÖR SİSTEMLERİ İÇİN PERFORMANS DEĞERLENDİRMESİ VE KÜTLE DENGESİ ÇALIŞMALARI

ÖZ

Bu çalışmada, evsel ve endüstriyel atıksu arıtımlarında yaygın olarak kullanılmaya başlayan, aktif çamur sistemleri ile rekabet halinde olan membran biyoreaktörler araştırılmıştır. Tez kapsamında, bir endüstriyel atıksu arıtma tesisinde kurulu olan gerçek ölçekte bir MBR sisteminin arıtma performansı değerlendirilmiş ve bu sistem için önemli tasarım ve işletme parametreleri dikkate alınarak kütle dengesi çalışmaları yapılmıştır ve bazı kinetik parametreler hesaplanmıştır.

Kütle dengesi çalışmalarını yapmak üzere İzmir Torbalı Organize Sanayi Bölgesindeki arıtma tesisi pilot tesis olarak seçilmiştir. Tesis yetkililerinden pH, kimyasal oksijen ihtiyacı, askıda katı madde, elektriksel iletkenlik, çözünmüş oksijen ve sıcaklık gibi bazı işletme parametreleri için bir yıllık veri temin edilmiştir. Elde edilen verilere göre sistem performansı değerlendirilmiştir. Ayrıca, bir hafta içinde birbirini takip eden 5 gün havalandırma havuzu girişi, havalandırma havuzu içi ve membran ünitesi çıkışından örnek alınmıştır. Alınan örneklerde, kimyasal oksijen ihtiyacı (KOİ), askıda katı madde (AKM), uçucu askıda katı madde (UAKM), toplam katı madde (TKM), toplam uçucu katı madde (TUKM), toplam azot ve toplam fosfor analizleri yapılmıştır. Bu parametrelere göre kütle dengesi oluşturulmuş ve Monod modeli uygulanarak bazı önemli kinetik parametreler hesaplanmıştır.

Anahtar kelimeler: Kinetik parametreler, kinetik çalışmalar, kütle dengesi, membran biyoreaktör, membran prosesleri, verim katsayısı

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Depending on rapid population growth, excessive industrialization, increasing drought, fresh water resources are being depleted rapidly on a global scale with excessive consumption. This problem, especially the Balkans and the Middle East where the geography of our country, is becoming more important in recent years and the ownership of water resources is one of the main factor of the strategic relations and a bargain between the countries. It can provide sustainable development in response to the growing demand for fresh water resources to increase technical and renew the restrictive economic terms, so there is a need for different practical solutions. In this context, the first way to protect fresh water resources is recycling of treated wastewater for use back in recent years and for many different activities and practices have been increased. Consumption of both freshwater resources back to the use of wastewater is reduced as well as the environmental impact of treated wastewater discharged can be minimized. Thus, water treatment technologies are getting more important part of our life. There are many processes as biological processes, which are the processes vital for a living organism to live, uses to treat water. The most commonly use process is activated sludge system but nowadays membrane bioreactor is in competition with it.

Membrane bioreactor is a process that combine a biological reactor and a membrane process to protect biomass. Reactor tank is likely the same with conventional activated sludge process but there is no need secondary disinfection and tertiary steps (Melin et al., 2006). Membrane bioreactor systems (MBR) are biological treatment systems with suspended growth, which is made liquid/solid separation of low pressure membrane filtration. Membrane separation processes are applied to treat municipal and industrial wastewaters. Researchers have used different types of membranes as solid-liquid separation device combining with

conventional biological treatment processes. Membrane units replace or modify the need for a secondary sedimentation tank (Chiemchaisri, Yamamoto, & Vigneswaran, 2011). Industrial wastewaters are the two most important characteristics of high organic loads and treatment-resistant compounds. Therefore there is a need for alternative treatment technologies such as MBR alongside conventional treatment techniques. Aerobic membrane bioreactor systems, has become a treatment technology used in treatment of industrial wastewater with anaerobic treatment. Generally, wastewater with high chemical oxygen demand (COD) amount is treated with anaerobic systems that are why MBR technologies in industrial wastewater are developed in this way. With the use of this process, biodegradable components are reduced; microbes, turbidity, particles and surfactants are increased. It provides mechanic disinfection for waste's hygienic quality and protects biomass in biologic reactor. This enhances performance of reactor (Chiemchaisri, Yamamoto, & Vigneswaran, 2011).

MBR is a new technology that has high efficiency to obtain high quality water. It has lots of advantages like complete solids, organic and nutrient removal, small footprint, physical disinfection (Jang et al., 2006). One of the other advantages of this process is that minimum sludge wastage by maintain low F/M ratio, reduced plant size by maintaining higher biomass concentration in the reactor (Chiemchaisri, Yamamoto, & Vigneswaran, 2011). In addition, MBR process is suitable for both domestic wastewater treatment and industrial wastewater treatment.

In this study mass balance studies are made for membrane bioreactor systems. Mass balance is a well-known process based on a principle that any matter cannot disappear or be created any reason. It is widely used in wastewater treatment facilities. Mass balance expression means output microorganisms flow through the inlet flow microorganisms and growing microorganism are added to them. Mass balance studies are important because all microorganism events, values can be recognized. Environmental engineers must know every processes and values and provide optimum conditions for treatment, so mass balance studies is necessary to obtain efficient treatment. Therefore mass balance should be regarded the

discharging limits and known all the pollutants included in the wastewater. As considering this information it is clear that flow, chemical oxygen demand, nitrogen and phosphorus, total suspended solids should be regarded as well. Dynamic and steady-state models are two options for mass balance in wastewater treatment facilities. If dynamic model is used, all information about influent of wastewater must be known such as reactor concentration, reactor sizes, and characteristics of influent. On the other hand if steady-state model is used, characteristic of influent is enough (Ekama, 2009).

Modeling must be used to execute mass balance studies. One of the important features of modeling is describing organic materials by using chemical oxygen demand (COD) instead of biological oxygen demand (BOD). Also COD is researched as dissolved, particular, inert, biologically degradable difficult and easy. Some systems as activated sludge system have complicated equalizations because of lots of parameters, so modeling is used to solve equalizations to remove complications. Kinetic parameters provide the necessity of modeling. Biological systems have lots of kinetic parameters. Volatile suspended solid, temperature; activated biomass can be examples for activated sludge systems.

1.2 Aim and Scope of the Thesis

Evaluation of the treatment performance and mass balance studies for a full-scale MBR system treating an industrial wastewater is reported on this thesis. The aim of this study is to evaluate monitoring the operational data and make mass balance analyses for the full-scale MBR system treating an organized industrial district wastewater. In addition to mass balance studies, some kinetic parameters, such as yield coefficient (Y), decay coefficient (b), saturation constant (K_s), and maximum specific substrate utilization rate (k), were also calculated. It is assumed that kinetic parameters are feasible for analyzing the performance of membrane bioreactor process for treating industrial wastewater. The kinetic parameters were calculated by Monod Model using data obtained from the experimental studies carried out in the scope of this study.

CHAPTER TWO
MEMBRANE BIOREACTOR SYSTEMS

2.1 Introduction of MBR Systems

Membrane bioreactor systems are being popular for both domestic and industrial wastewater. In this system a membrane unit is used in combination with either an aerobic or an anaerobic biological system to protect biomass. In addition, it can provide mechanical hygiene for wastewater. MBR systems are technically the same as traditional activated sludge, except for treating and separation of sludge. While the sludge separation is achieved by an external sedimentation tank on conventional activated sludge system, it can be done by membrane filtration on MBRs (Van Der Roest, Lawrence, & Van Bentem, 2002).

The main aims of MBR processes are to reduce biodegradable components and microbes, turbidity, particulars, and surfactants. MBRs used in activated sludge systems have some boundaries. These are effluent standards, limited areas, and enlarging existing facilities.

In typical treatment plants including MBR process, coarse and fine screening and equalization are applied before the MBR unit, and the primary sedimentation tank is not generally used. However, if suspended solids content of wastewater is too high, primary sedimentation tank is recommended. MBR processes are really flexible processes. By applying required conditions for denitrification, both carbon and nitrogen removal can be obtained in the MBR system. Denitrification can be provided by setting a closed part without air that supplied anoxic conditions. In the aeration tank, removal of both organic carbon and ammonium nitrogen can be achieved. Besides, anaerobic part can be settled to remove phosphorus biologically or some chemicals such as metal salts may be added to the aeration tank to remove phosphorus chemically. Thus, MBR processes are also suitable for nutrient removal (Judd, 2011). A typical MBR processes' flow scheme is given in Figure 2.1. (Yiğit, 2007).

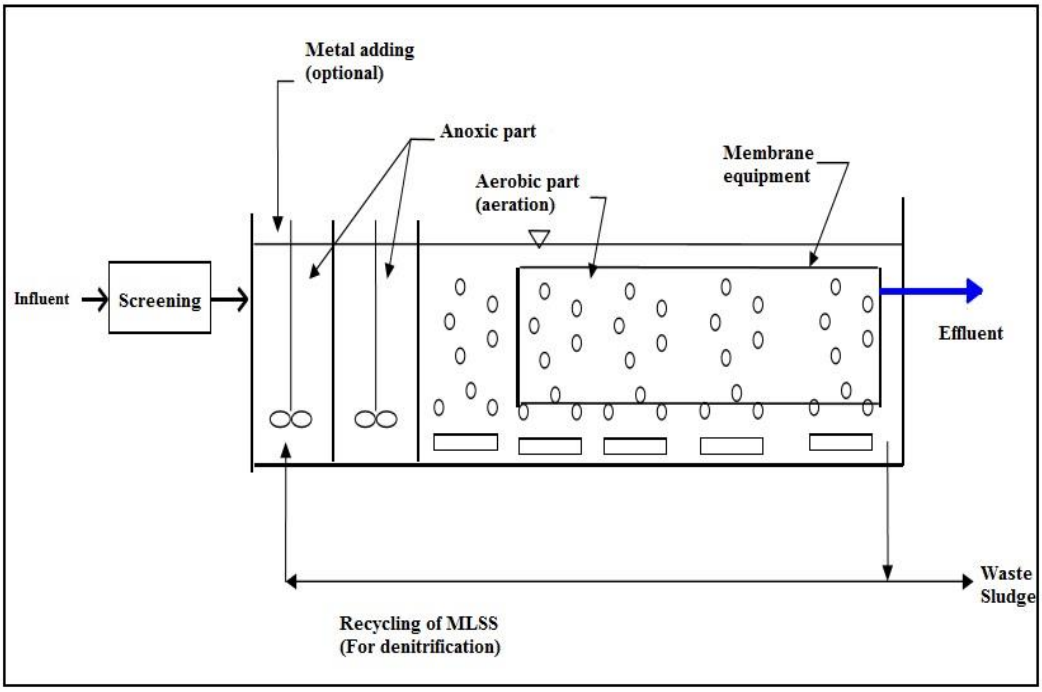


Figure 2.1 Flow scheme of a typical MBR processes (Yiğit, 2007)

Optimum characteristics of geometry and configuration for a membrane are large membrane field or pore and total module volume rate, high turbulence level for supporting transfer of mass on feed side, low cost of energy, low cost for a membrane field, a useful design for cleaning, providing modularization design.

There is three generation of MBR from the beginning until today. Nowadays, fourth generation has been providing. First generation of MBRs were generally used in municipal or domestic wastewater treatments that are in small areas or do not have sewage system. Based on technologic developments, second generation of MBRs was needed in practice. Second generation's has an important advantage that it provided nitrogen and phosphorous removal. Third generation of MBRs has aimed to increase membrane flow rate and capacity, to reduce solid retention time (SRT) and biomass, also to reduce total cost (Crawford et al., 2000). Their criteria of designs are given in Table 2.1 (Crawford et al., 2000).

Fourth generation has been providing. The reason of fourth generation necessity has been based on two main matters. First one is increment of size and scale of

MBRs and the other reason is providing competition of MBRs' equipment in the marketplace. Thus, the owner and consultants can select the design of MBR, according to SRT and MLSS. The bigger volume of MBR constitutes the less MLSS concentration. However, bigger volume also constitutes increment of MBR flux and this causes more waste sludge. So, consultants should think of cost of all plant when selecting equipments (Jenkins & Wanner, 2014).

Table 2.1 Development of generation of MBRs, according to criteria of MBRs' design (Crawford et al., 2000)

	1st Generation	**2nd Generation**	**3rd Generation**
SRT (day)	50 +	20 +	< 10 – 15
MLSS (mg/L)	20,000+	20,000	10,000
NH_3 removal	Existent	Existent	Existent
Total nitrogen removal	Existent	Existent	Existent
Phosphorous removal	Existent	Existent	Existent

2.2 Types of MBR Processes

There are two types of membrane bioreactor configurations. One of them is external submerged; the other one is internal submerged. At the beginning of using this process, external cross-flow operated membranes were used to apply (Figure 2.2). However, this method has required a lot of energy. The energy was for generating the sludge velocity, cleaning the membranes, pressure drop for permeation. Because of all these energy requirements, cross-flow operated MBR has not been used on treatment anymore (Van Der Roest, Lawrence, & Van Bentem, 2002).

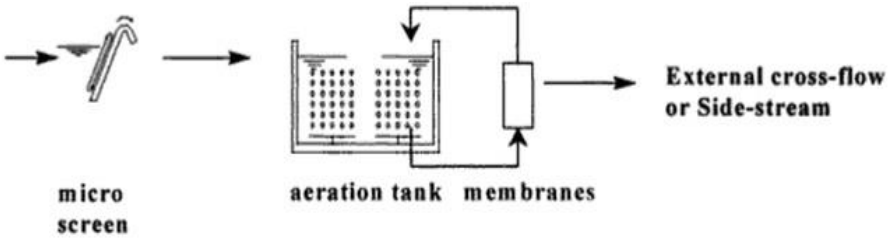


Figure 2.2 External cross-flow operated membrane bioreactor system (Van Der Roest, Lawrence, & Van Bentem, 2002)

When reduction of energy requirements was aimed for the process, there was an acceptable development about MBRs. This development is submerged MBRs. Submerged can be in aeration tank (internal) or out of aeration tank (external) (Figure 2.3). Under favor of this system, energy consumption extremely reduced. Also, required pressure for permeation is much lower than cross-flow membrane (Van Der Roest, Lawrence, & Van Bentem, 2002). Submerged MBR modules are shown in Figure 2.4. MBR processes are also very practical because existing conventional treatment plants can be easily transformed to MBR processes under favor of submerged system. Two type of aeration apply in internal MBR processes. First one is with coarse air bubbles on the floor. It aims oxygen requirement of biomass. Second one is fine air bubbles on the surface. It aims to prevent of accumulation.

When external and internal MBR systems are compared, there are lots of differences between them. First of all is cost of aeration. Cost of aeration in internal MBR processes is much more than in external MBR processes. In external MBRs there is a cost for pumping. While low flux is important for internal MBRs, high flux is essential for external MBRs. As it is expected, the investment and cleaning cost of external MBRs is very high (Judd, 2008).

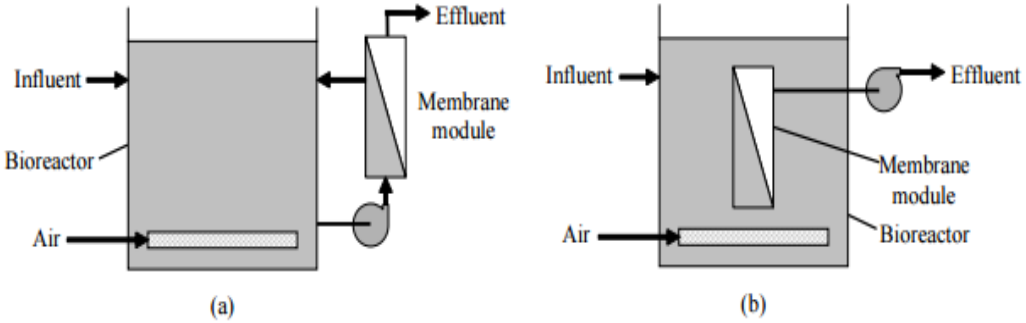


Figure 2.3 MBR systems configurations: a) external, b) internal (Ng & Kim, 2007)

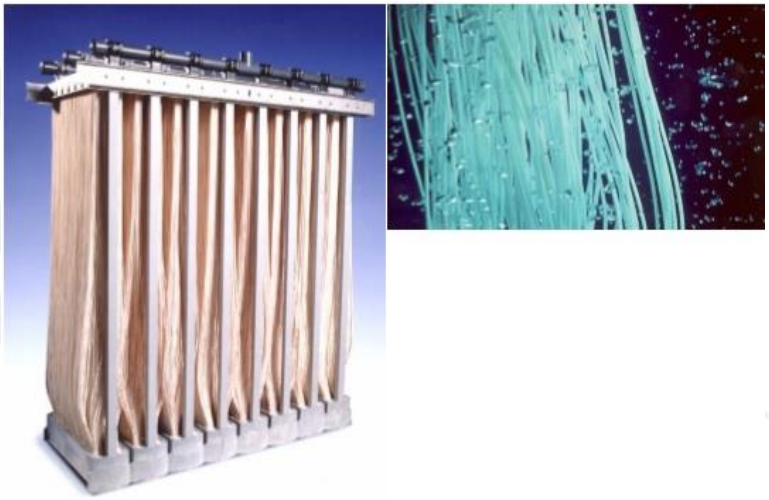


Figure 2.4 Modules of submerged MBRs (Yiğit, 2007)

MBR processes can be chosen according to their membrane's pore size, their used pressure, molecular weight cut-off. In general, ultra-filtration and micro-filtration are used in MBR processes. But micro-filtration is the one that common choice. Its pore size is about 0.05-2µm (Van Der Roest, Lawrence, & Van Bentem, 2002). While treatment operation, these pores became smaller, so efficiency of removal microorganism and suspended solids increase. Membrane configuration, operating parameters, energy consumption for MBRs can be seen in Table 2.2.

Table 2.2 Membrane configuration, operating parameters, energy consumption for MBRs* (Gander et al., 2000)

Configuration:									
Process	SUB	SUB	SUB	SUB	SS	SS	SS	SS	SS
Membrane	P&F	P&F	HF	HF	T	T	HF	HF	T
Material	PS	PE	PE	PE	PS	C	C	PS	$Al(OH)_3$
Pore size (µm)/ MWCO (kDa)	0.4 µm	0.4 µm	0.1 µm	0.1 µm	50 kDa	300 kDa	0.1 µm	0.1 µm	~0.5 µm
Surface area (m^2)	0.24	0.96	2	4	2.6	0.08	1.1	0.39	-
TMP (bar)	0.1	0.3	0.13	0.15	5	2	2	2.75	2.25
Permeate flux ($1m^{-2}h^{-1}$)	7.9	20.8	8	12	170	175	77	8.3	20
Cross flow velocity (ms^{-1})	0.5	0.3-0.5	-	-	1-2	3	1.5-3.5	-	2.2-3.6
Energy consumption, permeate ($kgWhm^{-3}$ product)	-	0.013	0.0055	0.23	0.17	9.9	32	0.045	140
Energy consumption, aeration ($kgWhm^{-3}$ product)	4.0	0.0091	0.14	70	0.52	2.8	9.1	10	10
Total energy consumption, ($kgWhm^{-3}$ product)	4.0	$0.022x10^{-2}$	0.14	70	0.69	13	41	10	50

*SUB: submerged; SS: Side-stream; PS: Polysulphone; PE: Polyethylene; P&F: Plate and Frame; HF: Hollow fiber; T: Tubular; C: Ceramic

2.3 Advantages and Disadvantages of MBR Processes

While all treatment process on MBRs occurs in only a tank, the system is more complex mechanically than conventional systems. However treatment performance of MBRs' is certainly higher. It can clearly be seen from the effluent properties (Table 2.3).

Table 2.3 Quality of typical effluents for municipal wastewater on MBR processes (Yiğit, 2007)

Parameter	Typical amounts
Biological Oxygen Demand (BOD_5)	<2.0 mg/L
Total Suspended Solid (TSS)	<2.0 mg/L
NH_3-N	<1.0 mg/L
Total Phosphorous	<1.0 mg/L
Total Nitrogen	<10.0 mg/L (in average hot climates)
Total Nitrogen	<3.0 mg/L (in hot climates)
Silt Density Index (SDI)	<3.0
Turbidity	<0.5 NTU
Microbiological:	
Bacteria	5-6 log removal
Viruses	1-2 log removal
Protozoa	Full removal

While there is no requirement primary and secondary sedimentation tank, MBR processes do not need very large areas. However its investment cost is quite expensive compared with conventional treatment systems, since the cost of membranes are high.

Hydraulic retention time (HRT) is an important parameter for the design of aeration tanks. HRT reduces the volume of aeration tank. Required HRT for MBRs is lower than conventional systems. It provides smaller volume of aeration tanks. So it also contributes first investment cost (Judd, 2008).

Under favor of ultrafiltration and microfiltration on MBRs, all of biomass is nearly kept (Ortiz et al., 2007). So, effluent suspended solids concentrations are extremely low. Therefore, amount of turbidity is low, almost none.

Mixed liquor suspended solid (MLSS) concentration is quite excessive on MBRs. It provides much more SRT. So, because of treated internal respiration, new biomass reduces and it means removal cost of waste sludge gets cheap. Also, high SRT

increases efficiency of nitrification. Based on high SRT, sludge production is quite lower in MBR processes. Comparison of sludge production with various treatment processes is given in Table 2.4.

Table 2.4 Comparison of sludge production in MBRs with various treatment processes (Gander et al., 2000)

Treatment Process	**Sludge Production (kg/kg BOİ)**
Submerged MBR	0.0-0.3
Structured media biological aerated filter (BAF)	0.15-0.25
Trickling filter	0.3-0.5
Conventional activated sludge	0.6
Granular media BAF	0.63-1.06

CHAPTER THREE
MASS BALANCE STUDIES ON BIOLOGICAL PROCESSES

3.1 Importance of Mass Balance

Mass balance uses the law of conservation of mass about physical research regarding inputs and outputs of substances in treatment facilities. Mass conservation states that no matter can disappear or be created without any reason so the conservation law implemented in the method depends on this problem. Therefore environmental engineering studies use commonly mass balance.

Input-output calculations are defined with mass balance in environmental processes in practice. It is said in other words that input substances include output substances and accumulation, and this is called mass balance equation. Also to calculate mass balance all flows of activated sludge composition, which are in and outgoing, are needed to be known (Puig et al., 2008).

Mass balance which is used in many engineering implementations included such as reactor design and process evaluation is a well-known assessment method. Reliable information is important to increase cost for wastewater treatment, so optimized operation and design is needed in the wastewater treatment. This necessity can be resolved under favor of mass balance. This method is a calculation procedure that assumes the remaining stable outputs and inputs of substances in the system. Calculation of mass balance is very important point in wastewater treatment facilities for environmental engineers by reason of computing fluxes of input and output according to wastewater characteristics, comparing with other operational conditions and viewing general situation. However, mass balance studies are not very easy studies to compute. Because treatment processes are very dynamic systems and input loads in the facility fluctuate (Puig et al., 2008).

Having reliable information from raw wastewater data is not certain, however mass balance studies are commonly preferred to increase water quality. It should be

known that all influent and effluent data, all characteristics of activated sludge, production of sludge so mass balance studies can be more reliable.

3.2 Kinetic Analysis on Biological Systems

Kinetic analyses are implemented on activated sludge systems as membrane bioreactors. Empirical parameters which are based on experimental processes are in use of activated sludge processes' designs in the past. They are organic loading, hydraulic loading, and etc. But, these methods have some disadvantageous that include problem of construing data and optimizing processes. In addition to that operational failure occurs and results cannot equalize to effluent standards. Because of all this reasons, designs of processes are based on kinetic parameters.

Using parameters of kinetic equations provide to success the emergence of bio kinetic theory, design and operation of process. These kinetic equations mean that biological growth rate, substrate utilization rate, food to mass ratio, the mean cell residence time. The emergence of soluble effluent substrate concentration, which they are biological oxygen demand, chemical oxygen demand, total organic carbon, mixed liquor suspended solids concentration (MLSS), nitrogen, phosphorus and oxygen demand and sludge production (Bin Che İbrahim, 2007).

The most important thing for the achievement of modeling is based on biological kinetics coefficients used. There are coefficients that extremely influence the design of processes. These coefficients are Y, maximum specific substrate utilization rate (k), saturation coefficient (K_s), microbial decay coefficient (b or k_d). At first researcher should know heterotrophic yield (Y_H), after that biodegradable substrate's concentration can be obtained. Total chemical oxygen demand and soluble chemical oxygen demand must be known because under favor of this information cell chemical oxygen demand can be known. Therefore Y_H can be calculated. Y_H states subtraction of total COD and cell COD. It should be done more than once, so there can be an approximate estimation (Henze et al., 2000). These parameters are based on the characteristic of wastewater treatment. If it is industrial wastewater, these

parameters are more important for process. Treatment efficiency is developed under favor of evolvement of bio kinetics.

Experimental studies and calculations are important to justify variability in the solid contents, microorganism present in the wastewater. It is determined that how microorganisms influence from the treatment as well as the performance of the membrane bioreactor process. Process kinetics supplies to obtain evaluation and design of a membrane bioreactor process treating various types of wastewaters (Bin Che İbrahim, 2007).

Kinetic parameters for MBR process in treating industrial wastewater contribute to obtain mixed liquor suspended solids (MLSS) evaluation. So it demonstrates concentration of microorganisms in the reactor, effluent microbial concentration and bacterial decay coefficient. MBR process similarly shows differences from activated sludge system. While non- flocculating microorganisms are in sight in activated sludge processes, floc-forming and disorderly microorganisms are obtained in MBR processes (Ng & Hermanowicz, 2005).

This study elucidates that how influent and effluent of MBR process influence from chemical, physical and biological experiments. Analyses which are pH, temperature, dissolved oxygen values, electrical conductivity are made and created graphics. According to graphics and results, interpretations can be done. Experimental studies to occur kinetic parameters on COD removal for MBR in treating industrial wastewater are one of the main purposes of the thesis. MBR processes certainly succeed on COD removal. Also it can be analysed that how much effluent quality of wastewater. In addition to that sludge retention time and hydraulic retention time are important on analysing kinetic parameters. Control of MBR processes is greater than activated sludge processes due to the uncoupling of sludge retention time and hydraulic retention time. These parameters are recognized by bio-kinetic of the system. This means their speed of breaking down the components of the wastewater in the mixed liquor suspended solids (Judd, 2008). In this study Monod kinetics are implemented. By approach of this method, yield

coefficient (Y) and death coefficient (b) are reached up. The role of these parameters is important for treatment. Y describes the using mass of substrate ratio to maximum mass of cells (Çankaya, 2013).

Monod kinetic is a common method that is used for mass balance studies. It is mathematical model for the growth of microorganisms. It is usually used in the activated sludge model for sewage treatment. It also has been widely used to design biological systems. So in this study, this method has been used. After studying monod kinetic model, some kinetic parameters are gathered and performance of biological processes evaluates based on the parameters. These parameters are yield coefficient (Y), microbial decay coefficient (b), saturation constant (K_s) and specific substrate utilization rate (k). Y is the most important parameter that refers performance of the treatment. Typical values of kinetic coefficients for activated sludge are given in Table 3.1(Naghizadeh, Derakhshani, & Yari, 2013).

Table 3.1 Typical values of kinetic coefficients for activated sludge systems (Naghizadeh, Derakhshani, & Yari, 2013)

Coefficient	Basis	Value	
		Range	Typical
K ($k=\mu_{max}/Y$)	day^{-1}	2-8	4
k_d	day^{-1}	0.03-0.07	0.05
K_s	mg/l, BOD_5	40-120	80
	mg/l COD	20-80	80
Y	VSS/ BOD_5	0.3-0.7	0.5
	VSS/COD	0.2-0.5	0.4

When equalized mass balance, it can be said that the models used in mass balance studies are in two options. These are dynamic models and steady-state models. While dynamic models are more complex, steady-state models are simpler. If dynamic models are chosen, all influent characteristics, all reactor information must be known. If steady-state models are chosen, influent characteristics are enough to unit operation performance (Ekama, 2009).

Naghizadeh et al. (2013) have aimed to study kinetic properties of a MBR system treated urban wastewater. They have prepared a synthetic substrate and the substrate has simulated as municipal wastewater. Their purpose is that gathers information consumption of substrate and cell growth rate. After all analyses, yield coefficient is obtained as 0.67 and decay coefficient, k_d is obtained as 0.056. According to the results, they can be used in improvement of design and operation of MBR process.

Talaie Khozani et al. (2010) have studied to determine biokinetic coefficients of crude oil degradation by *pseudomonas aerogenusa*. Most of researcher have studied degradation of crude oil, but according to them biological treatment is the most suitable method for it based on economic conditions. Thus, their results are that Y is 0.882 mg/L, k_d is 0.107, k is 9.39 l/day, and K_s is 169.3 mg/L.

When calculating mass balance in a wastewater treatment, all materials are important on modeling. It means that if a mass balance is made for an individual unit, it doesn't import just this unit. For instance, carbon doesn't mean anything to activated sludge models but it is important on anaerobic digestion because gas production completely is effected by carbon. Generally units which are primary sedimentation, activated sludge systems with phosphorus or nitrogen removal are needed to be modeled (Wentzel, Ekama, & Sötemann, 2006).

Mardani et al. (2010) worked out bio-kinetic coefficients efficiency on three activated sludge processes which includes conventional, extended aeration and contact stabilization. The activated sludge treatment plants are in Isfahan south and they treat municipal wastewater. Their study took for six months and they gathered the results. Their results are given in Table 3.2.

Table 3.2 Monod kinetic results that belong to study of Mardani et al. (2010)

Process	MLSS (mg/l)	Y (mg/mg)	K_d (1/day)	K_s (mg/l)	K (1/day)	μ_{max} (1/day)
Conventional	2000 3000	0.4872 0.8035	0.0258 0.0189	52.1 71.12	1.95 1.22	0.95 0.98
Extended aeration	4000 5000	0.6174 1.2512	0.0309 0.0198	311.7 508	3.17 2.53	1.96 3.17
Contact stabilization	2000 3000	0.713 0.6322	0.0172 0.0387	50.8 13.8	0.586 0.366	0.42 0.23

Nakhla et al. (2006) worked on a project that has been aimed to investigate aerobic biodegradation kinetics for high oil and grease wastewater. They used Monod and Haldane model. According to their Monod model results, Y is between 0.135-0.416 mgVSS/mgCOD, k is between 1.469-4.856 mgSCOD/mgVSS-d and K_s is between 17,669 to 61,336 mg/L.

Pala and Bölükbaş (2005) have a study which aimed to determine of kinetic parameters, nitrification and denitrification rates using batch reactor required for the design of nitrification-denitrification-biological phosphorous removal systems (NDBPR). They have used Monod model and their results are given. Y is obtained as 0.70 mgVSS/mgCOD and k_d is obtained as 0.0022 h^{-1}. These parameters are important for design of NDBPR.

3.3 Mass Balance Studies for MBR Systems

There are several types of mass balance equations for the membrane bioreactor, such as for the dissolved oxygen concentration in wastewater, for the soluble inert organic matter, for the concentration of readily biodegradable substrate, for the soluble microbial product concentration, for the concentration of particulate inert organic matter, and for the Nitrogen concentration in the wastewater (Jadhao & Dawande, 2012). The mass balance study boundary should be determined considering the type of the MBR system and the aim of the study.

Park et al. (2015) give an example for setting up mass balance equations for an MBR system consisting of a continuous stirred tank bioreactor and an immersed membrane system (Figure 3.1). For the mass balance analyses, the system boundary includes the bioreactor with the submersed membrane. They also indicated the kinetic parameters used for setting up mass balance equations.

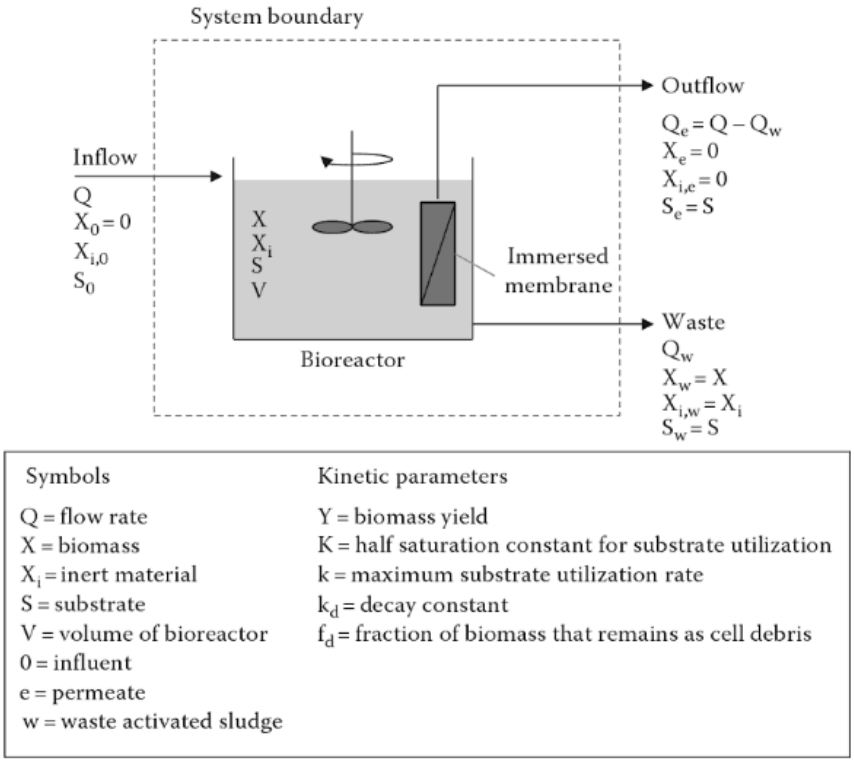


Figure 3.1 Schematic diagram of a bioreactor of an MBR plant for setting up mass balance equations (Park et al., 2015)

Fan et al. (1996) investigated the overall performance of the Membrane Bioreactor (MBR) process for municipal wastewater treatment to determine the characteristics of activated sludge under different Sludge Retention Times (SRT) and Hydraulic Retention Times (HRT). They made mass balance studies in terms of COD, nitrogen and inorganic suspended solids and they found that 28%, 42%, and 48% of influent COD were converted into activated sludge at SRTs of 20, 10, and 5 days, respectively.

CHAPTER FOUR
MATERIAL AND METHODS

This chapter consists of information about the full-scale pilot plant, and analytical procedures of the study and experiments which have applied.

4.1 Introduction to Full-scale Plant

The aim of this thesis is to make the mass balance studies for MBR systems. For this aim, Izmir Torbalı Organized Industrial Zone (ITOB) wastewater treatment plant where MBR is employed was selected as a full-scale plant. ITOB infrastructure in Izmir Torbalı Organized Industrial Zone has been completed; it's ready to invest and is one of the two closest to the city center organized zone. Region is situated 32 km from the center of Izmir, 12 km from Menderes district, and 18 km from Adnan Menderes Airport. Cumaovası - Aliaga railway line passes through the inlet region. There are 250 hectares of industrial plots ranging from 1,000 m^2 to 30,000 m^2 installation of 372 units.

The region's companies are concentrated in food, iron and steel industry, chemical, plastics, machinery, electrical and electronics industries. The total area is 2.500.000 m^2, the total number of parcels is 372, the number of operated firms is 105, and the total number of participant 330 (Figure 4.1). The main aims of ITOB establishments are given below:

- Providing opportunity to SMEs easier, efficient and inexpensive production by taking advantage of common infrastructure services,
- To promote systematic and orderly structuring,
- Reduce the city traffic load,
- Contributing to the regional and national economy,
- Region's manufacturers of all types of infrastructure services, to carry out continuously without interruption
- To find solutions to Industrialists' problems,

- To contribute social, cultural and economic developments,
- To prevent environmental pollution.

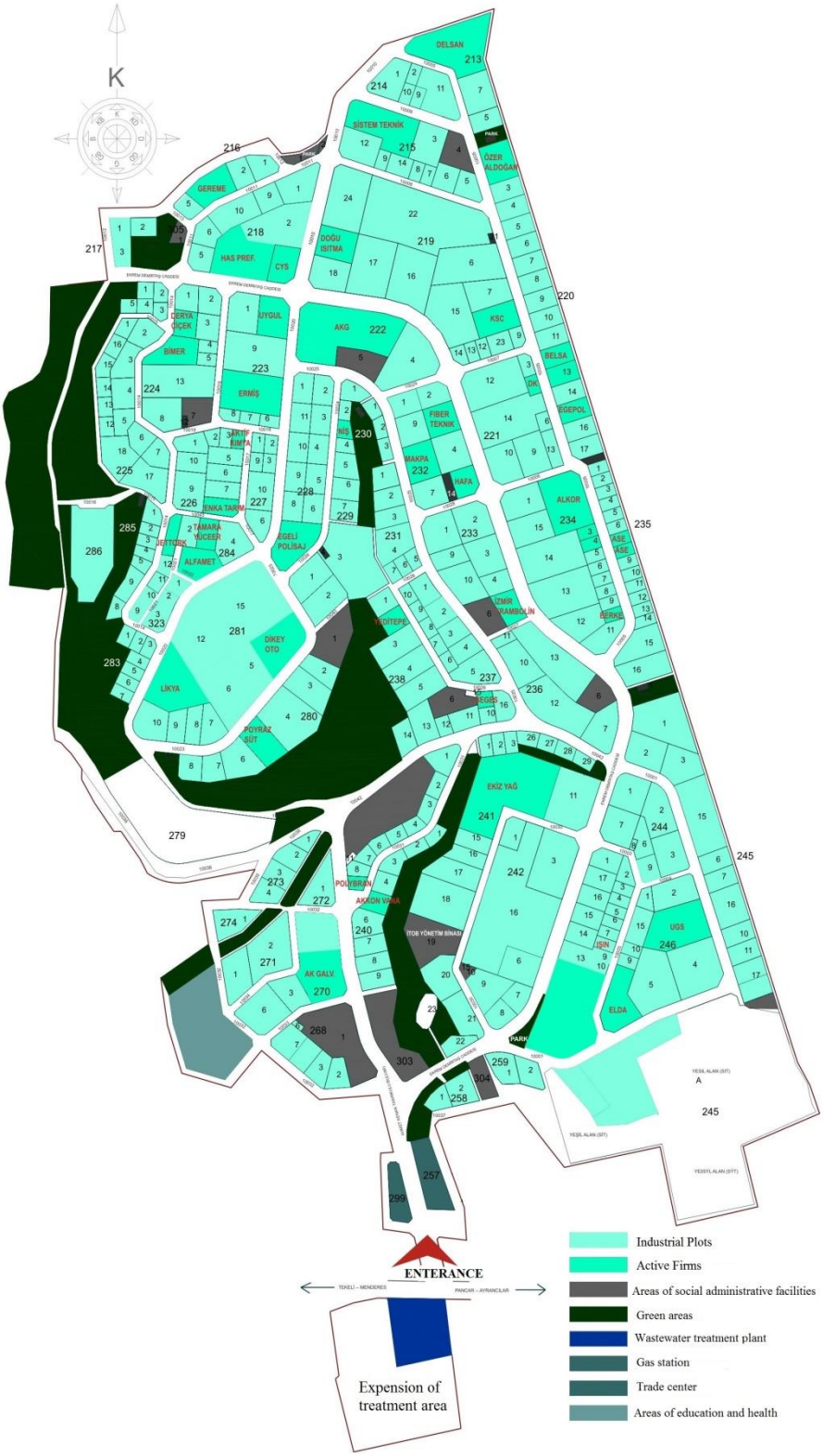


Figure 4.1 Layout of İTOB organized industrial zone

Tap water which is distributed to the participants in the region is obtained from water wells. At present, water is stored in the water tank of 1,000 m^3 and is distributed to the participants in the 4-6 bar pressure. In case of increasing consumption of water, water wells are opened by using groundwater resources of land south of the region which is wealthier, collecting tanks and transmission line are made. These wells will be commissioned later date, so there are no long-term water supply problems in the region. Wastewater is collected with corrugated pipe, a total of 21 km of waste water network in the region. Wastewater discharge standards are being sought in the infrastructure of the companies that use water in the process.

The wastewater treatment plant area of 8,000 m^3/day has a capacity of 2,000 m^3/day in the first place to put into operation in September 2008 the Izmir Governor's Office of Environment and Forestry Directorate 14.05.2009 / 670 dated discharged permits was taken. The general overview of the treatment plant is shown in Figure 4.2.



Figure 4.2 The general overview of the treatment plant of İTOB

The wastewater treatment plant includes physical, chemical and biological processes and treatment process is stable Membrane Bioreactor (MBR) process which comprises of 0,01 micron ultra-filtration so output water quality is very high.

To remove coarse solid materials, coarse and fine screening units are first applied. After the equalization basin, wastewater is introduced to the aerobic MBR system. In the MBR unit, Ultrafiltration membranes of pore sizes of 0.01 micrometer are used. Aerobic tanks are combined with anoxic tank to remove nitrogen. The flow scheme of the treatment plant is given in Figure 4.3.

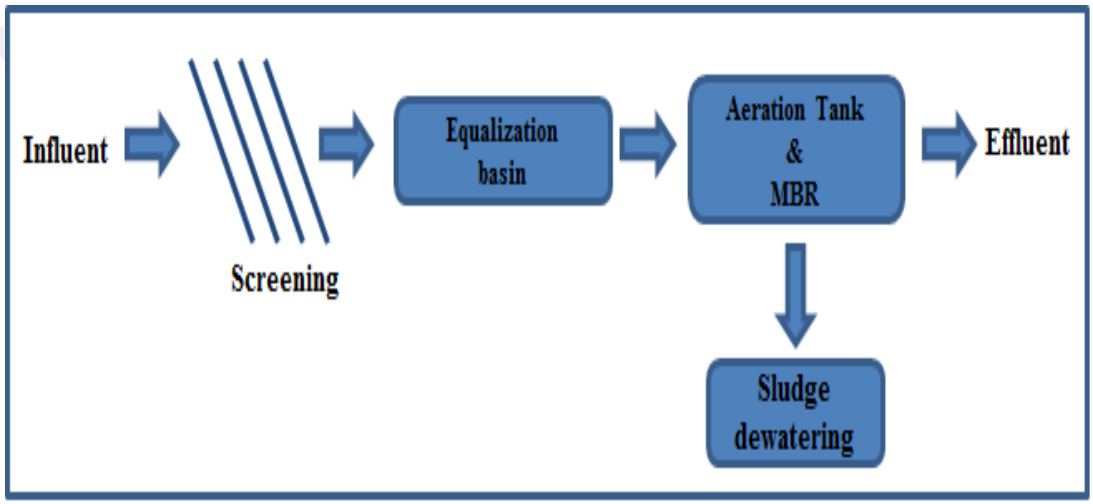


Figure 4.3 Flow scheme of the treatment plant of ITOB

The main line system is that, physical pre-treatment which is occurred by coarse grid, pumping station, fine screening, and grid-oil separator is used for solids in wastewater, which cannot be biodegradable or cause damage to mechanical equipment, suspended solids and oils which can cause in negative to treatment efficiency (Figure 4.4).



Figure 4.4 Fine screening and grid/oil separator

Equalization (Figure 4.5) is used before biological treatment. Aeration tank and activated sludge is used for removal of dissolved organic matter in the wastewater. Biological treatment which includes submerged membranes (MBR) comprised of 0,01 micron ultra-filtration is used instead of sedimentation tank to realize the treated water discharged. To remove phosphorus, chemical treatment in conjunction with a biological treatment is sometimes applied. Chemical dosing units which are occurred

by dosing pumps, storage tanks is used for phosphorus supplied the required standards.



Figure 4.5 Equalization basin

Discharge standard of wastewater effluent for organized industrial zone taken from Table 19 on Water Pollution Control Regulation that is published on Official Gazette of the Republic of Turkey is shown in Table 4.1 (T.R. Official Gazette, 2004). According to table, performance evaluation can be considered on full-scale plant.

Table 4.1 Discharge standards of receiving water of complex industrial wastewater (T.R. Official Gazette,2004).

PARAMETER	UNIT	COMPOSITE SAMPLE FOR 2 HOURS	COMPOSITE SAMPLE FOR 24 HOURS
CHEMICAL OXYGEN DEMAND (COD)	(mg/L)	400	300
SUSPENDED SOLID (SS)	(mg/L)	200	100
OIL VE GREAS	(mg/L)	20	10
TOTAL PHOSPHORUS	(mg/L)	2	1
TOTAL CHROME	(mg/L)	2	1
CHROME (Cr^{+6})	(mg/L)	0.5	0.5
LEAD (Pb)	(mg/L)	2	1
TOTAL CIYANIDE (CN^{-})	(mg/L)	1	0.5
CADMIUM (Cd)	(mg/L)	0.1	-
IRON (Fe)	(mg/L)	10	-
FLUORINE (F^{-})	(mg/L)	15	-
COPPER (Cu)	(mg/L)	3	-
ZINC (Zn)	(mg/L)	5	-
MERCURY (Hg)	(mg/L)	-	0.05
SULFATE (SO_4)	(mg/L)	1500	1500
TOTAL KJELDAHL-NITROGEN (*)	(mg/L)	20	15
pH	-	6-9	6-9

Since there is an MBR system, the amount of excess sludge is very low. There is a sludge dewatering unit that consists of sludge conditioning equipment and decanters.

Effluent quality is very high (Figure 4.6). It has been used firstly as irrigation water. Then it is planned to reuse as second quality water for factories that use over water consumption.



Figure 4.6 Effluent Quality

4.2 Analytical Procedure

To perform the mass balance studies for the MBR system, following three sampling points were determined around the MBR unit:

1. Influent to the MBR unit
2. Inside the aeration tank
3. Effluent from the MBR unit

The mass balance studies were carried out considering suspended solid (SS), volatile suspended solid (VSS), total solid (TS), total volatile solid (TVS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) parameters.

TN and TP parameters analysis were done by using Merck Test Kits. The analyses of other the parameters were carried out according to procedures given in the Standard Methods that is published by the American Public Health Association, American Water Works Association, and the Water Environment Federation (Water Environment Federation, & American Public Health Association, 2005). Samples were taken five consecutive days at the same time at each day. All analyses were done in the Department of Environmental Engineering, Dokuz Eylül University and the experiments were done in triplicate.

CHAPTER FIVE
RESULTS AND DISCUSSION

In this chapter treatment performance of the full-scale treatment plant is given and the results of mass balance studies are commented. The treatment performance of the plant is discussed depending on the results of the analyses carried out by the authorized people of the plant. Mass balance studies are made depending on the laboratory studies carried out in the scope of this thesis.

5.1 Treatment Performance of the Wastewater Treatment Plant

Biological treatment relies on conversion of organic and inorganic matter into innocuous products by microorganisms and, as such, the biological community must be healthy and sustainable. Microbial growth relies on appropriate conditions of total dissolved solids (TDS) concentration, pH and temperature. Most microorganisms can only function in relatively dilute solutions, around neutral pH and at ambient temperature (Judd, 2011). So, these parameters should be monitored regularly for the effective operation of biological systems.

Some operational parameters of the full-scale pilot plant have also been regularly monitored by the authorized people. pH, temperature, electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), and suspended solid (SS) parameters are considered as significant operational parameters in the full-scale plant. These parameters are the typical performance parameters monitored for an MBR. The average monthly values of these parameters for the equalization basin effluent and MBR effluent are shown in Figure 5.1 – 5.7.

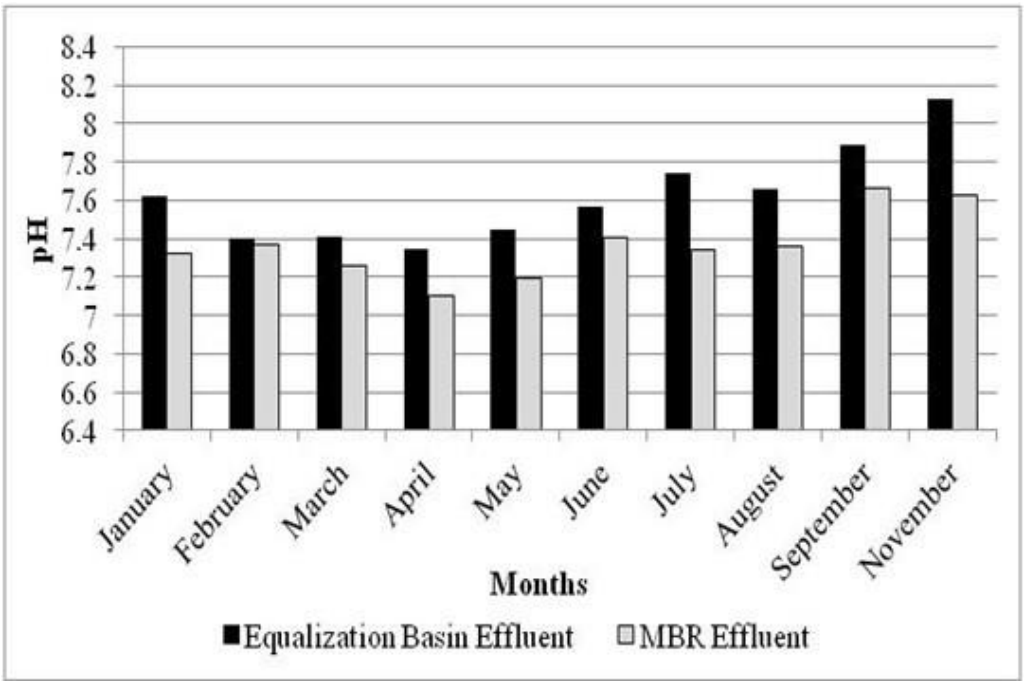


Figure 5.1 pH values of the equalization basin and MBR effluents

In Figure 5.1, pH variations of the equalization on basin effluent and MBR effluent are given. As seen from the figure, pH of the equalization basin is always more than MBR effluents. The pH decreases may be from the nitrification reactions in the aeration tank. According to the effluent standards of organized zone, it should be between 6 and 9.

NH_4-N variations in equalization basin and MBR effluents are given in Figure 5.2. As seen from the figure, ammonia is removed efficiently in the MBR unit. There is over 97% ammonia conversion in the reactor by nitrification.

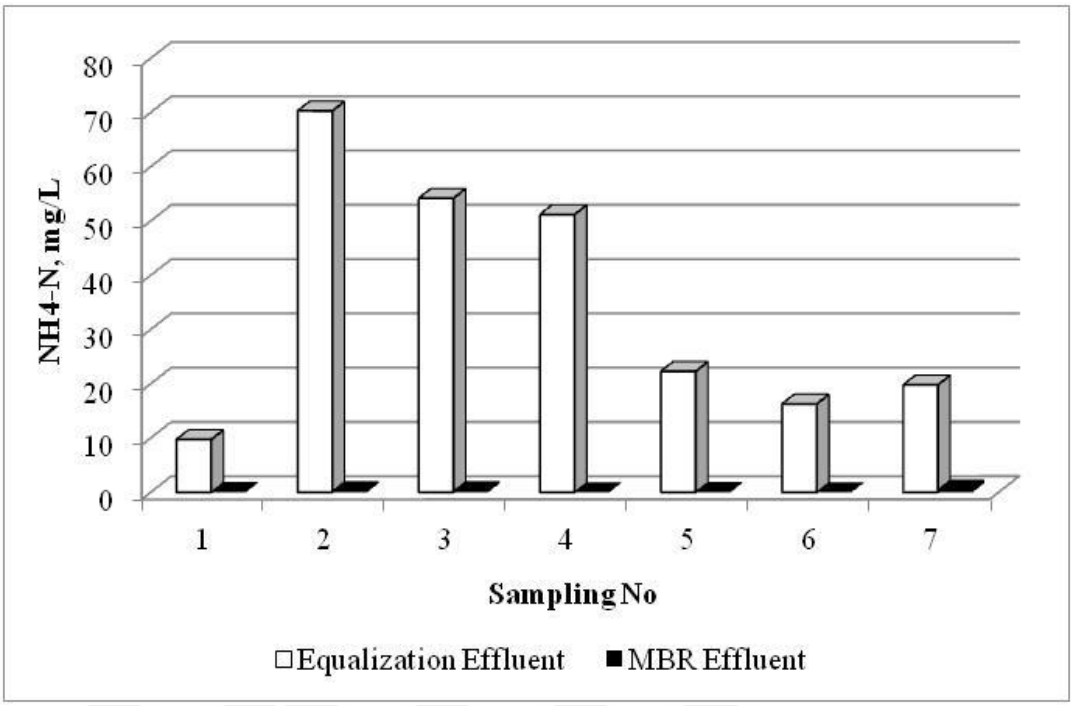


Figure 5.2 NH_4-N variations in equalization basin and MBR effluents

Temperature is a very important operational parameter for the biological systems. While most aerobic biological processes are operated at ambient temperatures, the microorganisms usually have mesophilic temperature optima, such that pumping operations in submerged MBRs can provide additional benefit in raising the reactor temperature to both increase bio treatment efficacy and reduce liquid viscosity (Judd, 2011). Also, microorganisms are very sensitive. If temperature changes continuously, microorganisms can't keep step with the new situation. It can take a few days to get used to it. The temperature changes versus operating months are seen in Figure 5.3. It is clearly seen that both values of equalization basin and MBR values are always same. According to standards, temperature values can be 12-20 °C. As it is expected, depending on climate change, temperature values are increasing in summer period. The temperature values range is 10 °C – 30 °C.

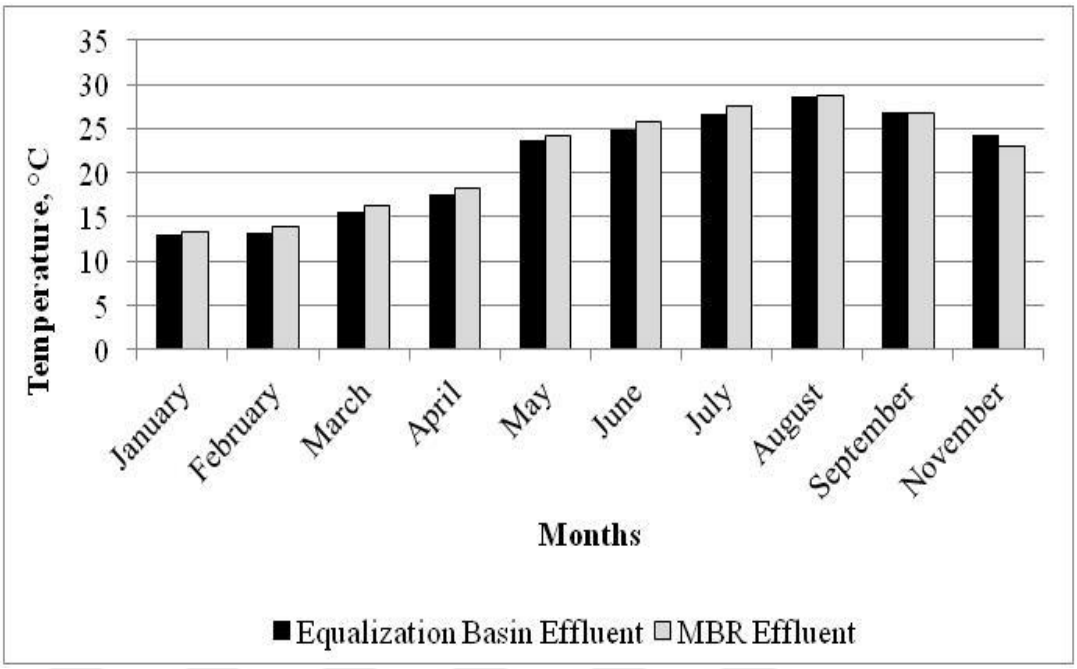


Figure 5.3 Temperature values of the equalization basin and MBR effluents

For sustaining microbiological activity, certain amount of dissolved oxygen must be kept constant in the aeration reactor. Figure 5.4 indicates that dissolved oxygen values of the equalization basin lower than MBR effluents. In MBR systems, aeration provides sufficient amount of oxygen for microbial community and adequate turbulence to keep organic solids in suspension and to provide membranes from plugging. The values range of equalization basin is 0.5 – 2.5 mg/L and values range of MBR effluents are 4.0 – 9.0 mg/L. These values on MBR are quite high. It means that the requirement oxygen of the plant is really high and their cost is extremely expensive for the facility.

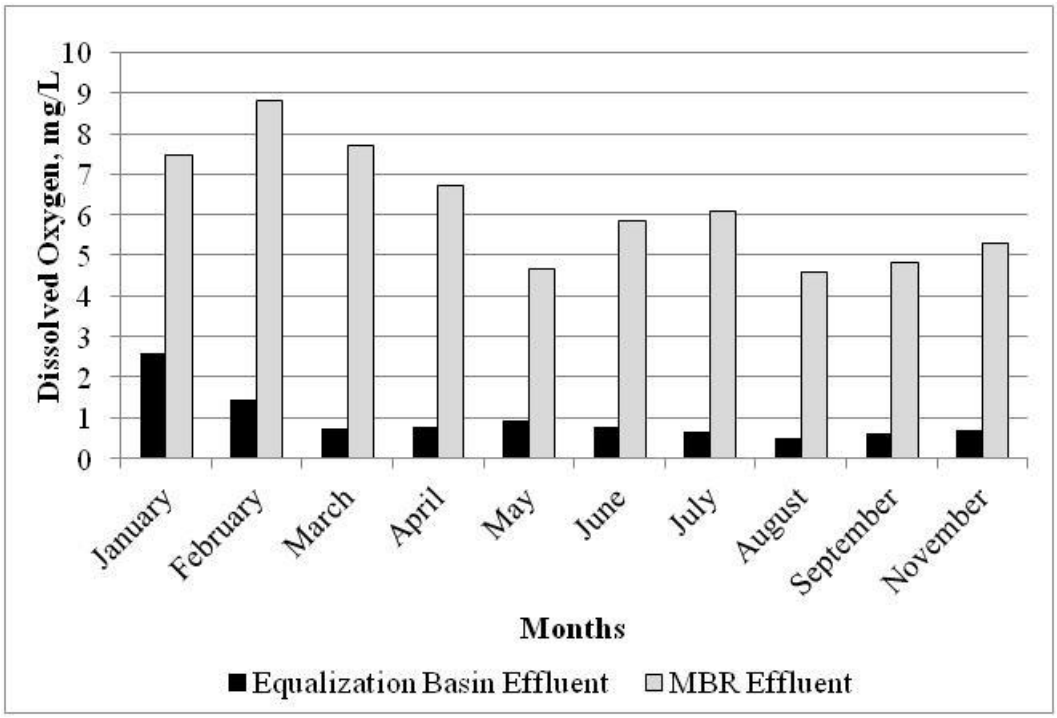


Figure 5.4 Dissolved oxygen values of the equalization basin and MBR effluents

There is no direct effect of salinity on membrane performance because the membranes used in MBR have enough pores that can pass inorganic ions freely and do not cause osmotic pressure. However, salinity indirectly affects membrane performance by affecting the floc size, the fine particle concentration, and the quality and quantity of biopolymers. There is no established guideline for the maximum allowable salinity without causing a significant membrane fouling, but it can be somewhere around 3.5 to 7.0 g/L as NaCl or 5 to 10 mS/cm as conductivity in long-term operations, assuming the salinity does not swing abruptly (Yoon, 2015). Electrical conductivity (EC) values of the full-scale plant are seen in Figure 5.5. As seen the figure EC changes between 2 to 6 dS/m (mS/cm = dS/m). So, salinity is lower than the maximum acceptable level.

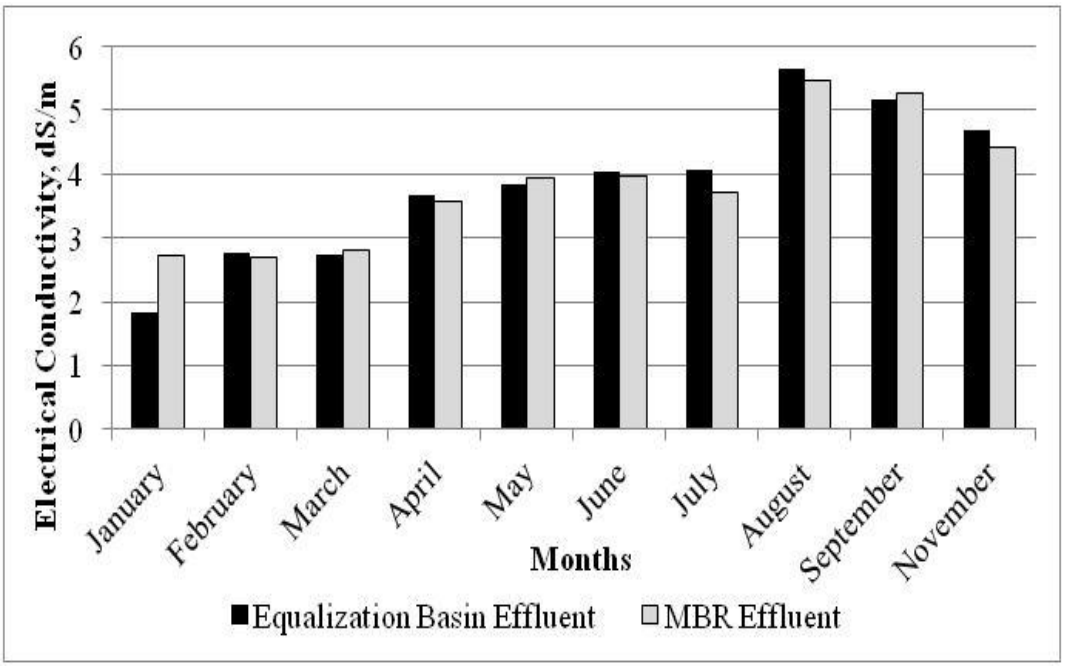


Figure 5.5 Electrical conductivity values of the equalization basin and MBR effluents

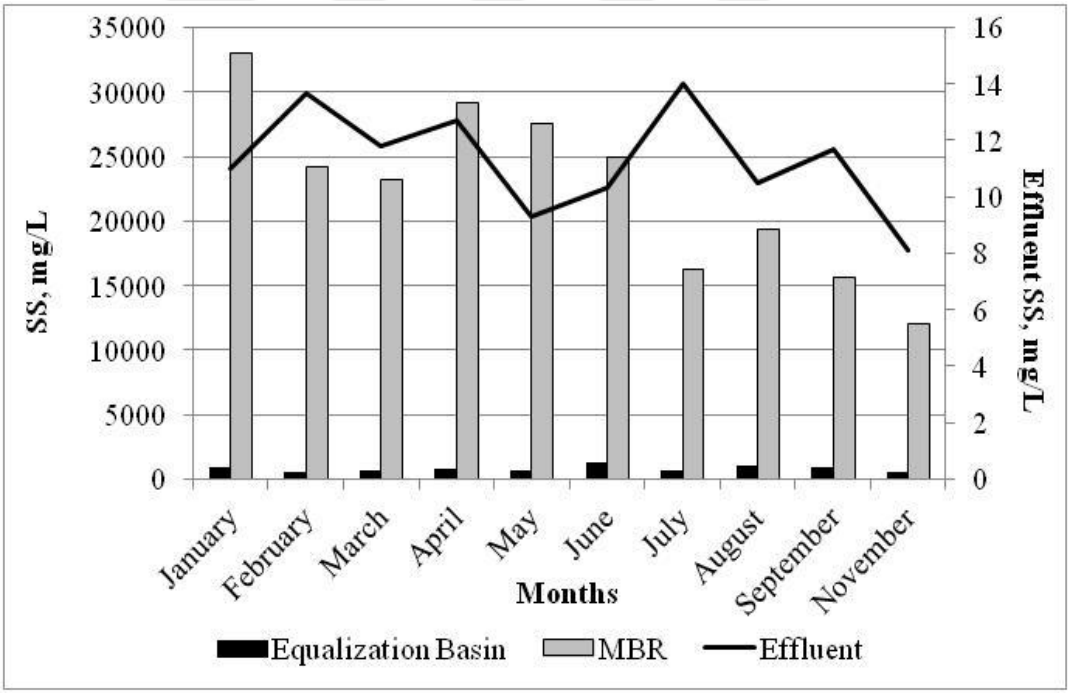


Figure 5.6 Suspended solids values

Suspended solids concentrations of the equalization basin effluent, MBR unit, and effluent of the MBR unit are given in Figure 5.6. In MBR reactor, suspended solids concentrations change between 10000 and 30000 mg/L. Most of the activated sludge

consists of suspended solids. As it is expected the SS content of the MBR effluent is very low, which is about 10 mg/L. According to the discharge standards of the organized zone, it should be maximum 100 mg/L. So, effluent quality of the plant is very high in terms of suspended solids.

MBR systems can remove organic materials effectively and COD removal efficiencies of MBR systems are very high. COD concentrations of the equalization basin effluent and MBR effluent are seen in Figure 5.7. As seen from the figure, COD removal efficiencies almost over 90%.

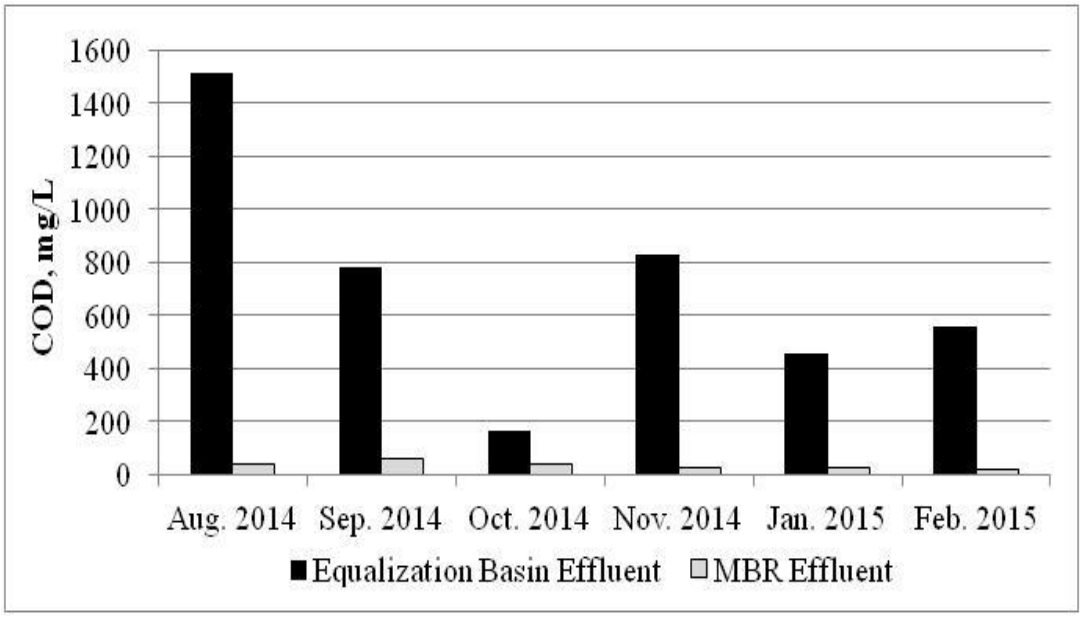


Figure 5.7 COD variations

5.2 Results of the Experimental Analysis

In addition to operational data given from the authorized people of the full-scale plant, to determine the mass balance of the MBR system, some significant data was monitored regularly for a week. In this case, samples were taken from equalization basin effluent (influent to MBR), MBR unit, and MBR effluent. The results of the performed analyses are given in Figure 5.8 – 5.15.

The results of the total COD analyses are given in Figure 5.8. As seen from the figure, effluent COD concentration is lower than 60 mg/L. Since there is huge amount of suspended solids, COD concentration in MBR unit is very high. When the samples were taken from the plant on fourth day, nearly all analyses results were very high. This is because there was a problem about plugging in MBR unit. The other day, operators cleaned and the lower results can be seen.

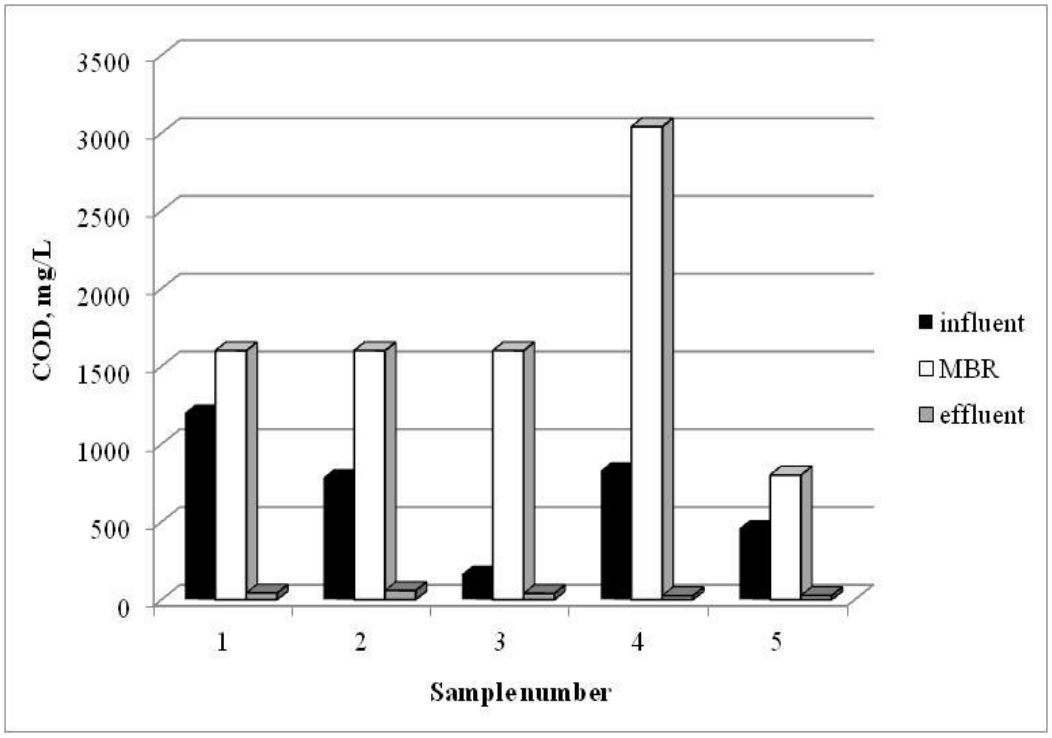


Figure 5.8 COD analysis results

Other significant data are total suspended solids and total volatile suspended solids. The results of these analyses are given in Figure 5.9 and Figure 5.10, respectively. It can be concluded that MBR system removes almost all TSS and TVSS. Typical MLSS concentrations in MBR systems are 10000 mg/L to 12000 mg/L. Here, MLSS concentrations are higher which is about 18000 mg/L.

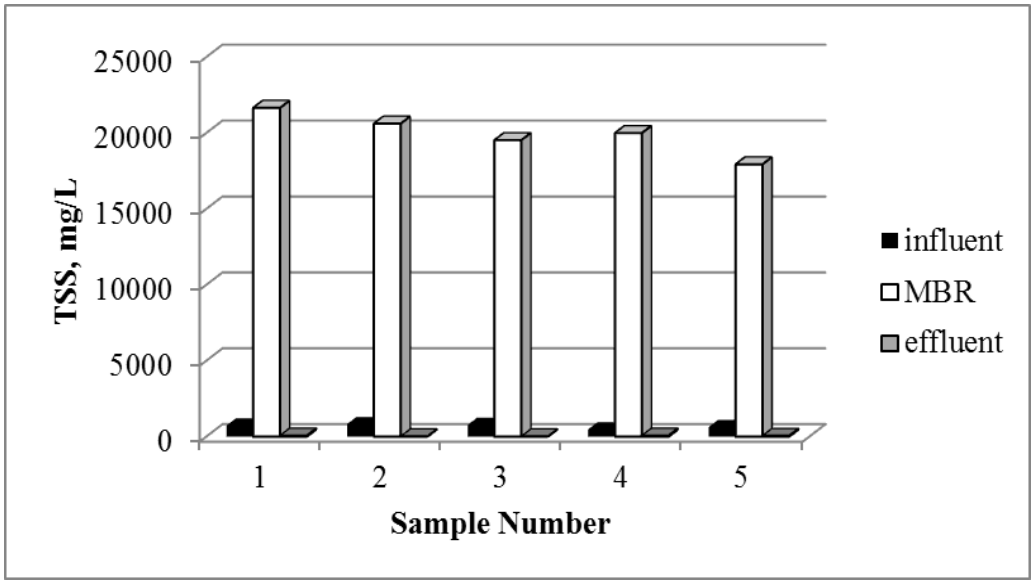


Figure 5.9 TSS analysis results

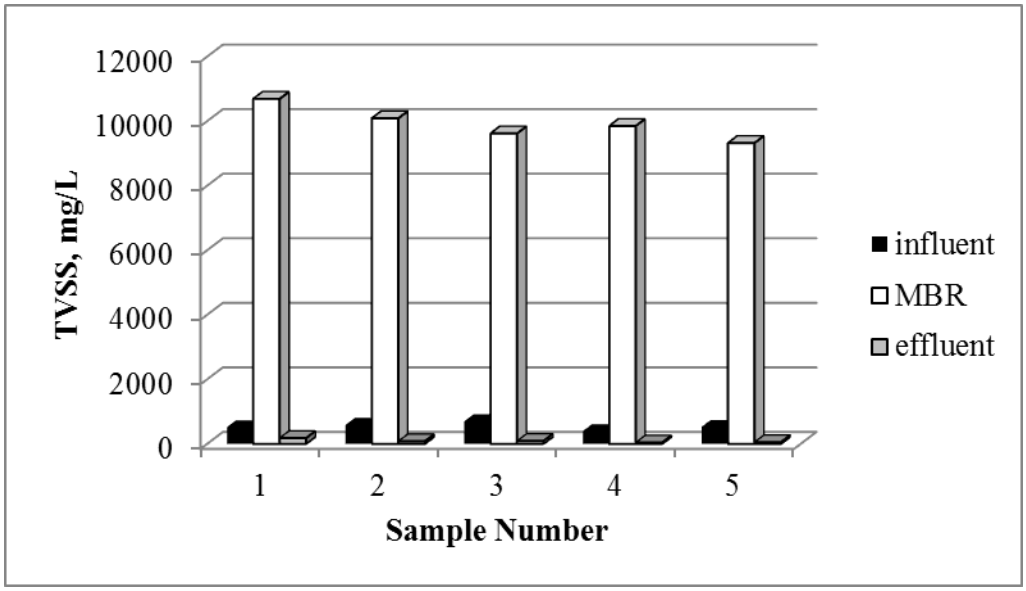


Figure 5.10 TVSS analysis results

Figure 5.11 and 5.12 shows the TS and TVS analyses results. As seen from Figure 5.11, TS concentration of influent and effluent are almost the same. Like the other parameters, total solids concentration in MBR is higher.

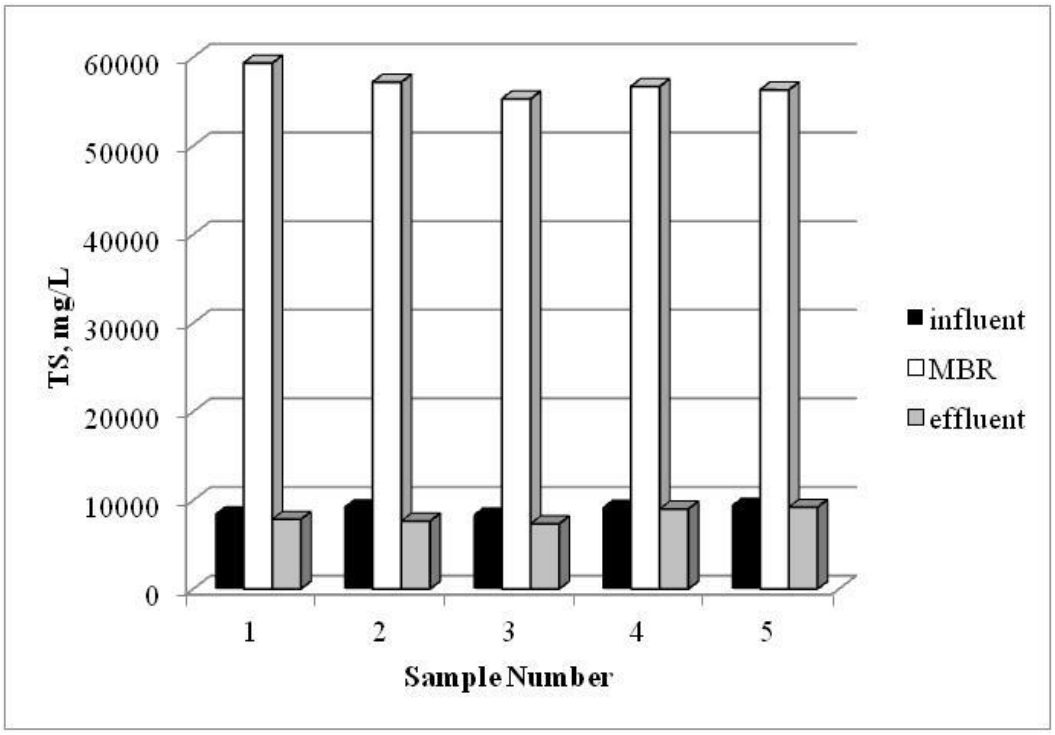


Figure 5.11 TS analysis results

By contrast with total solids, total volatile solids are removed efficiently except for fourth day (Figure 5.12).

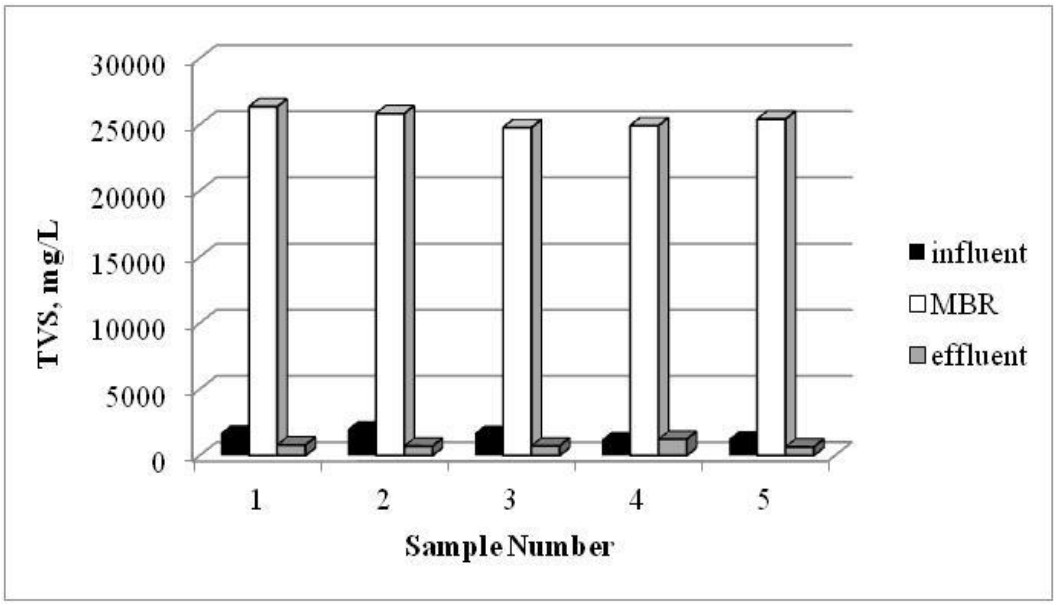


Figure 5.12 TVS analysis results

Figure 5.13 refers amount of volatile fraction of solids. According to the figure it can be said that, total volatile suspended solids are about 50% of total suspended solids and total volatile solids are about 45% of total solids.

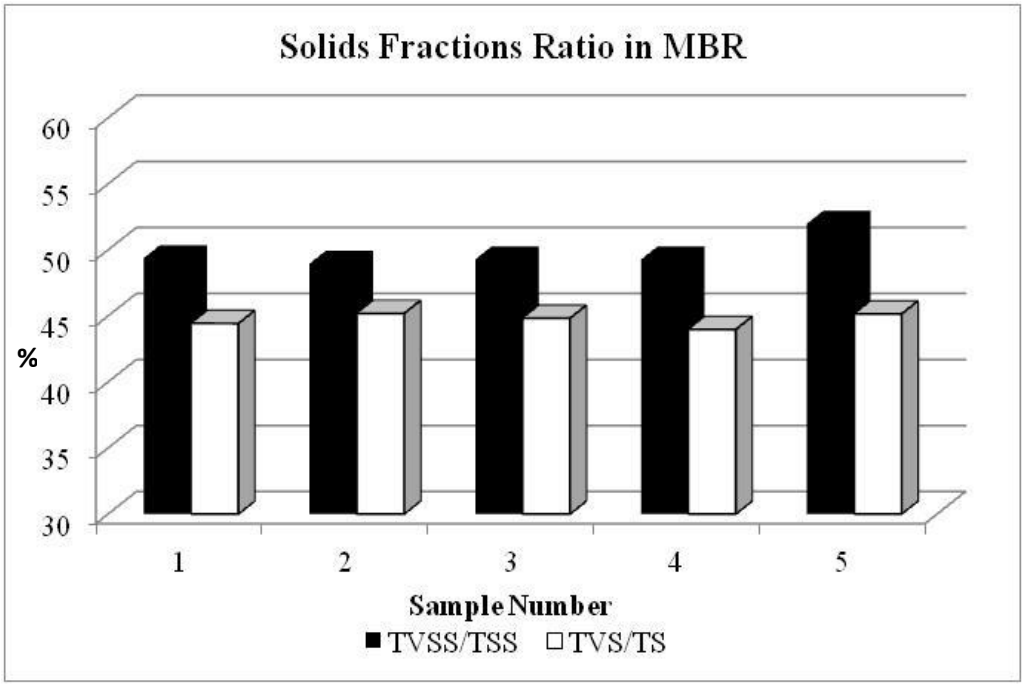


Figure 5.13 Solids fractions ratio in MBR

Total nitrogen and phosphorus concentrations of influent and effluent are given in Figure 5.14 and 5.15. By nitrification on MBR unit, ammonia nitrogen is converted to nitrate; but nitrate cannot be converted to nitrogen gas since there is no denitrification zone in the biological unit. Hence, total nitrogen concentrations of the effluent are very high. However there is no discharge standard for nitrogen parameters. Total phosphorus concentrations of effluent are very low. Phosphorous removal is adequate. It is done by dosing metal salt on MBR unit in this plant. It can also be done by A^2O processes in the wastewater treatment plants. But it increases investment cost, so this method generally doesn't prefer for removal of phosphorous on MBR processes. According to the standards, it should be maximum 1 mg/L. These plant's results are quite low.

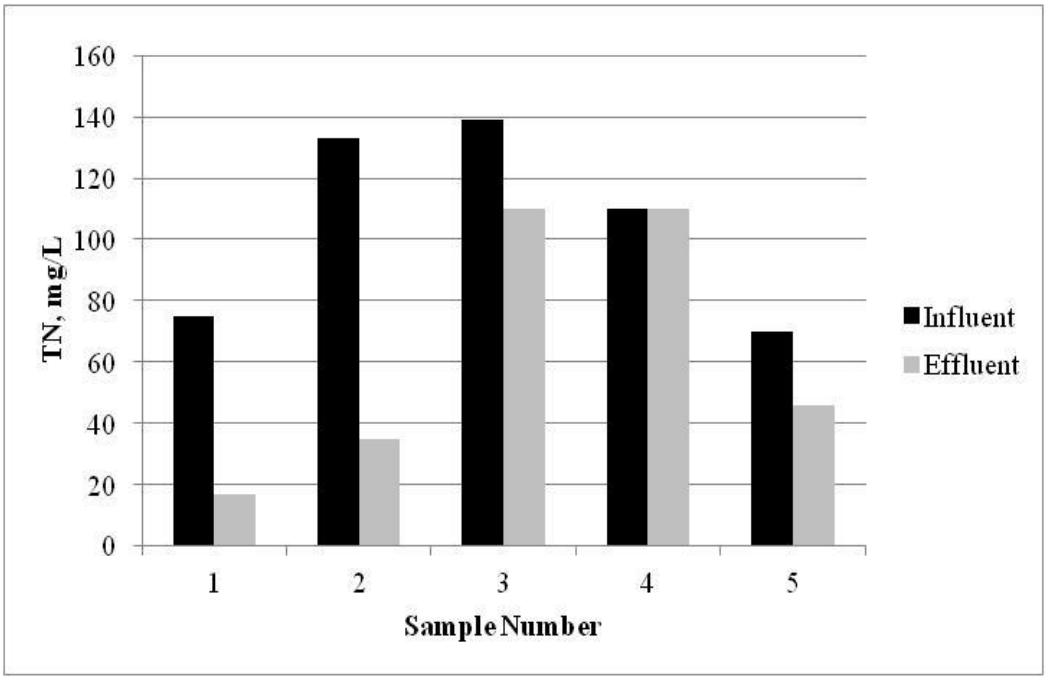


Figure 5.14 Total nitrogen concentrations

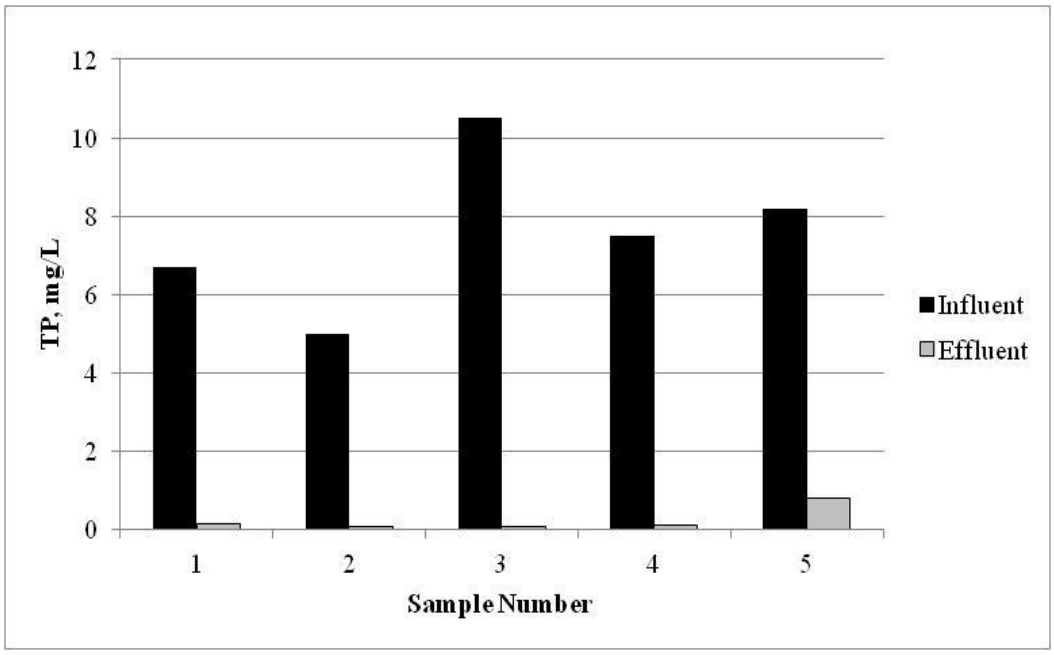


Figure 5.15 Total phosphorus concentrations

5.3 Evaluation of the Results

5.3.1 Mass Balance

A mass balance is an accounting of a specific material for a particular system. So, the amount of the material in the influent and effluent is very important for mass balance studies. The difference between them shows us the consumed, converted or storage parts of the material.

In the scope of this study, for the mass balance studies, the system boundary was selected as the surrounding of the MBR unit. All the mass balances were made based on the analysis of the samples taken for 5 days. Mass balance studies were carried out for COD, SS, VSS, TS, and TVS parameters.

The required mass values of the parameters were calculated using the following equation:

$$\text{Mass (L)}(\text{kg/day}) = \text{Concentration (C)}(\text{kg/m}^3) * \text{Flow rate (Q)}(\text{m}^3/\text{day}) \quad (5.1)$$

Although the treatment plant capacity is 8000 m^3/day, the existing operational flow rate is 2000 m^3/day and mass loads were calculated considering existing situation. The results from first day to fifth day as mass unit are shown in Figure 5.16. The influent values are input of membrane bioreactor and the effluent values are output of the reactor. Results are also given in Table 5.1.

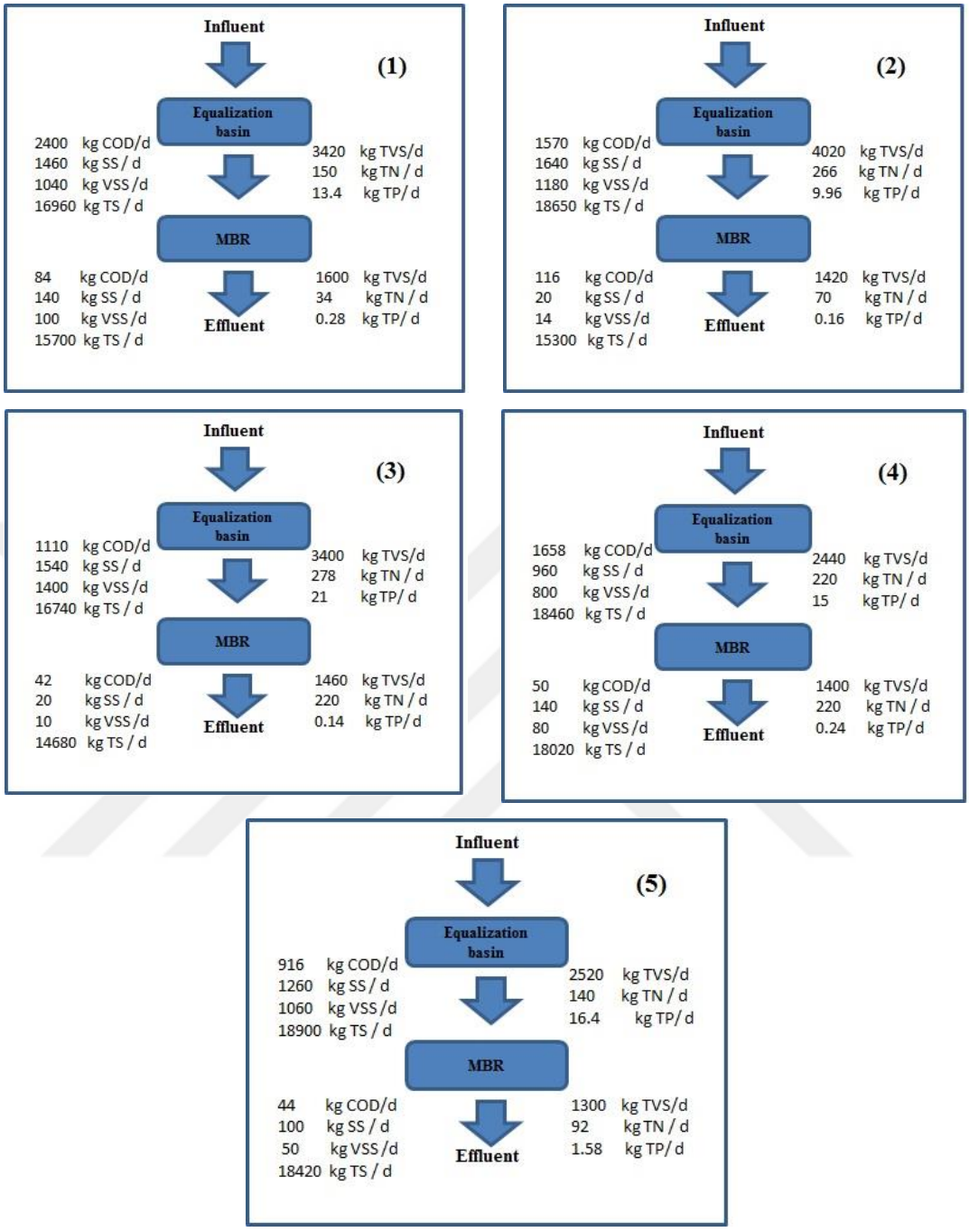


Figure 5.16 Mass balance calculation results

Mass balances of the MBR unit in terms of COD, solid fractions, nitrogen and phosphorus were made. It was found that approximately 95.5% influent COD is removed in the MBR unit. Most of the COD is oxidized in this unit and the rest of it is removed as excess sludge.

Table 5.1 Summary of mass balance study

		COD (kg/day)	SS (kg/day)	VSS (kg/day)	TS (kg/day)	TVS (kg/day)	TN (kg/day)	TP (kg/day)
1st day	Inf.	2400	1460	1040	16960	3420	150	13.4
	Eff.	84	140	100	15700	1600	34	0.28
2nd day	Inf.	1570	1640	1180	18560	4020	266	9.96
	Eff.	116	20	14	15300	1420	70	0.16
3rd day	Inf.	1110	1540	1400	16740	3400	278	21
	Eff.	42	20	10	14680	1460	220	0.14
4th day	Inf.	1658	960	800	18460	2440	220	15
	Eff.	50	160	80	18020	1400	220	0.24
5th day	Inf.	916	1260	1060	18900	2520	140	16.4
	Eff.	44	100	50	18420	1300	92	1.58

As a result of the study, over 90% suspended solids is removed in the MBR unit. Typical sludge concentrations for immersed MBRs are between 15 and 25 g/L, elimination of organic matter and turbidity is almost independent on SRT, and average removals normally achieved for COD and SS are over 90 and nearly 100%, respectively (Radjenović et al., 2008).

5.3.2 Kinetic Study

Monod kinetic has been widely used to design biological systems. “Using known bio-kinetic constants, the system kinetics and mass balance can be used to define the rate of substrate degradation, nitrification, biomass growth and sludge production” (Judd, 2011). Monod kinetic equations are given below (Metcalf & Eddy, 2004):

$$L_r = \frac{1}{X} * \frac{ds}{dt} = \frac{k*S}{Ks+S} = \frac{Q*(S_0-S)}{V*X_r} \quad (5.2)$$

$$\frac{1}{\theta_c} = (Y* L_r) - b \quad (5.3)$$

$$\theta_c = \frac{V^* X_r}{Q^* X_e} \quad (5.4)$$

Where:

L_r : Specific substrate utilization rate (mg/mg.d)

k: Maximum specific substrate utilization rate (d^{-1})

Ks: Saturation concentration (mg COD/L)

S: Concentration of effluent COD (mg /L)

X_e: Effluent microbial concentration (mgVSS/L)

X_r: Concentration of microorganisms in the reactor (mgVSS/L)

θ_c: Solids retention time (SRT, d^{-1})

b: Bacterial decay coefficient (d^{-1})

Y: Yield coefficient (mgVSS/mgCOD)

By applying the Monod model, four kinetic parameters were calculated for the examined full-scale plant:

- Y, yield coefficient
- b, decay coefficient
- Ks, saturation constant
- k, maximum specific substrate utilization rate

To apply the Monod equations, sludge age parameter should be calculated. Sludge age (SRT or Θ_c) was calculated from the following equation:

$$SRT = \frac{VX_r}{QX_e} \quad (5.5)$$

Here;

SRT: sludge retention time, d

V: Volume of the reactor, m^3

X_r: Biomass concentration in the reactor, mg/L

Q: Flowrate, m^3/d

X_e: Effluent biomass concentration, mg/L

Depending on the hydraulic retention time and the biomass concentration in the reactor and effluent, sludge age was calculated between 26 – 31 days.

Graph of L_r and $1/\theta_c$ has been plotted in the Equation 5.3. Based on curve of the equation (y = ax+b), a shows Y and b shows b decay coefficient. The graph is given in Figure 5.17.

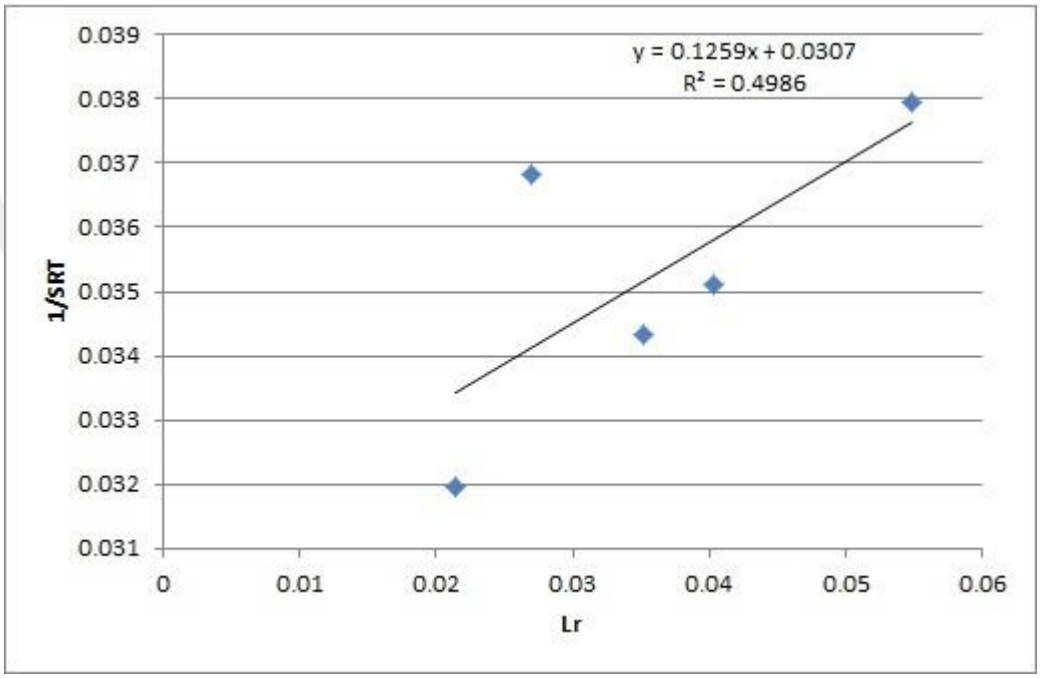


Figure 5.17 Graph of equation 5.3

Graph of 1/Lr and 1/S has been plotted in the Equation 5.2. Based on the curve of the equation (y = ax + b) a shows Ks/k and b shows 1/k. This graph is shown in Figure 5.18.

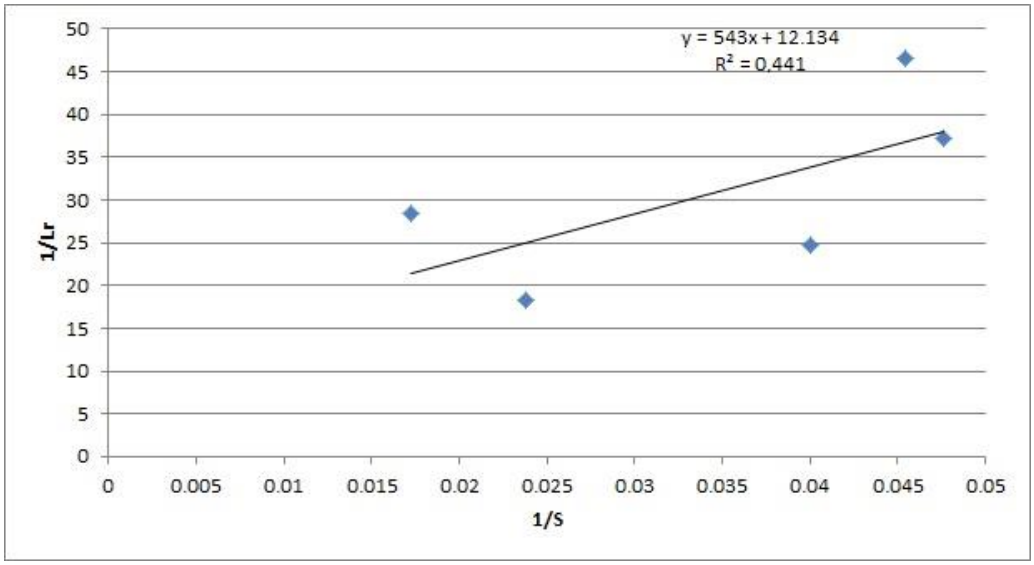


Figure 5.18 Graph of equation 5.2

According to Figure 5.17 and 5.18, yield coefficient (Y) is obtained 0.13, decay coefficient (b) is obtained 0.031 d^{-1}, k is obtained 0.082 d^{-1} and K_s is obtained 45 mg/L. The results show that the Monod model has a low degree of fit ($R^2 < 0.5$).

According to Henze et. al. (2000) typical stoichiometric parameter of Y is 0.625 for municipal wastewater. Thus, our result is low because this plant treats industrial wastewater.

Fan et al. (1996) found that the estimated true yield and decay rate coefficients of the activated sludge were 0.61 kgVSS/kgCOD and 0.050 d^{-1}, respectively, for an MBR system.

Xue et al. (2011) found the half saturation constant for COD removal K_s as 34.6 mg/L for the activated sludge in the aerobic tank of an MBR municipal wastewater treatment plant.

CHAPTER SIX
CONCLUSIONS AND RECOMMANDATIONS

6.1 Conclusions

Performance evaluation of an MBR system treating an industrial wastewater and to study mass balance on membrane bioreactor systems were aimed in the scope of this thesis. A treatment plant was chosen, which is in Izmir Torbalı Organized Industrial Zone, as a full-scale plant. Some operational parameters of the plant have been regularly monitored by the authorized people. These are pH, dissolved oxygen, electrical conductivity, SS, COD. Performance evaluation studies were carried out considering these data. For mass balance and kinetic studies, samples from influent, MBR unit, and effluent were taken and some significant parameters, such as COD, SS, VSS, TS, TVS, nitrogen and phosphorus, were analyzed.

In accordance with this study, the following conclusions were obtained:

- COD, suspended solids, and total phosphorus removal efficiencies of the MBR system are almost over 90%.
- Effluent quality of the MBR system is very high.
- Mass balances for COD, solids fractions, TN, and TP were generated.
- Yield coefficient (Y) is 0.13 mgVSS/mgCOD, decay coefficient (b) is 0.031 d^{-1}, maximum specific substrate utilization rate (k) is 0.082 d^{-1} and saturation constant (K_s) is obtained 45 mg/L.
- Low correlation coefficient is found for Monod model.

6.2 Recommendations

In this thesis performance evaluation and mass balance study has been applied on the membrane bioreactor system. For the mass balance studies, more experiments should be carried out and waste sludge sampling and characterization in addition to

wastewater sampling should be done. Of course it is not easy to determine mass balances on a treatment unit with different influent loading. To obtain more accurate results, more sampling and characterization studies are needed.

MBR systems have been operated especially for municipal wastewater and mass balance and kinetic studies have been generally carried out for municipal wastewaters. However, MBR systems are also applied for industrial wastewater treatment. Therefore, more studies should be carried out for different types of industrial wastewaters.

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