ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

INVESTIGATION OF COD BEHAVIOR BY MODELLING OF ACTIVATED SLUDGE SYSTEM WITH A MEMBRANE MODULE (MASM)

M.Sc. THESIS

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Department of Environmental Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MODİFİYE EDİLMİŞ KOİ DAVRANIŞLARININ MEMBRAN MODÜLÜ KULLANILAN AKTİF ÇAMUR SİSTEMLERİNDE İNCELENMESİ

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Ayşe Begüm YÜCEL, a M.Sc. student of ITU Graduate School of Science Engineering and Technology student ID 501171802, successfully defended the thesis entitled "INVESTIGATION OF COD BEHAVIOR BY MODELLING OF ACTIVATED SLUDGE SYSTEM WITH A MEMBRANE MODULE (MASM)'' which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

FOREWORD

First, I would like to thank my thesis advisor Prof. Dr. Seval SÖZEN for her precious support, leadership and especially her limitless patient during my three years M.Sc. period. She was always kind and I appreciate to her not only for scientific guidance but also her meaningful advices.

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June 2019 Ayşe Begüm YÜCEL

Bioengineer

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ABBREVIATIONS

MASM	: Activated Sludge Model with MBR module
ASM1	: Activated Sludge Model 1
MBR	: Membrane Bioreactor
PSD	: Particle Size Distribution
COD	: Chemical Oxygen Demand
SRT	: Sludge Retention Time
HRT	: Hydraulic Retention Time
WWTP	: Wastewater Treatment Plant
SF	: Superfast

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INVESTIGATION OF MODIFIED COD BEHAVIOR BY MODELLING OF ACTIVATED SLUDGE SYSTEM WITH A MEMBRANE MODULE (MASM)

SUMMARY

Modeling of activated sludge systems with different configurations is a prediction method for wastewater treatment systems since 1986. To understand the behavior of the activated sludge processes, the modeling studies were developed for different conditions that consider different types of processes such as removal of organic compounds (ASM1), nitrogen (ASM2), phosphorus (ASM2d).

Nowadays, all these activated sludge models can be configurated with a membrane which is a ground-breaking milestone for the traditional activated sludge process. Membranes can separate the compounds according to their size threshold. This provides a solution to the main problems comparing to conventional systems. Therefore, it is a major leap which allowed to replace the always problematic gravity settling by membrane filtration of biomass. Aside from a high-quality effluent suitable for reuse, this innovation ended the restrictions of gravity settling on biomass concentration in the reactor, simply by uncoupling hydraulic retention time (HRT) and sludge age (SRT), in a much smaller footprint.

Usage of membranes in wastewater treatment systems leads us to examine the operational and kinetical mechanisms of this technological development. To be able to do this, Activated Sludge Models (ASMs) can be used as again a perfect method to understand the behavior of this treatment system which should be investigated in lab-scale conditions before applying in real life. Therefore, many studies investigate the activated sludge models that are modified with membranes.

According to this subject, this study focuses on creating a modified ASM1 as a new model that requires a model structure for performance evaluation and control. In this context, this study aims to define a new model, MASM for the activated sludge reactor with a membrane module and evaluate its implications based on modified COD fractionation and particle size distribution for different process configurations. Besides biological treatability experiments, particle size distribution analysis gives valuable information about wastewater characteristics. Therefore, the studies that combine the information obtained from conventional characterization with biodegradation experiments and PSD analysis are preferred for this study. Especially PSD analysis should be used by making assessments about MBR modeling researches because their operational mechanisms behave the same due to the separation of compounds according to their size ranges.

Domestic, textile, and tannery wastewaters are the four wastewaters selected for this study. All information about the wastewaters is obtained from recent studies that include both biological treatment and PSD analysis. In this context, conventional characterization gives information about the amount of particulate and soluble

substance in wastewater. The biological treatability analysis demonstrates the information about the soluble part of the wastewater by respirometry test which mainly focuses on the hydrolyzation mechanism. PSD analysis provides information about the size of pollutants by applying membranes with different size thresholds.

With the light of all these informations, a conventional ASM1 and a MASM were set and they both consist of 3 bioreactors with the same volume. ASM1 system ends up with a point separator as a settling tank and included a recycling system where the MBR system ends up with a point separator as membrane also included a recycling system. The conventional AS model has inflow, outflow, and recycle flow as 10.000 m^3/day and the COD characterizations were introduced to model directly based on selected references. Inflow and outflow of MASM are the same value with ASM1 but recycle flow MBR model is four times more than the inflow as 40.000 m^3/day and the COD characterizations were introduced to the model according to their size ranges. Therefore, COD components in the influent stream of the MBR model includes captured COD if the COD parameter belongs to the size threshold larger than the membrane.

Usage of MBR changes the COD concentration in the reactor because while some of the soluble compounds pass through the membrane and appear in the outflow, some of them captured by membrane due to their size thresholds larger than the pores of the MBR. This makes these captured soluble compounds can be considered as particulate matter because they could not pass through the membrane. This provides lower COD concentrations in the effluent. In this study, the captured COD and effluent quality were examined for three different wastewaters and a comparison of the conventional and MBR system investigated based on their operational differences. Total soluble hydrolyzable COD, S_{HT}, and total soluble inert COD, S_{IT} were taken into account because they have a wide range of sizes range between 2-450 nm in related wastewaters and creates reliable differences when MBR used. In MASM system S_{HT} was subdivided as captured S_{HC} and remaining effluent S_{HE}. Similarly, S_{IT} is separated as S_{IC} and S_{IE}.

The model runs of both conventional AS and MBR based AS on different sludge retention times by changing the volumes of reactors and the amount of waste sludge. Then, the comparison of ASM1 and MASM models were done based on S_H and S_I removals and effluent quality. The results of the study were investigated in two steps; (i) AS configurations with different and (ii) same HRTs. Both steps include SRT values from 1 to 8 days indicates *superfast*, *high rate* and *conventional* operations. In the first step, the ASM1 model run with 4.000 mg/L MLSS while the MASM model run with 10.000 mg/L due to smaller volume while there was no limitation on the concentration of MLSS in the reactors of the second step.

According to Step 1, two main observations were displayed based on ASM1 and MASM; (i) S_{HE} values of MASM system were lower than ASM1 under superfast (SF) conditions while SRT is below 2 days for domestic and textile wastewaters. Tannery wastewater has quite a high S_H load comparing those two wastewaters therefore minimum SRT value as 4 days were applied. In the results of the high rate (HR) and conventional operations, S_{HE} remained similar for two wastewaters; for HR operation around 3-5 mg/L for domestic and 13-20 mg/L for textile, for conventional operation 1-3 mg/L and 4-8 mg/L respectively. (ii) S_H removal rates were mostly lower for the

MASM systems because it was calculated by excluded S_{HC} fraction from initial S_{H0}. The conditions of Step 1 are not proper for the treatment of tannery wastewater even high SRT levels were used; from 4 to 18 days. The outputs always display the usage of the MASM system has lower removal rates and require modification which was applied in Step 2.

According to the results of Step 2; (i) MASM system under SF conditions resulted in lower S_{HE} concentrations for all wastewaters. For example, in Step 1, S_{HE} value of textile wastewater at SRT value of 1 day was 95 mg/L for ASM1 and 33 mg/L for MASM; in Step 2, the values are 95 mg/L and 18 mg/L respectively. (ii) Tannery wastewater has a great improvement in the results in Step 2 also. While the S_{HE} result of MASM at SRT 4 days in Step 1 was 152 mg/L, it degreases to 59 mg/L in Step 2. Besides, this value is more than 25% lower than 80 mg/L obtained in the system operation of ASM1. On the other hand, in Step 2, the performance of MASM is better than ASM1 at SRT as 4 days. However, when SRT increases, the performance of MBR getting decreases. This might be the result of the effect of components that are captured and accumulated in the bioreactor throughout the membrane.

Different COD fractions affect the effluent quality under different operational conditions; especially soluble residual COD fractions, S_P, the influent soluble inert COD, S_{I1}. In the ASM1 system, inert COD will appear always in the effluent. Therefore, the MASM system is more favorable in this aspect. For example, while S_{IT} concentration of tannery wastewater is 214 mg/L will appear in the effluent of ASM1, in the MASM model, 45% of S_{IT} will be captured by the membrane and 118 mg/L will stay in the effluent. On the other hand, the effluent quality of ASM1 and MASM systems are approximately the same in Step 1 while this ratio changes in Step 2, and the S_{TE} concentrations of MASM resulted in 16% less COD concentration than ASM1 system due to better operational conditions.

As a future perspective, different modifications of conventional and MBR AS systems for better operational results on effluent quality of wastewater and efficient system runs considering used energy and sludge reduction may be developed by similar modeling studies.

MODİFİYE EDİLMİŞ KOİ DAVRANIŞLARININ MEMBRAN MODÜLÜ KULLANILAN AKTİF ÇAMUR SİSTEMLERİNDE İNCELENMESİ

ÖZET

Aktif çamur sistemlerinin farklı konfigürasyonlarla modellenmesi, 1986 yılından bu yana atık su arıtma sistemleri için bir öngörü yöntemi olarak kullanılmaktadır. Aktif çamur proseslerinin davranış mekanizmasını ve kirleticilerin giderilme süreçlerini anlamak için farklı modelleme çalışmaları mevcuttur. Örneğin, organik bileşiklerin, azotun ve fosfor gibi bileşimlerin atıksudan uzaklaştırılması için farklı koşullarda çalışan sırasıyla ASM1, ASM2, ASM2d gibi modeller vardır.

Günümüzde, tüm bu aktif çamur modelleri, membran kullanılarak modifiye edilebilir ve bu sayede geleneksel aktif çamur prosesleri bu yeni teknoloji ile iyileştirilebilir. Membranlar filtre şeklindeki yapısı sayesinde atıksudaki bileşikleri boyut büyüklüklerine göre ayırabilirler. Bu durum, geleneksel sistemlerde oluşabilen bazı temel sorunlara bir çözüm sağlar. Bu nedenle, membran filtrasyonu, standart aktif çamur sisteminde en büyük problemlerden biri kabul edilen çökelme tankındaki biyokütlenin çökelememe sorunu için bir çözüm oluşturur. Bu yenilik, atıksuyun arıtımı sonrasında yüksek kaliteli su oluşturup bu suyun tekrardan kullanıma uygun hale gelmesinin yanı sıra, reaktördeki biyokütle çökelmesi için sorun olan yerçekimi kısıtlamalarını hidrolik bekletme süresini (HRT) ve çamur yaşını (SRT) ayarlayarak daha düşük ayakiziyle sağlar.

Atıksu arıtma sistemlerinde membran kullanılması, geliştirilen bu teknolojinin operasyonel ve kinetiksel mekanizmalarının detaylı şekilde incelenmesini gerektirmektedir. Bu arıtma sistemlerinnin davranış biçimerinin anlaşılması için en iyi yöntem Aktif Çamur Modellerinin (ASMs) kullanılmasıdır. Bu sebeple literatürde membran kullanılarak modifiye edilmiş aktif çamur sistemlerinin modellenmesiyle ilgili pek çok çalışma mevcuttur.

Bu çalışma temel olarak performans değerlendirilme ve kontrolüne ihtiyaç duyan modifiye edilmiş yeni bir ASM1 modelini oluşturmayı hedef alır. Bu açıdan çalışmanın temel amacı membran modülü kullanılarak modifiye edilmiş MASM olarak adlandırdığımız bir aktif çamur sisteminin farklı proses konfigürasyonları için modifiye edilmiş KOİ fraksiyonları ve partiküler boyut dağılımı (PSD) üzerindeki etkilerinin yorumlanmasıdır. Biyolojik arıtılabilirlik deneylerini yanı sıra partiküler boyut dağılımı çalışmaları atıksu karakteri ile alakalı olarak önemli ve detaylı bilgiler sunmaktadır. Bu sebeple bu tezde biyolojik arıtılabilirlik çalışmalarıyla elde edilen konvansiyonal KOİ karakterizasyonu ve PSD analizlerinin yapıldığı çalışmalar tercih edilmiştir. Özellikle PSD analizi, çalışma mekanizmasının benzerliği itibariyle MBR modelinin araştırılması ve yorumlanması için öenm arz etmektedir.

Bu çalışma için üç atıksu; evsel, tekstil ve deri atıksuları seçilmiştir. Atıksular hakkındaki detaylı tüm bilgiler biyolojik arıtılabilirlik ve PSD analizlerinin bir arada yapıldığı çalışmalardan alınmıştır. Bu noktada, geleneksel karakterizasyon atıksu içerisindeki partiküler ve çözülebilir maddeler hakkında, biyolojik arıtılabilirlik

testleri ise hidroliz mekanizmasını baz alan respirometre yöntemi sayesinde, çözülebilir kısımla alakalı bilgi sağlar. PSD analizi ise kullanılan membran sayesinde kirleticileri boyutlarına göre ayırarak sınıflandırır.

Bu bilgiler ışığında her biri eşit hacimli 3 reaktörden oluşan biri konvansiyonel ASM1 ve diğeri MASM olarak iki farklı model geliştirildi. ASM1 prosesi çökelebilir tank ile MASM sistemi ise modelde 'point seperator' olarak adlandırılan membran ile sonlanır. İki modelde de geri devir mekanizması kullanılmıştır. Konvansiyonel AS modelinde giriş, çıkış ve geri devir akımları 10.000 m^3/gün olmakla beraber KOİ karakterizasyonu seçilen referanslar baz alınarak sisteme tanıtılmıştır. MASM sisteminde ise giriş ve çıkış akımları ASM1 ile aynı iken geri devir akımı 4 kat fazla olup 40.000 m^3/gün'e tekabül eder. Bu modelde KOİ fraksiyonları boyut dağılımları da dikkate alınacak şekilde modele tanıtılmıştır. Bu sebeple MASM prosesinin giriş akımındaki KOİ fraksiyonları, membran por boyutundan büyük olup içeride tutulan KOİ fraksiyonlarını da kapsamaktadır.

Membran biyoreaktör (MBR) kullanımı, bazı çözülebilir materyaller membrandan geçip çıkış akımında bulunurken, bazıları ise boyut büyüklüğü nedeniyle membran tarafından tutulur ve reaktörün içerisindeki KOİ konsantrasyonunu değişmesine sebep olur. Membran vasıtasıyla tutulan bu fraksiyonlar çıkış suyunda yer almayıp çamura karışacağından partiküler madde olarak kabul edilebilir. Bu durum ise çıkış suyundaki KOİ miktarının azalmasını sağlamış olur. Bu çalışmada tutulan KOİ ve çıkış suyu kalitesi 3 farklı atıksu için geleneksel ve MBR sistemlerinde operasyonel farklılıkları dikkate alınarak incelendi. Bu çalışmada, özellikle boyut dağılımı geniş aralıkta yereden (2-450 nm) toplam hızlı hidroliz olabilen KOİ, S_{HT}, ve toplam çözülebilen inert KOİ, S_{IT}, MBR kullanıldığında dikkate değer farklılıklar yarattığı için dikkate alınmıştır. MASM sisteminde S_{HT}, membran tarafından tutulan S_{HC} ve tutulamayıp çıkış suyunda gözlemlenen S_{HE}, S_{IT} ise S_{IC} ve S_{IE} fraksiyonlarına ayrılmıştır.

Çalışmada reaktörlerin hacimleri ve sistemden atılan atılan çamur miktarları değiştirilerek farklı çamur yaşları için farklı konfigürasyonlar oluşturulmuştur. Daha sonra ASM1 ve MASM sistemleri S_H, S_I giderilmesi ve çıkış suyu kalitesi dikkate alınarak kıyaslanmıştır. Sonuçlar iki aşamada; AS konfigürasyonları (i) farklı ve (ii) aynı hidrolik bekletme süreleri (HRT) şeklinde değerlendirilmiş ve iki konfigürasyonda da SRT değeri 1'den 8 güne kadar olan süreler *superfast (SF), high rate (HR)* ve *conventional* olarak adlandırılmıştır. Birinci aşamada ASM1 sistemi MLSS konsantrasyonu 4.000 mg/L, küçük reaktör hacimlerinde çalışıldığı için MASM sisteminde 10.000 mg/L olarak seçilmiştir. İkinci aşamada ise reaktör içlerinde herhangi bir MLSS kısıtlaması olmadan modeller çalıştırılmıştır.

Birinci aşamada (Step 1) iki temel sonuç gözlemlenmiştir; (i) evsel ve tekstil atıksuları için MASM sistemindeki S_{HE} değerleri SRT değerinin 2 gün ve daha az olduğu SF koşullarında ASM1'e kıyasla daha düşüktür. Deri atıksuyu diğer iki atıksuya göre daha kuvvetli ve bu nedenle girişteki S_H konsantrasyonları daha yüksek olduğu için minimum SRT değeri 4 gün olarak alınmıştır. Bu sebeple SF koşullarında çalıştırılmamaktadır. HR ve konvansiyonel SRT operasyonlarında S_{HE} değeri iki atıksu için benzer sonuçlar vermiştir; HR koşullarında evsel için 3-5 mg/L, tekstil için 13-20 mg/L, konvansiyonel koşullarda sırasıyla 1-3 mg/L ve 4-8 mg/L KOİ değerlerine sahiptir. (ii) MASM sisteminde S_H yüzdesi, başlangıçtaki S_{H0} fraksiyonundan S_{HC} fraksiyonu çıkartılarak hesaplandığı için ASM1'e göre düşük kalmıştır. Step 1'deki koşullarıyla yüksek KOİ değerlerine sahip deri atıksuyu için 18 güne kadar çıkan SRT değerleri uygulansa bile yeterli arıtmı sağlayamamıştır. Step 1'de MASM sisteminde düşük giderim olması sebebiyle mıdifiye edilerek modeller Step 2'de tekrar uygulanmıştır.

Step 2'nin sonuçlarına göre; (i) SF koşullarında MASM sistemi tüm atıksular için düşük S_{HE} konsantrasyonu vermiştir. Örneğin Step 1'de tekstil atıksuyunun SRT değeri 1 gün iken ASM1 sisteminin S_{HE} değeri 95 mg/L MASM sisteminin 33 mg/L iken Step 2'de bu değer ASM1 için aynı kalırken (95 mg/L) MASM'de 18 mg/L'ye düşmüştür. (ii) Deri atıksuyu model sonuçları ise Step 2 koşullarında daha iyi giderim sonuçları vermiştir. MASM sistemi SRT 4 gün koşulunda çalıştırıldığında Step 1'de S_{HE} değeri 152 mg/L iken, Step 2'de bu değer 59 mg/L'ye düşmüştür. Ayrıca, aynı koşullarda ASM1 sisteminde sonuç veren 80 mg/L S_{HE} değeri, Step 2'de %25 azalmıştır. Bununla beraber Step 2 koşullarında MASM SRT değeri 4 güne kadar ASM1'e göre daha iyi giderim performansı gösterirken, SRT değeri arttıkça MBR performansında düşüş gözlemlenmektedir. Bunun sebebi membran sayesinde reaktör içerisinde tutulan ve biriken kirleticilerin etkisi olabilir.

Çeşitli operasyonel koşulların yarattığı farklı KOİ fraksiyonları çıkış suyu kalitesini farklı şekillerde etkileyebilir; özellikle biyodegredasyon sonrası oluşan çözülebilir KOİ, S_P ve giriş suyunda yer alan çözülebilir inert KOİ, S_I. Konvansiyonel ASM1 sisteminde inert KOİ hiç bir zaman reaksiyona girmediğinden her zaman çıkış suyunda bulunur. Bu açıdan membranın kullanıldığı MASM sistemleri bu KOI fraksiyonlarının tutulması açısından daha çok tercih edilirler. Örneğin, deri atıksuyundaki S_{IT} değeri ASM1 sisteminde girişte olduğu gibi çıkış suyunda da 214 mg/L konantrasyonundadır. MASM sisteminde ise bu miktarın %45'I membran tarafından tutulur ve 118 mg/L'si çıkış suyunda gözlemlenir. Diğer bir taraftan, çıkış suyu kalitesi ASM1 ve MASM sistemleri için Step 1 koşullarında yaklaşık olarak aynı iken, Step 2 koşullarında bu durum değişir ve MASM sistemininde S_{TE} konsantrasyonu ASM1'e göre %16 azalmıştır.

Gelecekte yapılması beklenen çalışmalara destekleyici olarak konvansiyonel ve MBR AS sistemlerinin farklı modifikasyonlarının çıkış suyu kalitesi açısından operasyonel olarak iyileştirilmesi; enerji ve oluşan çamur miktarının azaltılması için benzer modelleme çalışmalarının geliştirilmesi önerilmektedir.

1. INTRODUCTION

Activated sludge process is the main biological process configuration with a universally accepted model for not only treatment of wastewaters but also understanding and evaluating the fate of contaminants and biomass in the reactor. Single or multi-component activated sludge models (ASMs) are structured based on COD as the sole parameter, which defines all components of organic carbon and biomass together with COD fractionation based on different biodegradation characteristics.

The organic content in wastewaters contains soluble and particulate matter. In biologically treated conventional systems most of the soluble matter considered as consumed by biomass and some of particulate matter are exposed to hydrolysis reaction and most of it are separated by gravity settling. However, this mechanism is not enough for high strength wastewaters to meet discharge criteria.

Membrane bioreactor treats the organic pollutants in the wastewater by biomass and through membrane filter. Activated sludge processes with different membrane modules are mostly used for treatment of wastewaters which has high COD levels. Most of these wastewaters are classified as industrial wastewater. The treatment processes basically start with a biological or chemical treatment or both, and instead of gravity settling, the effluent pass throughout a membrane filter. Accordance with the discharge criteria, the effluent after membrane filtration can be discharge to the receiving body.

The feature of COD fractions depends on mainly their specific process kinetics that must be introduced to the ASMs. Information of process kinetics can be understood by respirometry technics and it is one of the major achievements to understand substrate behavior in biological systems. Further more, assessment of pollutants in wastewater also depends on their physical characteristics. The particle size distribution (PSD) analysis by using lab-scale membranes gives information about approximate size of the pollutants which can be very useful for estimating the fate of the COD fractions. The PSD analysis includes separation of pollutants by membranes with size threshold as 2 nm, 2-3 nm,3-5 nm, 5-8 nm, 8-13 nm, 13-220 nm and 220-450 nm.

Assessment of a typical conventional system can be operated by standard methods that provides the conventional COD fractionation of related wastewater. The soluble and particulate matter in wastewater can be differentiated by using a single size threshold, 450 nm membrane (Henze, 1992; Orhon et al., 1998; Insel et al., 2019). The particulate part of the sample is assumed to be retained in the reactor as part of the biomass, whereas its soluble counterpart by-passes the reactor. The soluble part is subject to the respirometry analysis to understand the behaviour of soluble pollutans; direct consumption of readly biodegredable COD or hydrolyzable COD. This structure is successfully applied for ASM1 model that separetes sludge with gravity settling however it is invalid for AS with membrane seperation because: the 450 nm size threshold membrane becomes inefficient to the effective filtration size of the selected membrane; this result a certain change in COD fractionation, with mass balances and model structure. Therefore, the current practice of using ASMs for membrane systems would greatly distort and undervalue system performance.

Depending on the wastewater characteristics the structure of the organic matter differs, and the process should be arranged for proper treatment. Many industrial treatment plants must deal with high COD load and apply difficult and expensive treatment procedures. On the other hand, after treatment process, the produced sludge is another problem that must be solved with different ways. The usage of membrane plays a role solving these problems by decreasing the amount of produced sludge throughout running the system with lower volumes. Besides high quality effluent which can be used for other processes, the MBR innovation solves the restriction problems of gravity settling.

In this context, this study aimed to investigate three different wastewaters: domestic, textile and tannery by modelling of activated sludge system with a membrane module. The important part of the study was to understand the behavior of the soluble organic compounds which could not pass through membrane filter and accumulated inside the reactor, the effect of using MBR on effluent quality comparing to the conventional system and operating conditions. To reach this aim, the study combines the respirometry methods with PSD analysis by using related studies.

In short, AS system with a membrane module (MAS) needs a new model as modified version of standard ASM1 to be able to recover the performance and control of the system. The evaluation of the model for different process configurations is based on modified COD fractionation and PSD analysis which are applicable for domestic, textile and tannery wastewaters with the information of related recent studies.

2. LITERATURE REVIEW

2.1 Activated Sludge System

Activated Sludge (AS) processes as the main step of Wastewater Treatment Plants (WWTPs) always aim that provide healthy operation for all different loads of plants as steady conditions as possible (O'Brien et al., 2011). As the oldest and most widely used wastewater treatment method, a WWTP is a facility that has mechanical, physical, chemical and biological operations that must be chosen according to wastewater type which can be categorized as domestic, municipal, industrial and so on (Hreiz et al., 2015). The biological part of the activated sludge process includes extremely different microorganisms, groups of heterotrophs, autotrophs which are together to perform different functions such as organic carbon removal, nitrification, denitrifications, phosphorus removal, etc. (Orhon, 2015).

Historical Development

The history of activated sludge systems has been dating back to the late 19th century. In the 1880s, Dr. Angus Smith discovered the effect of supplying oxygen to the wastewater provides quick removal of organics in wastewater (Ranede et al., 2014). In 1914, Arden and Lockett realized that the amount of sediment is directly proportional to the number of batches after the application of aeration. Therefore, they understood that applying aeration has a huge effect on sludge because active biomass consists of microorganisms and named the system as Activated Sludge Process (ASP) due to aerobic stabilization of organic pollutants in wastewater (Ardern and Lockett, 1914). After this innovation different experimental investigations were applied by researches in England and the US that are focused on solving operational problems due to mysterious microbial activities. The development of empirical expressions according to the modifications of different processes always continue for maintaining the stability and performance of ASPs in proper conditions (Orhon, 2015).

Basic Process Description

The developed ASP for treatment of different types of wastewaters like domestic, municipal, and even industrial must contain basic components: a tank for aeration named as bioreactor provides biological treatment followed by a settling tank also called clarifier. It also includes a return activated sludge (RAS) system that transfers the settled sludge that comes out from settling tank to the bioreactor for further usage of active biomass. This configuration showed in Figure 2.1.

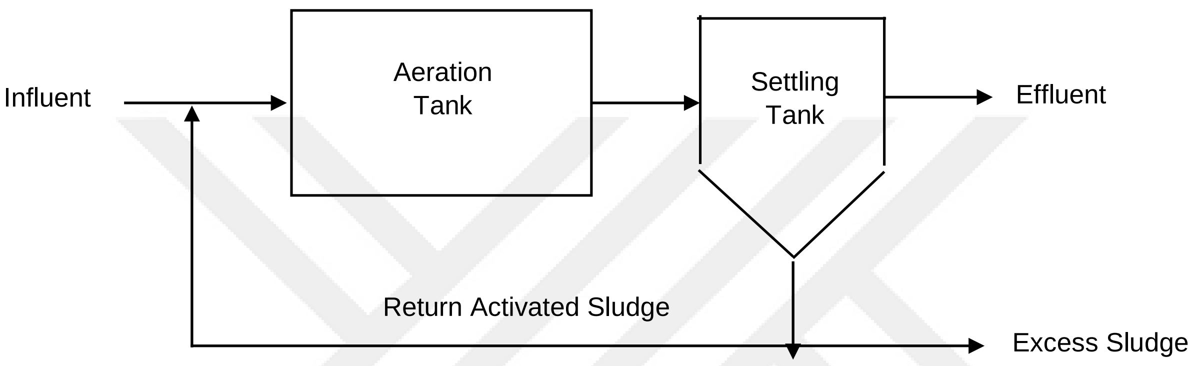


Figure 2.1 : The configuration of the conventional activated sludge process (Metcalf and Eddy, 2003).

Before enter aeration tank, primary treatment should apply for sewage or industrial wastewater by screen or primary sedimentation methods physically or chemically. After that, the influent is introduced to the aeration tank where the biological activity takes place. The combination of influent wastewater and biomass is known as mixed liquor. Biodegradable pollutants in the influent stream are consumed by active biomass in bioreactor and this removal process depends on hydraulic retention time which depends on the volume of the aeration tank and flowrate of wastewater. The COD concentration, food to microorganism ratio, amount of oxygen supplied and all operational conditions like temperature could affect the removal efficiency. The effluent of the bioreactor is directed to a settling tank and, in this part, the treated water as effluent generally discharged to a natural water body if it does not need further treatment. The rest of wastewater is biomass and it is settled by gravity settling and named as sludge and some of it returns to the aeration tank to meet the needed mixed liquor suspended solids (MLSS) criteria. The rest of the excess sludge that must be removed from the process and must be also treated by other processes like aerobic or anaerobic digestion become available for disposal (Metcalf and Eddy, 2003).

This process expression is available for conventional activated sludge systems. Besides, the configuration may certainly change according to the wastewater type. Especially industrial wastewater must undergo very deep processes includes not only biological but also chemical, physical treatments. The most important concern during the decision process is the economical way of thinking of the treatment. Therefore, the treatment procedure must be decided according to discharge criteria and its economic impacts (Orhon, 2015).

2.2 Modelling of Activated Sludge System

Activated sludge models are used for very important reasons mainly to understand the operation of the wastewater treatment plants or to build the plant. In this way, scientists are used the AS models for teaching, design, control, and research studies about environmental purposes. To understand the complex nature of organics, named as Chemical Oxygen Demand (COD), their kinetics and behavior in treatment procedure should be understood for further researches.

With the increase in the usage of computers, environmental scientists combine the treatment processes with the models. At the beginning of the 1980s, International Water Association members developed the firs AS model as Activated Sludge Model No.1 (ASM1) (Henze et al., 1987). The model was designed for organic carbon removal, therefore, includes the related kinetic and mass balances. This model does not include nitrogen limitations and therefore led the researches to create other models. In 1995, the ASM1 was followed by ASM2 that covers not only carbon but also nitrogen removal (Gujer et al., 1995) and biological phosphorus removal was considered another model ASM2d. In 1999, the ASM3 model was developed and while it is similar to ASM1, it is differentiated from ASM2 because it does not include biological phosphorus removal. Besides, ASM3 is similar to ASM1, it also contains the storage mechanism of active biomass (Gujer et al., 1999).

Like all mathematical models, ASMs provide an opportunity to create a common language to understand the behavior of pollutants and the operation of the system. However, a model alone is not enough to evaluate the system work in real-time.

Therefore, the model must be combined with a lab-scale or plot plant process to make sure it works in real life.

The treatment processes can be differentiated according to their behavior depending on time which means they are stated as a function of time. Most mathematical simulations based on wastewater treatment developed as steady-state or dynamic models. The steady-state model which is relatively simple has a constant flow and loads and this makes them easy to be used in models. The dynamic models are complex comparing to steady-state version because their flows and load can be varied according to time. These models are useful for making predictions about the responses of time depending on parameters (Henze et al., 2008).

For modeling purposes, there are different simulation programs such as SUMO, AQUASIM, GOLDSIM, etc. and all of them serves for evaluation of different wastewaters in different operations, environmental conditions, for making parameter estimations or sensitivity analysis. One of the advantages of these programs is that researchers do not have to enter all the model configurations every time, they include predefined processes that are ready to use (Reichert et al., 1998).

2.3 Application of membrane module in ASM

In recent years the effluent quality becomes one of the primary concerns not only for disposal but also for recycling and reuse activities because of the high increment of water usage. Therefore, conventional Activated Sludge (ASM1) systems needed new developments to meet the discharge criteria.

Usage of membranes in wastewater treatment activities as a solution to the problems mentioned above is an advanced technology dating back to the late 1960s (Smith et al., 1967). The technology-based on a combination of a bioreactor with a membrane module and called Membrane Bioreactor (MBR) and provide valuable advantages. A membrane serves as a barrier for suspended solids or the pollutants which have the sizes higher than the size thresholds of membrane pores. The wastewater treatment process with MBR ends up with a high-quality effluent and can be reused for industrial purposes or even some household consumption (Visvanathan et al., 2000). MBR provides a smaller size of the plants which causes a smaller footprint with reducing sludge production. Therefore the wastewater treatment processes with MBR give reliable results comparing to the ASM1.

The efficiency of biological processes developed by MBR is relatively complex than other conventional processes. Optimization of MBR processes must include many parameters together such as; concentrations of solids, sludge, and hydraulic retention times together. On the other hand, from the operational way, the flux rate, material, and energy costs should be considered. Membranes are classified as their material type; metal or ceramic, membrane type; microfiltration, ultrafiltration or nanofiltration, and module type; plate, tubular or hollow fiber. Also, filtration surfaces; inner or outer skin, and module status as static or dynamic membranes and combinations of all of them should be considered (Visvanathan et al., 2000). Nowadays, the combinations of MBR like moving bed MBRs; membrane adsorption or coagulation reactors; vertical submerged MBRs, anammox, anaerobic MBRs are used with different biological reactor alternatives (Barwal and Chaundary, 2014; Tian et al., 2008a; 2008b)

The model structure of the conventional system can be used in models based on conventional characterization where 450 nm size threshold differentiated particulate and soluble matter which are major COD fractions (Orhon et al.1998). However, this definition is not applicable for MBR models because 450 nm size threshold becomes unsufficient to the effective filtration size of the selected membrane which can have much lower size thresholds like 220 nm, 13 nm, 2 nm, etc. (Rieger et al., 2012). Therefore, it is vital to create models for MBR systems which is much more complex than ASM1. To used the information needed for the model, Particle Size Distribution (PSD) analysis must be applied with the addition of conventional characterization and respirometric analysis.

COD as a specific fingerprint of wastewaters must be fractionated by the methods introduced in the literature (Ekama et al., 1986). Identification of COD profile and kinetic and stoichiometric coefficients can be done by Oxygen Uptake Rate (OUR) profile. The experimental method developed by Germirli in 1971, serves to quantify inert COD fractions and endogenous residual metabolic products based on COD balance (Germirli et al, 1971; Orhon et al, 1999).

Besides these characterization methods, PSD analysis gives valuable information about the physical characteristics of wastewater. It based on applying sequential filtration/ultrafiltration from 1600 nm down to 2 nm, providing a specific size fingerprint for selected samples. The supernatant of each filtration step must undergo a respirometry test to identify the amount of COD for each size threshold (Dülekgürgen et al, 2006).

In the literature, there are many PSD studies with the combination of OUR measurements applied not only domestic but also the industrial type of wastewaters to understand the character of wastewater related COD fractionations deeply (Dogruel et al., 2012, Karahan et al., 2008). In recent research, the PSD results of domestic wastewater matched with soluble COD fractions with cumulative and differential size distribution of soluble COD. In the study, the influent wastewater had the total soluble COD as 120 mg/L and consists of 40 mg/L readily biodegradable COD, 62 mg/L of soluble hydrolyzable COD and 18 mg/L inert COD. After biological treatment effluent was included 27 mg/L of SH and 35 mg/L of soluble microbial products, SP. According to the PSD analysis result, COD fractions at the size range of 2-8 nm can only include SI and SP because SS completely consumed during biological treatment. COD particle at higher sizes could be assumed as remaining SH.

As industrial wastewater, tannery wastewater had been used by Karahan et al. (2008) for a similar evaluation. After sequential filtration, the supernatants of 450 – 2 nm and <2 nm were subjected to respirometry and it was clear that SS was found at size range below 2 nm and most of SH located at <2 nm and also between 13-220 nm. It was also realized that for tannery wastewater SI was distributed among all size intervals. These two studies indicate that the size of COD fractions may differ based on the type and nature of different wastewaters.

3. MATERIALS AND METHODS

3.1 Model Structure

The used model is a modified version of Activated Sludge Model 1 (ASM1) by the addition of the decay process and dual hydrolysis mechanism. This model includes all soluble, particulate, and inert COD fractions together the heterotrophic biomass and dissolved oxygen.

The main components of the model include not only conventional COD fractions but also the fractions that are the result of the physical separation of MBR. Influent COD fractions are total soluble (S_{T1}) and total particulate (X_{T1}) COD and they can be classified as follows; readily biodegradable COD (S_{S1}), readily hydrolyzable COD (S_{H1}), captured soluble hydrolyzable COD (S_{HC1}), soluble inert COD (S_{I1}), captured soluble inert COD (S_{IC1}), particulate hydrolyzable COD (X_{S1}), settleable particulate hydrolyzable COD (X_{SS1}), particulate inert COD (XI1), settleable inert COD (X_{IS1}), (2) produced residual microbial products by decay processes; soluble residual microbial products (S_P), particulate residual microbial products (X_P), (3) active heterotrophic biomass (X_H) and (4) dissolved oxygen (S_O).

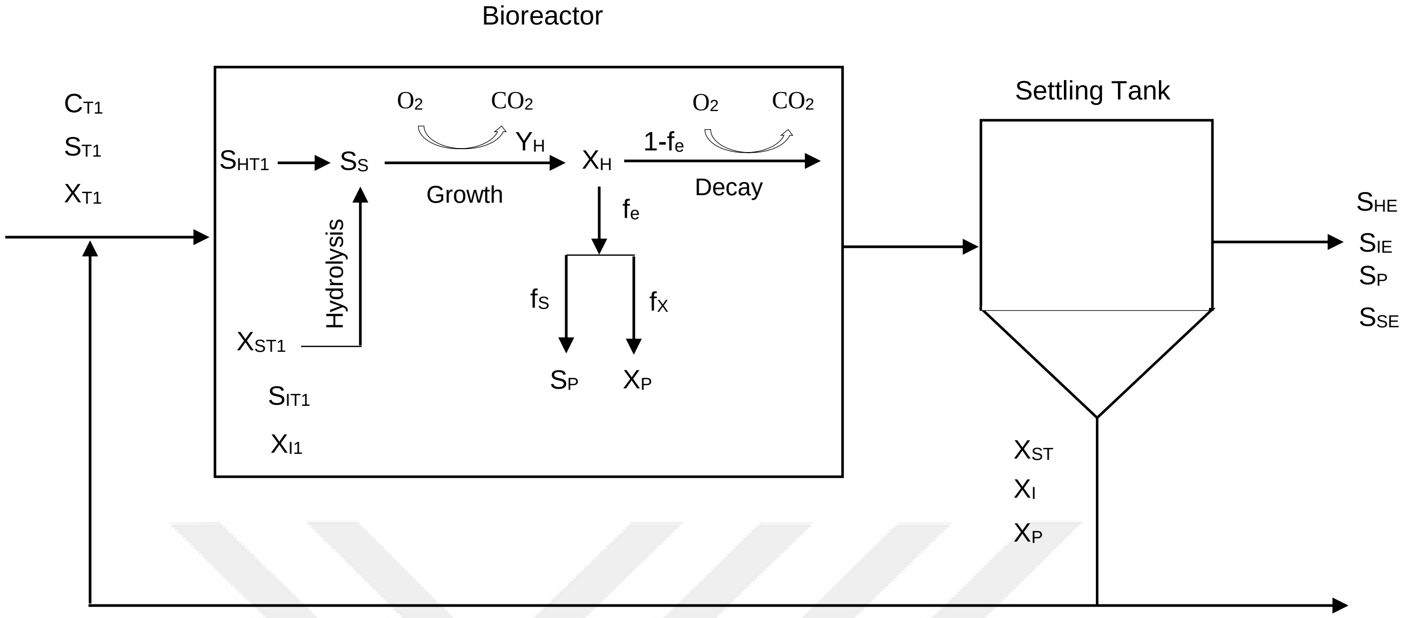
The biochemical processes of the model are (1) growth of the active heterotrophic biomass (X_H) by the consumption of readily biodegradable COD (S_S), (2) rapid hydrolysis of readily hydrolyzable COD (S_H) to readily biodegradable COD (S_S), (3) slow hydrolysis of particulate hydrolyzable COD (X_S) to readily biodegradable COD (S_S), (4) rapid hydrolysis of captured soluble hydrolyzable COD (S_{HC}) to readily biodegradable COD (S_S), (5) slow hydrolysis of particulate settlable COD (X_{SS}) to captured soluble hydrolyzable COD (S_{HC}) and decay of active heterotrophic biomass (X_H).

The structure mentioned above is given by Figure 3.1 and the components and the processes of the model are shown in Table 3.1.

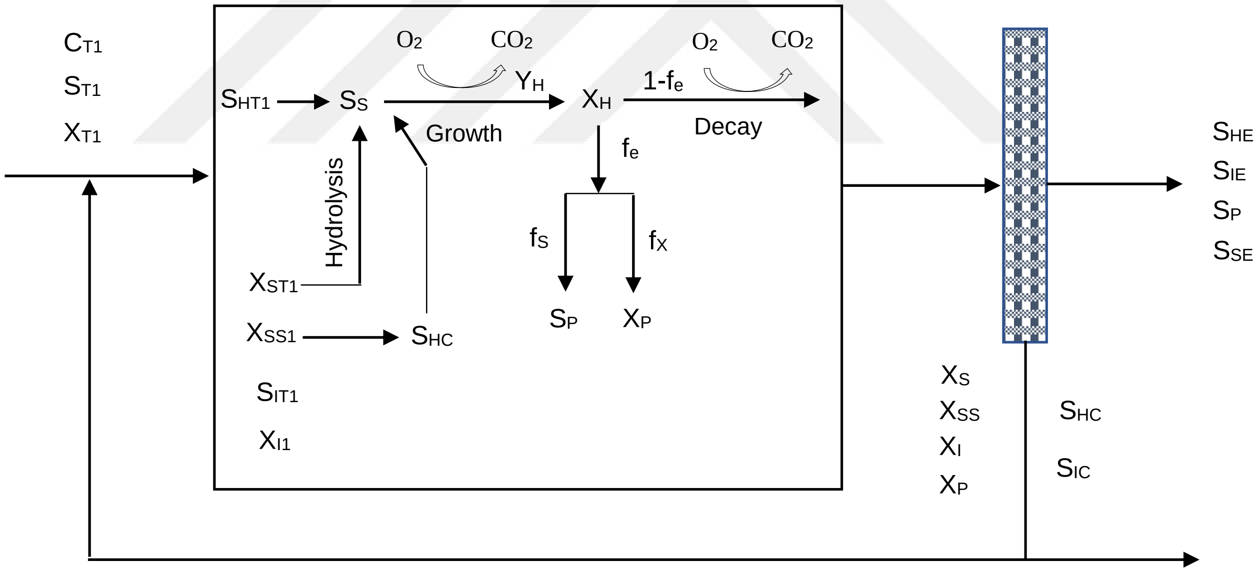
The components S_S, S_H, X_S, S_I, X_I represent total measured COD. Readily biodegradable COD (S_S) is the first component consumed by biomass and may consist of simple components like simple carbohydrates, volatile fatty acids (VFAs) alcohols, etc. and heterotrophic growth occurs by the utilization of this molecules as a function of Monod type expression. Readily hydrolyzable COD (S_H) is converted to readily biodegradable COD (S_S) by the hydrolysis process. In this model, the hydrolysis process takes place dually and not only hydrolysis of soluble larger complex organic molecule but also particulate organic molecules undergo to second hydrolysis process to become simpler organics for utilization. This includes the hydrolysis of particulate hydrolyzable COD (X_S) due to the hydrolyzation process deals with the larger organic molecules, it is a slower reaction than the utilization of readily biodegradable COD. The inert COD fractions as soluble inert COD, S_I, and particulate inert COD, X_I never go through a biochemical reaction and while SI directly leaves the activated sludge process, X_I can only be removed by sludge wastage.

The model emphasis also the main role of dissolved oxygen concentration (S_O) which is a parameter in the switch functions of process rates.

The residual microbial products as S_P and X_P are the components of decay associated processes.



(a)



(b)

Figure 3.1 : Description of model components of the MASM a) Conventional mechanism b) MBR mechanism.

3.1.1 Reaction rates of models

Matrix representations for ASM1 and MASM were shown in Table 3.1 and Table 3.2 respectively. Model components of the conventional system are S_{IT}, X_I, S_S, S_{HT}, X_{ST}, S_O, X_P, S_P, and X_H which undergo growth, decay, and hydrolysis processes according to the given process rates. In all models, switching functions were not considered due to unlimited oxygen, S_O, and nutrients supplement.

Inert components as S_{IT} and X_I do not expose any reaction and directly appear in the effluent stream. According to matrix given in Table 3.1, the rate of readily biodegradable COD; S_S can be described as:

$$\frac{dS_S}{dt} = -\frac{\mu_H}{Y_H}\frac{S_S}{K_S+S_S}X_H + k_h\frac{S_H/X_H}{K_X+S_H/X_H}X_H + k_{hX}\frac{X_S/X_H}{K_{XX}+X_S/X_H}X_H \qquad (3.1)$$

While growth reaction consumes, the hydrolyzation reactions produce S_S. The first hydrolyzation consumes S_{HT} where the second one hydrolyzes X_{ST}:

$$\frac{dS_{HT}}{dt} = -k_h\frac{S_H/X_H}{K_X+S_H/X_H}X_H \qquad (3.2)$$

$$\frac{dX_{ST}}{dt} = -k_{hX}\frac{X_S/X_H}{K_{XX}+X_S/X_H}X_H \qquad (3.3)$$

The residual microbial products as X_P and S_P are produced by decay related reactions:

$$\frac{dS_P}{dt} = f_S b_H X_H \qquad (3.4)$$

$$\frac{dX_P}{dt} = f_P b_H X_H \qquad (3.5)$$

Table 3.1 : Matrix representation of the modified ASM1 for conventional system (Orhon and Artan, 1994).

Model components → / Process ↓	S_{IT}	X_I	S_S	S_{HT}	X_{ST}	S_O	X_P	S_P	X_H	**Process rate**
Growth of X_H			$-\frac{1}{Y_H}$			$-\frac{1-Y_H}{Y_H}$			1	$\hat{\mu}_H \frac{S_S}{K_S+S_S} X_H$
Hydrolysis of S_H			1	-1						$k_h \frac{S_H/X_H}{K_X+S_H/X_H} X_H$
Hydrolysis of X_S			1		-1					$k_{hX} \frac{X_S/X_H}{K_{XX}+X_S/X_H} X_H$
Decay						$-(1-f_S-f_X)$	f_X	f_S	-1	$b_H X_H$
Parameter	COD	COD	COD	COD	COD	S_{O2}	COD	COD	Cell COD	

For MBR models, the matrix modified according to the captured COD where there are two more hydrolysis reactions; settleable slowly hydrolyzable COD; X_{SS} into captured hydrolyzable COD; S_{HC} and S_{HC} into S_S. The hydrolyzation rate of S_H is just the same as the hydrolyzation of S_{HT} shown in equation (3.2). The modified reaction on S_S and added reactions for X_{SS}, S_{HC} can be shown as follows:

$$\frac{dS_S}{dt} = -\frac{\mu_H}{Y_H}\frac{S_S}{K_S+S_S}X_H + k_h\frac{S_H/X_H}{K_X+S_H/X_H}X_H + k_{hX}\frac{X_S/X_H}{K_{XX}+X_S/X_H}X_H + k_h\frac{S_{HC}/X_H}{K_X+S_{HC}/X_H}X_H \quad (3.6)$$

$$\frac{dX_{SS}}{dt} = -k_{hX}\frac{X_{SS}/X_H}{K_{XX}+X_{SS}/X_H}X_H \quad (3.7)$$

$$\frac{dS_{HC}}{dt} = -k_h\frac{S_{HC}/X_H}{K_X+S_{HC}/X_H}X_H + k_{hX}\frac{X_{SS}/X_H}{K_{XX}+X_{SS}/X_H}X_H \quad (3.8)$$

Table 3.2 : Matrix representation of the proposed model, MASM.

Model components → Process ↓	S_I	S_{IC}	X_I	S_S	S_H	X_S	S_O	X_P	S_P	X_{SS}	S_{HC}	X_H	**Process rate**
Growth of X_H				$-\frac{1}{Y_H}$			$-\frac{1-Y_H}{Y_H}$					1	$\hat{\mu}_H \frac{S_S}{K_S+S_S} X_H$
Hydrolysis of S_H				1	-1								$k_{hS}\frac{S_H/X_H}{K_{hS}+S_H/X_H} X_H$
Hydrolysis of S_{HC}				1							-1		$k_{hS}\frac{S_{HC}/X_H}{K_{hS}+S_{HC}/X_H} X_H$
Hydrolysis of X_S				1		-1							$k_{hX}\frac{X_S/X_H}{K_{hX}+X_S/X_H} X_H$
Hydrolysis of X_{SS}										-1	1		$k_{hX}\frac{X_{SS}/X_H}{K_{hX}+X_{SS}/X_H} X_H$
Decay							$-(1-f_S-f_X)$	f_X	f_S			-1	$b_H X_H$
Parameter	COD	COD	COD	COD	COD	COD	S_{O2}	COD	COD	COD	COD	Cell COD	

SUMO Structure

The SUMO is a simulation program that is used for environmental aspects especially for modeling of activated sludge systems mostly municipal or industrial wastewater treatments. It can simulate standard biokinetic models based on biochemical reactions in a dynamically or steady-state base according to simulation modes. In the data archive of the program called SUMO Museum, most known published models, C, N, and P removal are included and ready for direct use.

In the program, the designer can make different configurations by design tools and the plant set up by arranging tank volume, return sludge rates, sludge wastes, and so on. The user can select any existing standard models or introduced a new model and the model parameters and run the model. The output of the created model depends on the user demands and again the designer must introduce the output requirements.

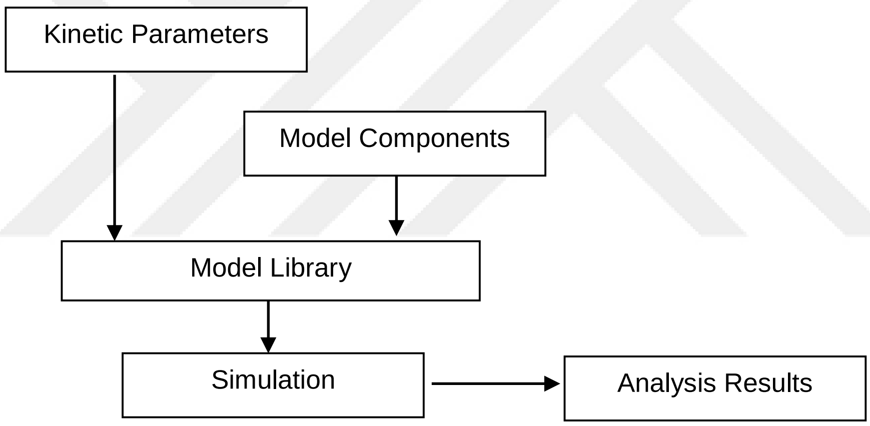


Figure 3.2 : The elements of model structure.

Figure 3.2 describes the basis of the SUMO simulation model. According to the chosen model, the kinetic parameters are assigned, and the user introduced the values of the parameters depending on the wastewater kinetics. The influent composition of the wastewater describes the model components and initial known COD fractions must be remarked to the model. The model library is an excel format file and includes the definition of all parameters, components, reactions, model matrix, and the variables that should be calculated by the model.

The configuration of this modeling study consists of three CSTR that were linked to each other and at the end of the process a point separator act as MBR. From the MBR module, the return activated sludge was linked to the first CSTR compartment and the waste activated sludge undergoes to the dewatering process. Figure 3.3 describes the configuration of the used model.

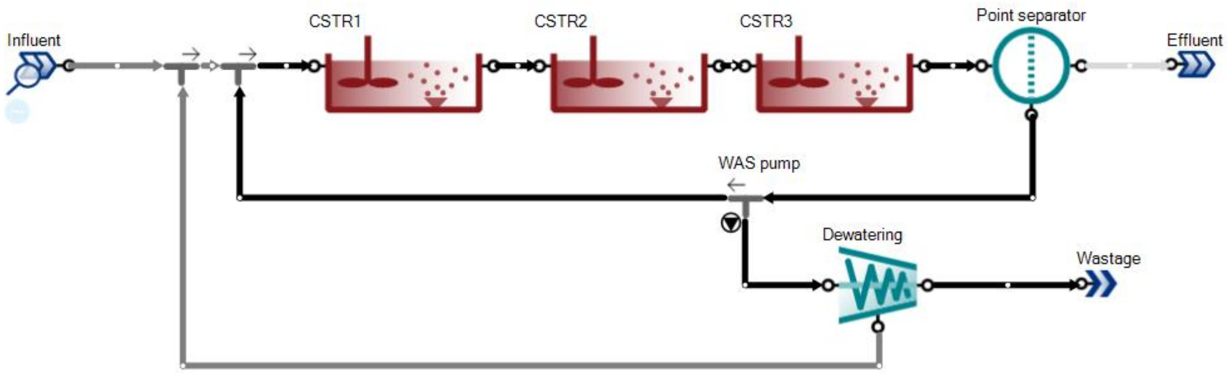


Figure 3.3 : The configuration of MASM.

3.2 Structure of MASM

In this study, the modified model, MASM, run two treatment process as conventional and MBR, and both systems operated with different conditions through selected HRT and SRT values. The rate of the bioreactors differs according to the sludge age and the wastewaters with lower COD loads like domestic and textile could be examined with lower SRTs. Therefore, in this study, domestic and textile wastewaters run with superfast; 0,3, 0,5, 1, 1,5, 2 days and high rate; 3, 4 days besides conventional; 6 days operational conditions. However, the wastewaters which have high COD loads like a tannery, run with high SRT values. On the other hand, the study divided into two parts: Step 1 and Step 2. In the first step, the aim was to keep MLSS values as 4.000 mg/L for conventional and 10.000 mg/L for the MBR system. In Step 2, there was no limitation on MLSS but the same volumes for ASM1 and MASM were selected and run. Because the volume of the reactors was the same, HRT values were the same also. Table 3.3 and Table 3.4 indicates a summary of the operational conditions of this study.

Table 3.3 : Operational conditions for system configurations in STEP 1.

Wastewater type	Runs	ASM1		MASM	
		Θ_X (days)	Θ_h (hours)	Θ_X (days)	Θ_h (hours)
Domestic					
	Run1	0,3	07	0,3	0,2
	Run2	0,5	1,1	0,5	0,4
	Run3	1	2,2	1	0,7
	Run4	1,5	2,5	1,5	0,9
	Run5	2	3,2	2	1,4
	Run6	3	4,3	3	1,7
	Run7	4	5,6	4	2,3
	Run8	6	8	6	3
	Run9	8	9,4	8	3,9
Textile					
	Run1	0,3	0,9	0,3	0,7
	Run2	0,5	2,2	0,5	0,85
	Run3	1	3,6	1	1,8
	Run4	1,5	5	1,5	2,2
	Run5	2	5,8	2	2,7
	Run6	3	8,6	3	3,6
	Run7	4	10,8	4	4,7
	Run8	6	14,4	6	6,5
	Run9	8	16,6	8	7.2
Tannery					
	Run1	4	18,7	4	6,5
	Run2	8	28,8	8	13
	Run3	12	42	12	18
	Run4	15	47	15	22
	Run5	18	57,6	18	25

As mentioned before, domestic and textile wastewater run at same and low SRT values covering 8 runs for each wastewater where tannery wastewater run at higher SRT values to achieve an effective treatment with 5 trials. To make the correct command, the same SRT values were used in Step 2.

Table 3.4 : Operational conditions for system configurations in STEP 2.

Wastewater type	Runs	ASM1-MASM	
Domestic		Θ_X (days)	Θ_h (hours)
	Run1	0,3	0,4
	Run2	0,5	0,72
	Run3	1	1,44
	Run4	1,5	2,2
	Run5	2	2,9
	Run6	3	4,4
	Run7	4	5
	Run8	6	6,5
	Run9	8	8,6
Textile			
	Run1	0,3	1,2
	Run2	0,5	2,4
	Run3	1	3,6
	Run4	1,5	4,3
	Run5	2	5
	Run6	3	7,2
	Run7	4	10,8
	Run8	6	14,4
	Run9	8	17,3
Tannery			
	Run1	4	19,4
	Run2	8	32,4
	Run3	12	43,2
	Run4	15	50,4
	Run5	18	57,6

3.3 The Wastewater Characteristics

In this study, three different types of wastewaters; domestic, textile, and tannery were used to run by the modified model, and all information related to the study were obtained from recent studies. The most important and common properties of these wastewaters are that they have detailed characterization, not only conventional characterization but also COD fractionation conducted with respirometry tests, detailed biodegradability characterizations, and particle size distribution analysis (PSD). Table 3.5 shows the characterizations of wastewaters according to related studies.

Table 3.5 : Modified COD fractionation for selected wastewaters.

Wastewaters → Parameters ↓	Domestic (Noyan et. al. 2017)	Textile (Dulekgurgen et. al. 2006)	Tannery (Karahan et. al. 2008)
Total COD (mg/L), C_{T1}	415	1.340	2.284
Total soluble COD (mg/L), S_{T1}	120	965	1.297
Total particulate COD (mg/L), X_{T1}	295	375	987
Readily biodegradable COD (mg/L), S_{S1}	40	280	434
Total soluble hydrolysable COD (mg/L), S_{HT1}	62	460	649
Influent soluble hydrolysable COD (mg/L), S_{H1}	15	100	406
Captured soluble hydrolysable COD (mg/L), S_{HC1}	47	360	243
Total soluble inert COD (mg/L), S_{IT1}	18	225	214
Influent soluble inert COD (mg/L), S_{I1}	10	135	118
Captured soluble inert COD (mg/L), S_{IC1}	8	90	96
Total particulate hydrolysable COD (mg/L), X_{ST1}	253	360	720
Influent particulate hydrolysable COD (mg/L), X_{S1}	113	162	720
Settleable biodegradable COD (mg/L), X_{SS1}	140	198	0
Total particulate inert COD (mg/L), X_{IT1}	42	15	267
Influent particulate inert COD (mg/L), X_{I1}	19	7	120
Settleable inert COD (mg/L), X_{IS1}	23	8	147

Domestic Wastewater

Domestic wastewater taken from the inlet of the İstanbul, Ataköy wastewater treatment plant was used for the study (Noyan et. al. 2017). According to conventional characterization total COD of the wastewater is 415 mg/L; consist of 29% of soluble COD (S_{T1}) and 71% particulate COD (X_{T1}) parts. The respirometry tests was used also to estimate readily biodegradable COD; which resulted as 10% of the total COD; 40 mg/L (S_{S1}), readily hydrolysable COD as 15% of the total COD; 62 mg/L (S_{H1}) and slowly hydrolysable COD as 60% of the total COD; 253 mg/L (X_{S1}). The detailed characterization based on biodegradability outlined that inert organic matter consists of 18 mg/L soluble inert COD (S_{I1}) and 42 mg/L particulate inert COD (X_{I1}) so that 60 mg/L as total inert COD correspond to 15% of total COD. The amount of captured COD by membrane was introduced to the model according to the PSD analysis of the wastewater in related study. The amount of soluble hydrolysable COD that have bigger sizes that 8-13 nm size threshold was 47 mg/L corresponds 76% of the total soluble hydrolysable COD and this part is renamed as captured soluble hydrolysable COD (mg/L), S_{HC1}. The rest of the COD as 15 mg/L (S_{H1}) corresponds 24% of the total soluble hydrolysable COD can pass through the membrane. The soluble inert COD with size threshold bigger than 8-13 nm were also retained in the system which corresponds 8 mg/L as 44% (S_{IC1}) of total soluble inert COD and the rest of soluble inert part was 10 mg/L.

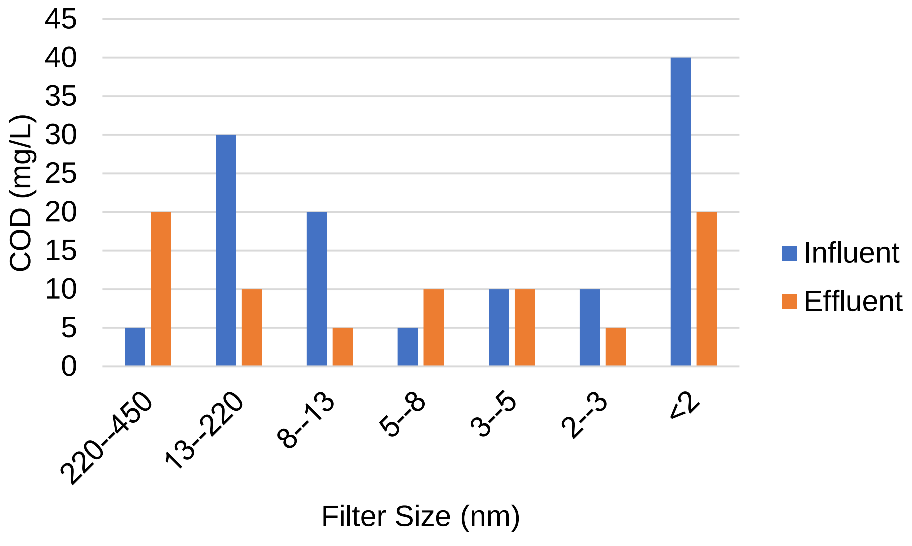


Figure 3.4 : Differential particle size distribution of domestic sewage.

Textile Wastewater

Characteristics of textile wastewater could be very different due to different type of excess processes. In this study, characteristics of textile wastewater obtained from a plant located in Istanbul and involves 20 different process operations include cotton or synthetic knit fabrics and dyeing processes. The conventional characterization resulted as total COD was 1.340 mg/L (C_{T0}) consisted of 965 mg/L soluble COD range of 72% (S_{T0}) and 375 mg/L particulate COD range of 28% (X_{T0}). According to respirometry results showed that readily biodegradable COD; 280 mg/L (S_{S0}), readily hydrolysable COD; 460 mg/L (S_{H0}) and slowly hydrolysable COD; 253 mg/L (X_{S0}). on the other hand, biodegradability experiments showed that the total soluble inert COD (S_{I1}) was 225 mg/L and only 5 mg/L (S_{IC1}) of it could captured by membrane and the total particulate inert COD was 15 mg/L. Therefore, 240 mg/L COD corresponds as 18% of total COD belongs to inert part. The PSD analysis of the study indicates that the soluble hydrolysable COD which have size threshold between 8-13 nm (S_{HC}) was 360 mg/L and the rest of total soluble hydrolysable COD as 10 mg/L can pass through the membrane due to lower size ranges.

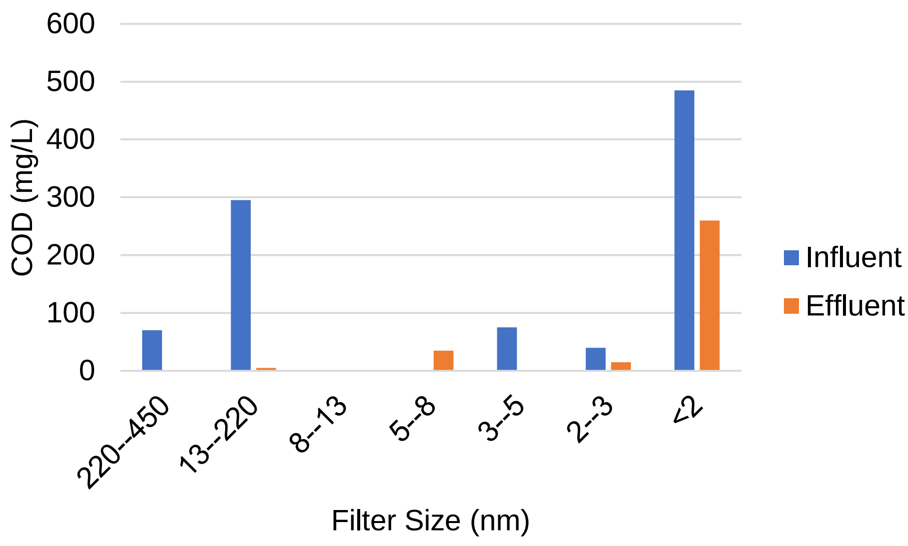


Figure 3.5 : Differential particle size distribution of textile wastewater.

Tannery Wastewater

Tannery wastewater has higher COD value comparing to domestic and textile wastewater. The sample was obtained from Istanbul Organized Leather Tanning Industrial District (Orhon et. al. 1999). According to related study, total COD was 2.284 mg/L with 1.297 mg/L soluble and 987 mg/L particulate part. Respirometry experiments resulted as the readily biodegradable COD was 434 mg/L, readily hydrolysable COD was 649 and slowly hydrolysable COD was 720 mg/L. Biodegradability characteristics of wastewater showed that 214 mg/L COD belongs to soluble inert and 267 mg/L particulate inert part. The hydrolysable soluble COD captured by membrane was 243 mg/L where there was no captured soluble inert COD. In Table pp, PSD results only given for influent stream of the wastewater due to no experiment had been done for effluent stream in related research.

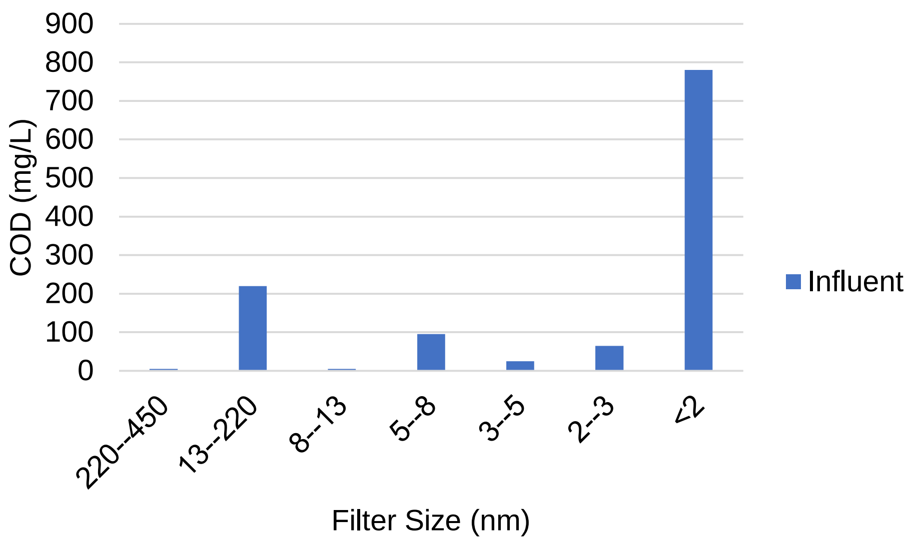


Figure 3.6 : Differential particle size distribution of tannery wastewater.

3.4 Kinetic and Stoichiometric Coefficients Selected for the Study

Kinetic and stoichiometric constants of domestic, textile, and tannery wastewaters were investigated from different resources. The most important point while deciding on the values of constants was the references that have used a dual hydrolysis mechanism. Dual hydrolysis kinetics in related studies listed in Table 3.6 with the values which were selected for the model of this study.

Table 3.6 : Kinetic and stoichiometric coefficients of different wastewaters.

Wastewater type	$\hat{\mu}_H$	K_S	b_H	Dual Hydrolysis k_{hS}	K_{hS}	k_{hX}	K_{hX}	References
Domestic								
	3,5	3	0,2	3,5	0,12	1,7	0,2	Tas et. al. 2009
	4,2	3	-	1,6	0,07	0,8	0,04	Orhon et. al. 2002
	3,5	6	0,2	3,8	0,2	1,9	0,18	Okutman et. al. 2001
	4	4	0,18	2,8	0,03	1,1	0,1	Hocaoğlu et. al. 2010
	-	-	0,24	3,1	0,2	1,2	0,5	Orhon et. al. 1998
Selected for model	4,2	3	0,2	2,96	0,12	1,34	0,20	
Textile								
	4,1	5	0,18	3	0,05	1	0,5	Babuna et. al. 1998
	5,3	5	0,14	3	0,05	1	0,2	Babuna et. al. 1998
	3,6	15	0,14	0,8	0,05	0,5	0,15	Babuna et. al. 1998
	-	-	-	2,5	0,4	0,1	0,5	Orhon et. al. 1998
	6	1	0,1	3,5	0,04	0,72	0,04	Yıldız et. al. 2008
Selected for model	3,6	15	0,14	2,45	0,09	0,68	0,28	
Tannery	1,8	12	0,08	1,8	0,01	1,7	0,05	Karahan et. al. 2008
	5,1	30-80	0,21	0,6	0,05	0,22	0,1	Munz et. al. 2008
	-	-	-	1,1	0,2	0,3	0,2	Orhon et. al. 1998
	2,1	30	0,15	0,4	0,2	0,28	0,1	Gorgun et. al. 2007
	2,1	30	0,19	0,63	0,2	0,35	0,1	Insel et. al. 2009
Selected for model	2,2	28	0,12	0,91	0,13	0,57	0,11	

3.4.1 Modelling approach

The model based on Activated Sludge System combined with a membrane module was run at different operational conditions based on different parameters; i.e. volume, recycled activated sludge, and sludge retention time. The results of the MASM and conventional ASM1models were compared for the same conditions. The influent flow rates of both two models were 10.000 m3/day. Conventional ASM has the same configuration with the MASM with the only difference of recycled sludge flow which is 10.000 m3/day for ASM1 and 40.000 m3/day for MASM. On the other hand, the influent parameters for MASM include the captured COD excluded from total COD.

The comparison of these two models mainly based on removal efficiency on hydrolyzable COD related to both volume and SRT parameters. Domestic and textile wastewaters run with SRT values as 0,3, 0,5, 1, 1,5, 2 days which can be considered as superfast, 3, 4 days as high rate, and 6 days conventional reactors. These SRT values were applied for both conventional and MBR models with the same and different volumes. Tannery wastewater has a higher COD load comparing to the first two wastewaters, therefore, the SRT values selected as 4, 8, 12, 15, 18 days.

4. RESULTS

4.1 Mass Balances for Hydrolyzation mechanism

The hydrolysis reactions of the models consider S_H, S_{HC}, X_S to S_S and X_{SS} to S_{HC} as demonstrated in Table 3.2. According to the table, mass balances S_{HE}, S_{HC} related to this study at steady state condition written as follows:

Mass balance for hydrolyzation of S_{HT1}:

$$QS_{HT1} - QS_{HE} + Vr_{SHT} = 0 \quad (4.1)$$

This expression is rearranged with equation 3.8 and since $S_{HE} \ll X_H$, S_{HE}/X_H can be ignored, remained k_h and K_X ratio is asummed as a constant, K_1:

$$S_{HT1} - S_{HE} - \Theta_H K_1 S_H = 0 \quad (4.2)$$

So, effluent S_{HE} can be written as:

$$S_{HE} = \frac{S_{HT1}}{1+\Theta_H K_1} \quad (4.3)$$

The behavior of S_{HC} in the system is just like the behavior of X_S because the membrane makes some of the soluble hydrolysable COD drive as particulate matter. Therefore, S_{HC} become a part of sludge and it can be shown as:

$$P_{SHC} = \frac{VS_{HC}}{\Theta_X} \quad (4.4)$$

According to information given above, the mass balance for hydrolyzation of S_{HC1}:

$$QS_{HC1} - \frac{VS_{HC}}{\Theta_X} + Vr_{SHC} = 0 \quad (4.5)$$

When the equation (3.8) is inserted to the equation 4.5, it becomes:

$$QS_{HC1} - P_{SHC} - V\left(k_h \frac{S_{HC}/X_H}{K_X+S_{HC}/X_H} X_H - k_{hX} \frac{X_{SS}/X_H}{K_{XX}+X_{SS}/X_H} X_H\right) = 0 \quad (4.6)$$

If a constant, K_2, is defined as the ratio of k_{hX} and K_{XX} and applied to the equation 4.5, the result is:

$$S_{HC1} - \frac{\Theta_H}{\Theta_X} S_{HC} - \Theta_H K_1 S_{HC} + \Theta_H K_2 X_{SS} = 0 \quad (4.7)$$

According to the equations above, both SHE and SHC are inversely proportional to HRT; when the hydraulic retention time increase, hydrolyzation increases, and therefore, the amount of S_{HE} decreases. Also, S_{HE} would be controlled by HRT where S_{HC} would be controlled by sludge retention time.

STEP 1

In this step, all conventional models run with MLSS values as 4.000 mg/L and for MBR 10.000 mg/L. Considering these values, the volumes for MASM were lower than the conventional ones as expected.

Firstly, the selected model conditions applied to domestic wastewater according to its characteristics and kinetic information were given in Table 3.5 and Table 3.6. In the selected domestic wastewater, the influent SH concentration constitutes 52% of total soluble COD which were 62 mg/L for ASM1 and 15 mg/L for MASM. This means there are some S_H components with high size ranges and captured by the membrane. This value was entered into the model according to the PSD study of Noyan (2017). The results were shown in Table 4.1.

When the models run with the operational conditions given in Table 4.1, the effluent SH concentrations resulted in a narrow range of 1,4-2 mg COD/L for both system configurations. If SH concentrations in the effluent are taken into account, the MASM gives better COD results on S_H.

For textile wastewater, the influent SHT1 concentration constitutes 48% of total soluble COD which were 460 mg COD/L and 360 mg COD/L of this SH, which was captured by the membrane. The S_{HE} decreased to 4 mg COD/L for ASM1 and 7 mg COD/L for MASM at 8 days of SRT.

Tannery wastewater with a high COD load has 649 mg COD/L SHT1 that equals 50% of total soluble COD according to the reference selected for this study. SRT values were selected as 4, 8, 12, 15, and 18 days to achieve wastewater treatment and at 18 days the model ends up with 10 mg COD/L SH for ASM1 and 40 mg COD/L S_H for MASM. The volume of the reactors at 18 days was 8.000 m3 for ASM1 and 3.500 m3 for MASM.

According to Step 1, two main observations were displayed based on ASM1 and MASM; (i) S_{HE} values of MASM system were lower than ASM1 under superfast (SF) conditions while SRT is below 2 days for domestic and textile wastewaters. Tannery wastewater has quite a high S_H load comparing those two wastewaters therefore minimum SRT value as 4 days were applied. In the results of the high rate (HR) and conventional operations, S_{HE} remained similar for two wastewaters: for HR operation around 3-5 mg/L for domestic and 13-20 mg/L for textile, for conventional operation 1-3 mg/L and 4-8 mg/L respectively. (ii) S_H removal rates were mostly lower for the MASM systems because it was calculated by excluded S_{HC1} fraction from initial S_{HT1}. The conditions of Step 1 are not proper for the treatment of tannery wastewater even high SRT levels were used; from 4 to 18 days. The outputs always display the usage of the MASM system has lower removal rates and require modification which was applied in Step 2.

Table 4.1 : S_H removal in ASM1 and MASM systems operated for different footprints (different SRTs).

Wastewaters	SRT (d)	ASM1			MASM		
		HRT (h)	S_{HE} (mg/L)	S_H removal (%)	HRT (h)	S_{HE} (mg/L)	S_H removal (%)
Domestic							
Superfast	0,3	0,7	60	3	0,2	14	6
	0,5	1,1	30	52	0,4	10	33
	1	2,2	15	76	0,7	8	53
	1,5	2,5	13	79	0,9	7	54
	2	3,2	9	85	1,4	5,5	67
High rate	3	4,3	5	92	1,7	4,6	73
	4	5,6	3,6	94	2,3	3,5	77
Conventional	6	8	2	97	3	2,6	83
	8	9,4	1,4	98	3,9	2	87
Textile							
Superfast	0,3	0,9	457	0,6	0,7	99	1
	0,5	2,2	212	54	0,85	54	46
	1	3,6	95	79	1,8	33	67
	1,5	5	56	88	2,2	29	71
	2	5,8	42	91	2,7	23	77
High rate	3	8,6	20	96	3,6	18	82
	4	10,8	13	97	4,7	13	87
Conventional	6	14,4	5,5	99	6,5	8	92
	8	16,6	4	99	7,2	7	93
Tannery							
High rate	4	18,7	83	87	6,5	152	77
Conventional	8	28,8	39	94	13	84	87
	12	42	19	97	18	59	90
Extended	15	47	15	98	22	48	93
	18	57,6	10	99	25	40	94

STEP 2

Activated sludge configurations adjusted to same HRT levels

Different than Step 1, in Step 2 the volumes of all models for conventional and MBR systems were accepted as the same, where the MLSS concentrations did not have any limitations. In other words, HRT values were kept the same for both models where the MLSS values of MASM were lower than the first step.

In this case, the models were compared according to volumes based on selected SRT values. The MLSS concentrations therefore approximately were the same for both model systems. According to Table 4.2, it is obvious that the effluent S_{HE} values belong to the MASM, are lower than the ASM1 system. However, the removal efficiency of MASM is higher only the 0,3 and 0,5 days SRT conditions while S_H removal ASM1 is higher for the high rate and conventional operating conditions.

Operational conditions of Step 2 set for textile wastewater again using the same SRT values in Table 4.1, but the reactor volumes are a bit higher than the domestic wastewater. The results are shown in Table 4.2 below. The textile wastewater gives better results under Step 2 conditions just like domestic wastewater. The concentration of SHE on MASM is higher than the ASM1 both at low and high HRT values.

According to the results of Step 2, (i) MASM system under superfast conditions resulted in lower S_{HE} concentrations for all wastewaters. For example, in Step 1, S_{HE} value of textile wastewater at SRT value of 1 day was 95 mg/L for ASM1 and 33 mg/L for MASM; in Step 2, the values are 95 mg/L and 18 mg/L respectively. (ii) Tannery wastewater has a great improvement in the results in Step 2 also. While the S_{HE} results of MASM at SRT 4 days in Step 1 was 152 mg/L, it degreases to 59 mg/L in Step 2. Besides, this value is more than 25% lower than 80 mg/L obtained in the system operation of ASM1. On the other hand, in Step 2, the performance of MASM is better than ASM1 at SRT as 4 days. However, when SRT increases, the performance of MBR getting decreases. This might be the result of the effect of components that are captured and accumulated in the bioreactor throughout the membrane.

Table 4.2 : S_H removal in ASM1 and MASM systems operated at the same HRT values.

Wastewaters	SRT (d)	HRT (h)	ASM1 S_{HE} (mg/L)	ASM1 S_H removal (%)	MASM S_{HE} (mg/L)	MASM S_H removal (%)
Domestic						
Superfast	0,3	0,4	60	3	14	7
	0,5	0,72	40	35	9	42
	1	1,44	25	61	6	60
	1,5	2,2	18	74	4,6	73
	2	2,9	13	81	3,4	77
High rate	3	4,4	8	87	2,2	85
	4	5	5,7	91	1,9	88
Conventional	6	6,5	4	94	1,4	91
	8	8,6	3	95	1	93
Textile						
Superfast	0,3	1,2	459	0,2	99	1
	0,5	2,4	197	57	27	73
	1	3,6	95	79	18	82
	1,5	4,3	68	85	15	85
	2	5	50	89	12	88
High rate	3	7,2	27	94	8	92
	4	10,8	11	98	5	95
Conventional	6	14,4	6,7	99	3,5	97
	8	17,3	3,6	99	3,2	97
Tannery						
High rate	4	19,4	80	88	59	86
Conventional	8	32,4	32	96	30	93
	12	43,2	18	98	20	96
Extended	15	50,4	13	98	15	97
	18	57,6	10	99	12	97

Superfast Activated Sludge Models

The most outstanding feature of Superfast Activated Sludge (SFAS) systems is that they have very low SRT values and their sludge separation mechanism based on membranes (Sözen et al., 2018). In this study, the SF system was applied for both ASM1 and MASM in Step 1 and Step 2 as shown in Table 4.1 and Table 4.2 only for domestic and textile wastewater, tannery wastewater has high COD load to apply superfast models. According to Step 1, there is almost no S_H removal both for domestic and textile wastewaters at HRT lower than 1 h which indicates SRT lower than 0,5 days. Besides, MASM at HRT between 1-3 h works much better than ASM1 for both Step 1 and 2 as a result of capturing S_{H1}, as S_{HC1}, accounted for the model MASM. In general, the SRT value of 2 days can be considered as a breaking point that achieves almost complete S_H removal in any case.

In Step 2 basically, HRT values were increased due to matching ASM1 and MASM systems based on volume and MLSS concentration. For the superfast systems point of view, HRT became a range between 0,4 to 2,9 h for domestic sewage and 1,2 to 5 h for textile wastewaters where SRT range still the same as Step 1. According to modeling results (i) even HRT values increased from 0,2 to 0,4 h for domestic and 0,7 to 1,2 h for textile wastewater, it did not affect the SHE concentration at SRT value of 0,3 d. At SRT 0,5 d, ASM1 is still staying as ineffective on SHE as a concentration of 40 mg/L while MASM stayed at a level lower than 10 mg/L for domestic wastewater because 47 mg/L influent SH was already captured by the membrane and returned to the reactor. The SRT levels between 0,5 and 2 d, again MASM work better and S_{HE} stayed 3,4 mg/L for domestic sewage and 12 mg/L for textile wastewater while the ratios of ASM1 are 13 mg/L and 50 mg/L for domestic and textile wastewaters respectively.

Additionally, the model evaluation was extended to better understand the effect on HRT on the removal of S_H. For this purpose, new runs based on the same SRTs as superfast conditions were applied while the HRT values from 1 h to 4 h were assessed for each SRT values as 0,3, 0,5, 1, 1,5, and 2 days. The results of MASM showed that S_{HE} concentration always remained below 10 mg/L for all runs of domestic wastewater and ASM1 results proved the decrease in S_{HE} with the increase of HRT. For example, at SRT 1 d, S_{HE} concentration was 28 mg/L for 1 h of HRT, and the concentration drops down to 7 mg/L when the HRT was increased to 4 h. For textile wastewater, similar results came up at a more visible scale because the wastewater has higher influent COD and therefore the HRT effect on S_{HE} seemed more apparent. For example, for conventional AS system at SRT 1 d, the S_{HE} concentration dropped from 240 mg/L to 81 mg/L when HRT increased from 1 h to 4 h. On the other hand, for the membrane system operated at SRT 1 d, the MASM model resulted in a decrease from

48 mg/L at HRT 1 h to 16 mg/L for HRT 4 h. These results indicate that the SH removal inversely proportional to HRT.

4.2 Effluent Quality

The effluent quality, based on COD fractionation, is another concern of this study. The results of each model ended up with its effluent quality that contains a small amount of S_S and S_H that could not be hydrolyzed. Also, the soluble inert COD, S_I that never goes under a reaction, and the produced endogenous products, S_P remain in the effluent. The particulate matter stays in the sludge as always. These actions are the same for both ASM1 and MASM. On the other hand, models with membrane separation also have the parameters; S_{HC}, S_{IC} as soluble, and X_{SS} as particulate matter, and these parts of COD could not be in the effluent stream due to action of the membrane and therefore they are present in the sludge part. The comparison of the effluent quality of wastewaters was based on the maximum SRT values that have been tested, and these are 8 days for domestic and textile where 18 days for tannery wastewater.

The results of the models belong to Step 1 shown in Table 4.3, 4.4, 4.5 for domestic, textile, and tannery wastewaters respectively. Effluent soluble COD of domestic wastewater, S_{TE}, was 27 mg/L for ASM1 where it decreased to 19,4 mg/L in MASM. However, this 30% drop could not be seen for other wastewaters where S_{TE} is 247 mg/L for textile and 294 mg/L for tannery wastewater. In addition to that, the effluent SH concentrations belong to membrane models even higher than conventional ones. The reason is clear due to Step 1 models run with lower reactor volumes for the MASM system than ASM1.

In Step 2, where the volumes of both ASM1 and MASM reactors are the same, results are very valuable. S_{TE} for domestic wastewater has a 35% reduction from 28 mg/L for the gravity settling model to 18 mg/L for the membrane model. This can be explained by the amount of soluble COD captured in the system. For textile and tannery wastewaters, the same reduction cannot be reached because almost all amount of soluble inert COD could pass through the membrane and appears in the effluent. On the other hand, S_{HE} concentrations are approximately the same for both ASM1 and MASM systems.

To sum up, different COD fractions affect the effluent quality under different operational conditions; especially soluble residual COD fractions, S_P, the influent soluble inert COD, S_{I1}. In the ASM1 system, inert COD will appear always in the effluent. Therefore, the MASM system is more favorable in this aspect. For example, while S_{IT} concentration of tannery wastewater is 214 mg/L will appear in the effluent of ASM1, in the MASM model, 45% of S_{IT} will be captured by the membrane and 118 mg/L will stay in the effluent. On the other hand, the effluent quality of ASM1 and MASM systems are approximately the same in Step 1 while this ratio changes in Step 2, and the S_{TE} concentrations of MASM resulted in 16% less COD concentration than ASM1 system due to better operational conditions.

Table 4.3 : Effluent COD fractionation of domestic sewage for different SRT and HRT values.

		ASM1								MASM						
		S_{S1}	S_{H1}	S_{I1}	S_{P}	S_{T1}	X_{T1}	C_{T1}		S_{S1}	S_{H1}	S_{I1}	S_{P}	S_{T1}	X_{T1}	C_{T1}
Influent COD (mg/L)		40	62	18	0	120	295	415		40	15	10	0	120	295	415
Effluent COD (mg/L)		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}	X_{TE}	C_{TE}		S_{SE}	S_{HE}	S_{IE}	S_{PE}		S_{TE}	
SRT (d)	HRT (h)								HRT (h)							
0,3	0,7	40	60	18	0	118	140	258	0,2	40	14	10	0		64	
0,5	1,1	2,6	30	18	0,4	51	70	121	0,4	4	10	10	0,5		25	
1	2,2	0,9	15	18	1,7	36	55	91	0,7	1,1	8	10	1,6		21	
1,5	2,5	0,8	13	18	2	34	55	89	0,9	0,8	7	10	2		20	
2	3,2	0,5	9	18	2,8	30	40	70	1,4	0,6	5,5	10	3		19	
3	4,3	0,4	5	18	3,8	27	40	67	1,7	0,4	4,6	10	3,8		19	
4	5,6	0,3	3,6	18	4,8	27	40	67	2,3	0,4	3,5	10	5		19	
6	8	0,3	2	18	6	26	40	66	3	0,4	2,6	10	6		19	
8	9,4	0,3	1,4	18	7	27	40	67	3,9	0,4	2	10	7		19	

Table 4.4 : Effluent COD fractionation of textile wastewater for different SRT and HRT values.

		ASM1								MASM						
		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}
Influent COD (mg/L)		280	460	225	0	965	375	1.340		280	460	225	0	965	375	1.340
		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}	X_{TE}	C_{TE}		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}		
SRT (d)	HRT (h)								HRT (h)							
0,3	1,2	278	457	225	0	960	140	1.100	0,7	280	99	220	0	599		
0,5	2,4	21	212	225	1,3	471	70	541	0,85	30	54	220	1,6	306		
1	3,6	4	95	225	3,4	327	55	382	1,8	4	33	135	5	177		
1,5	4,3	2,7	56	225	5	289	55	344	2,2	3,5	29	220	5,8	258		
2	5	1,9	42	225	7	276	40	316	2,7	2,4	23	135	8	168		
3	8,6	1,2	20	225	10	256	40	296	3,6	1,8	18	135	10	165		
4	10,8	0,9	13	225	13	252	40	292	4,7	1,4	13	135	13	162		
6	14,4	0,8	5,5	225	16	247	40	287	6,5	1	8	135	17	161		
8	16,6	0,8	4	225	19	249	40	289	7,2	1	7	135	19	162		

Table 4.5 : Effluent COD fractionation of tannery wastewater for different SRT and HRT values.

		ASM1								MASM						
		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}
Influent COD (mg/L)		434	649	214	0	1.297	987	2.284		434	406	214	0	1.297	987	2.284
Effluent COD (mg/L)		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}	X_{TE}	C_{TE}		S_{SE}	S_{HE}	S_{IE}	S_{PE}		S_{TE}	
SRT (d)	HRT (h)								HRT (h)							
4	18,7	4	83	214	17	318	140	458	6,5	6	152	214	14		386	
8	28,8	2	39	214	25	280	70	350	13	3	84	214	26		327	
12	42	1,1	19	214	33	267	55	322	18	2,5	59	214	32		308	
15	47	1	15	214	35	265	40	305	22	2	48	214	35		299	
18	57,6	0,7	10	214	38	262	40	302	25	2	40	214	38		294	

STEP 2

Table 4.6 : Effluent COD fractionation of domestic sewage for different SRT and same HRT values.

		ASM1							MASM						
		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}	S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}
Influent COD (mg/L)		40	62	18	0	120	295	415	40	62	18	0	120	295	415
Effluent COD (mg/L)		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}	X_{TE}	C_{TE}	S_{SE}	S_{HE}	S_{IE}	S_{PE}		S_{TE}	
SRT (d)	HRT (h)														
0,3	0,4	39	60	18	0	117	140	257	40	14	10	0		64	
0,5	0,7	2,8	40	18	0,2	61	70	131	4,6	9	10	0,4		24	
1	1,4	1	25	18	0,9	45	55	100	1,3	6	10	1,3		19	
1,5	2,2	0,7	18	18	1,9	39	55	94	0,8	4,6	10	2		17	
2	2,9	0,6	13	18	2,6	34	40	74	0,6	3,6	10	2,7		16	
3	4,4	0,4	8	18	3,7	30	40	70	0,4	2,4	10	3,9		16	
4	5	0,3	5,7	18	4,7	29	40	69	0,4	2	10	4,8		17	
6	6,5	0,3	4	18	6	28	40	68	0,4	1,5	10	6		18	
8	8,6	0,3	3	18	7	28	40	68	0,4	1	10	7		18	

Table 4.7 : Effluent COD fractionation of textile wastewater for different SRT and same HRT values.

		ASM1							MASM						
		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}	S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}
Influent COD (mg/L)		280	460	225	0	965	375	1.340	280	460	225	0	965	375	1.340
Effluent COD (mg/L)		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}	X_{TE}	C_{TE}	S_{SE}	S_{HE}	S_{IE}	S_{PE}		S_{TE}	
SRT (d)	HRT (h)														
0,3	1,2	279	459	225	0	963	140	1.103	280	99	220	0		599	
0,5	2,4	18	197	225	1,4	441	70	511	30	29	220	1,7		281	
1	3,6	4	95	225	3,4	327	55	382	5,5	19	220	4		249	
1,5	4,3	3	68	225	5	301	55	356	3,6	15	220	5,6		244	
2	5	2	50	225	7	284	40	324	2,5	13	220	7,5		243	
3	7,2	1	27	225	10	263	40	303	1,7	8	220	10		240	
4	10,8	0,8	11	225	13	250	40	290	1,2	4,6	220	13		239	
6	14,4	0,7	6,7	225	16	248	40	288	0,9	2,9	220	16		239	
8	17,3	0,5	3,6	225	19	248	40	288	0,8	2	220	19		241	

Table 4.8 : Effluent COD fractionation of tannery wastewater for different SRT and HRT values.

		ASM1							MASM						
		S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}	S_{S1}	S_{H1}	S_{I1}	S_P	S_{T1}	X_{T1}	C_{T1}
Influent COD (mg/L)		434	649	214	0	1.297	987	2.284	434	649	214	0	1.297	987	2.284
Effluent COD (mg/L)		S_{SE}	S_{HE}	S_{IE}	S_{PE}	S_{TE}	X_{TE}	C_{TE}	S_{SE}	S_{HE}	S_{IE}	S_{PE}		S_{TE}	
SRT (d)	HRT (h)														
4	19,4	4	80	214	16	314	140	454	4	59	214	17		294	
8	32,4	2	32	214	26	274	70	344	2,6	30	214	26		273	
12	43,2	1	18	214	33	266	55	321	2	20	214	32		268	
15	50,4	1	13	214	36	264	40	304	1,6	15	214	36		267	
18	57,6	0,7	10	214	38	263	40	303	1	12	214	38		265	

5. CONCLUSION AND RECOMMENDATIONS

This thesis aims to understand the behavior of model components, especially S_H, inside the reactor and also effluent under different operational conditions. The study has been set up on model-based evaluation where the standard ASM1 model modified through SUMO software for related operations. It is also important to say that three wastewater types were investigated from a low COD level to strength due to making valuable comparisons.

The basic ASM models based on a single size threshold of 450 nm which seperates soluble and particulate ones components in the wastewater. This system describes the COD fractions according to biodegredation characteristics regardless of any relation with particle size. The system assumes the remained soluble components will showe up in effluent and entire prticulate matter will stay in the bioreactor. This modeling process is not suitable for AS systems work with membrane and therefore needs a new sort of modeling where the size threshold decreased according to the filtration size of the membrane. In this study, the filtration size of 8-13 nm was considered as suitable for this new model based on recent related studies. This alteration mainly effects the soluble COD fractions as S_{HC1} and S_{IC1} which are captured by membrane and rest of hydrolyzable COD, S_H and inert COD, S_I which will appear in the effluent. This point gives the main novelty of this study and describes the proposed model as MASM and demonstrates the inadequency of ASM for applications on MBRs.

The new model structure created by MASM is necessary because (i) total soluble COD, S_{T1} contains S_{H1} as major fraction for many wastewaters. For instance, S_{H1} fraction covers 48 to 52% of total soluble COD for domestic, textile and tannery wastewater that were evaluated in this study. (ii) The S_{H1} should be classified as S_{HC1} that cover 76%, 78% and 37% of S_{H1} for domestic, textile and tannery wastewaters repectively. This range is considerably high comparing other COD fractions and therefore may cause incorrect evaluations if not considered in the model. (iii) This approach is also correct for S_{IC1}, the captured part of S_{I1} which is quite important fraction especially for effluent quality mostly for the conventional systems where the inert COD never goes under biodegredation reaction.

MASM system also pays attention the reactor volume because it determines the HRT level which directly effects the removal of S_H. For this reason, a compromise must be taken into account between preferable system performance and smaller footprint mainly for high rate MAS systems.

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