ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

MODEL BASED EVALUATION OF BIOGAS PRODUCTION POTENTIAL OF FULL SCALE WASTEWATER TREATMENT PLANT OPERATED UNDER LOW SLUDGE RETENTION TIME

M.Sc. THESIS

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501091817

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Thesis Advisor: Assoc. Prof. H.Güçlü İNSEL

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

DÜŞÜK ÇAMUR YAŞI İLE İŞLETİLEN TAM ÖLÇEKLİ ATIKSU ARITMA TESİSLERİNDE BİYOGAZ OLUŞUM POTANSİYELİNİN MODEL BAZLI İNCELENMESİ

YÜKSEK LİSANS TEZİ

Dilvin YILDIZ
(501091817)

Çevre Mühendisliği Anabilim Dalı

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Tez Danışmanı: Doç. Dr. H. Güçlü İnsel

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Dilvin Yildiz, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID 501091817, successfully defended the **thesis** entitled "**MODEL BASED EVALUATION OF BIOGAS PRODUCTION POTENTIAL OF FULL SCALE WASTEWATER TREATMENT PLANT OPERATED UNDER LOW SLUDGE RETENTION TIME**" which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assoc. Prof. H.Güçlü İNSEL** ....
İstanbul Technical University

Jury Members : **Prof. Dr. Bülent KESKİNLER** ....
Gebze Institute of Technology

Assoc. Prof. Didem OKUTMAN TAŞ ....
Istanbul Technical University

Date of Submission : 04 May 2012
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To my husband Ahmet YILDIZ ,

FOREWORD

I would like to express my deep appreciation to my advisor Assoc.Prof. Dr. H.Guclu Insel. Under his supervision, I always felt confident about how I should find the right answer to the problems that I faced to; and his ingenious personality helps me to learn how to be organized during my thesis. I would like to thank, with all my love, to my husband Ahmet YILDIZ for his strong support and patience during my MsC study. I thank all my profesors, collegues and researchers which are the staff of Istanbul Technical University, Environmental Engineering department. Especially thank to Assoc. Prof. Dr. Osman Atilla ARIKAN for sharing his knowledge with me. I thank Ankara Water and Sewage Admisnistration (ASKI) and Bel-ka A.S. for sharing extensive wastewater treatment plant information and operational data of wastewater treatment plant and especially to Cemalettin GIZLICE for his guidance about the wastewater treatment plant. In addition, I would like to thank to my father Ruhi CETINBAG, my mother Adviye CETINBAG, my sister Dilara CETINBAG, my friends Asli GOKCORA, Neyran GUNUCER, Basak ODER, Senem BASARAN, Gokce KOR, Dora OLCAY, Gulten YUKSEK for their help and support during my MsC study.

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Dilvin YILDIZ
Geology Engineer

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ABBREVIATIONS

ACWTP : Ankara Central Wastewater Treatment Plant
AD : Anaerobic digestion
AOB : Ammonia oxidizing bacteria
ASP : Activated Sludge Process
AnT : Anaerobic Tank
AnoT : Anoxic Tank
ASM : Activated Sludge Model
AT : Aerobic Tank
BEPR : Biological Enhanced Phosphorus Removal
BNR : Biological Nutrient Removal
BOD_5 : Biological Oxygen Demand for 5 days
CFI : Circulating Fluidized Bed Incinerator
CHP : Combined Heat and Power
COD : Chemical Oxygen Demand
CS : Conventional Activated Sludge System
DO : Dissolved Oxygen
DP : Drying Process
DST : Digested Sludge Thickener
DWW : Domestic Wastewater
EPA : Environmental Protection Agency
FBI : Fluidized Bed Incinerator
FC : Final Clarifier
GASM : General Model of Activated Sludge
GHGs : Green House Gases
HRT : Hydraulic Retention Time
IAWPRC : International Association on Water Pollution Research and Control
IPCC : Intergovernmental Panel on Climate Change
IS : Incineration System
LP : Low –pressure
MLSS : Mixed Liquor Suspended Solid
MLVSS : Mixed Liquor Volatile Suspended Solid
NOB : Nitrite oxidizing bacteria
OECD : Organization for Economic Co-Operation and Development
OF : Other Facilities
OLR : Organic Loading Rate
OTR : Oxygen Transfer Rate
PAOs : Phosphorus Accumulating Organisms
PC : Primary Clarifier
PHA : Poly Hydroxy Alkonate
PHB : Poly Hydroxy Butyrate
POM : Poly-cyclic Organic Matter
PT : Primary treatment

RST : Raw Sludge Thickener
SR : Sludge Recycling
SRT : Solid Retention Time
SS : Suspended Solid
ST : Sludge Treatment
SVI : Sludge Volume Index
TKN : Total Kjeldahl Nitrogen
TN : Total Nitrogen
TP : Total Phosphorous
TSS : Total Suspended Solid
VFA : Volatile Fatty Acids
VFD : Variable Frequency Drives
VOC$_S$:Volatile Organic Carbons
VSS : Volatile Suspended Solids
WEF : Water Environment Federation
WERF : Water Environment Research Foundation
WW : Wastewater
WWTP : Wastewater Treatment Plant

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MODEL BASED EVALUATION OF BIOGAS PRODUCTION POTENTIAL OF FULL SCALE WASTEWATER TREATMENT PLANT OPERATED UNDER LOW SLUDGE RETENTION TIME

SUMMARY

In the last decade, energy became a major concern for modern society due to its dependence on non-renewable energy sources such as fossil fuels of which negative environmental impacts are evident. In this case, increasing meaning of renewable energy sources like biomass energy cannot be rejected. The considerable biomass sources are known to be the feed stocks, manure and sludge generated from municipal wastewater treatment facilities. Aside from having high potential of biomass (sludge) generation, wastewater treatment plants account the considerable part of consumed energy.

The electrical energy required for the treatment of municipal wastewater per capital is given in the range of 20-50 kWh/ca.year depending upon the size and treatment technologies. The sludge can be regarded as an energy source for the wastewater treatment plants by using anaerobic digester technologies and/or thermo-chemical processes like incineration. Hence, the process selection and control of energy utilization in wastewater treatment plants may lead energy self-sufficient plants. Recently, modelling tools enable to test operational scenarios for process optimization and cost minimization for wastewater treatment plants.

The relevant approach for achieving to maintain energy efficient operation in wastewater treatment plants with the existence of different plant loads and to fix the effluent restrictions can be the model based evaluation approach. In this study, the effluent quality, biomass generation and biogas generation potential was simulated for the largest wastewater treatment plant in Turkey using general activated sludge model. The plant was designed only for organic carbon removal. Possible scenarios were built in order to analyze additional nitrogen removal effects on the system energy, and how incineration system effect the energy efficiency in wastewater treatment plants.

The results were evaluated by making electrical and heat energy balances over the wastewater treatment plant under study. As a conclusion of the evaluation, nutrient removal increase the energy consumption approximetely 36% due to additional oxygen demand and mixing energy needs of the new units. Furthermore changing the aeration process as the biggest energy consumer in conventional wastewater treatment plants from mechanical surface aeration to fine bubbled diffusion system decreases 30% the total energy consumption of the upgraded-wastewater treatment plant. Incineration system as alternative energy source rises the energy recovery for both organic carbon removal system and nitrogen removal system.

DÜŞÜK ÇAMUR YAŞI İLE İŞLETİLEN TAM ÖLÇEKLİ ATIKSU ARITMA TESİSLERİNDE BİYOGAZ OLUŞUM POTANSİYELİNİN MODEL BAZLI İNCELENMESİ

ÖZET

Son on yılda, olumsuz çevresel etkileri kanıtlanmış olan yenilenebilir olmayan enerji kaynaklarının (fosil yakıtlar) tükenmesi ve yeni enerji kaynaklarına olan ihtiyaç, modern toplumun enerji konusuna olan ilgisini arttırmıştır. Fosil yakıtların dünya genelinde kullanım yüzdesi yaklaşık olarak yüzde 85 (IPCC, 2011) gibi bir rakama denk gelmektedir. Yenilenemeyen enerji kaynaklarının limitli olması ve ekonomik değerlerinin günden güne artması nedeniyle yenilenebilir enerji kaynakları global enerji otoritelerinin odak noktası haline gelmiştir. Biyokütle yenilenebilir enerji kaynakları arasında en geniş orana sahiptir (IPCC,2011).

Bu durumda biyokatı gibi yenilenebilir enerji kaynaklarının artan önemi reddedilemez bir hal almaktadır. Günümüzde önemli biyokatı kaynakları ,gübre ve belediye atıksularından elde edilen çamur olarak bilinmektedir. Atık su arıtma tesisleri bir yanda yüksek miktarda çamur üretme potansiyeline sahipken diğer yandan enerji tüketimleri oldukça fazladır. Önceki çalışmalarda belediye atıksu arıtma tesisleri için gerekli olan kapital başına enerji aralığı arıtma tesisinin büyüklüğüne ve yürüttüğü arıtma teknolojisine bağlı olaraktan 20-50 kWh/ca.year olarak bulunmuştur.

Anaerobic özümleme ve/veya termo-kimyasal yakma prosesleri, atıksu arıtma tesislerinde çamurdan enerji elde etmek için uygulanan işlemlerdir. Çamur atıksu arıtma tesisleri için önemli bir enerji kaynağıdır. Dolayısıyla atıksu arıtma tesislerinde tasarım aşamasında arıtma yöntemi seçimi ve uygulama aşamasında enerji kullanımının kontrol edilmesi enerji açısından verimli atıksu arıtma tesislerinin var olmasını sağlayacaktır.

Atıksu arıtma tesislerinde harcanan enerjinin çoğunluğunu havalandirma sistemlerinde harcanan enerji temsil etmektedir. Havalandırma sistemlerinin enerji kullanımını etkileyen başlıca faktörler oksijen transfer hızı, çözünmüş oksijen miktarı ve havalandırıcılardır. Eğer oksijen seviyesi dşürülürse, havalandırma hızıda düşecektir. Düşük havalandırma hızı gereksiz enerji sarfiyatını engeller. Bunun yanında en önemli faktör hangi tip havalandırıcıların kullanıldığıdır. Genel olarak havalandırıcılar mekanik ve difüzör tipli olarak ikiye ayrılır. En çok kullanılan mekanik tip havalandırıcı yüzeysel havalandırmadır, yaklaşık olarak kWh enerji başına 1.40-1.45 kg oksijen sağlar. Difüzör tipli havalandırıcılar kalın ve ince difüzörlü sistemler olarak ikiye ayrılırlar. Bu sistemlerden ince difüzörlü olanalar kWh enerji başına 2.00- 3.00 kg oksijen sağlarlar. Sözkonusu havalandırıcı tipleri arasında en verimli olanı ince diffüzörlü olanıdır. Atıksu arıtma tesislerinde enerji elde edimi için anaerobik özümleme tankları ve yakma sistemi kullanılmaktadır.

Anaerobik tanklarında anaerobik özümleme prosesi sonucunda biyogaz elde edilir. Elde edilen biyogaz ortalama bir değer verirsek % 55-70 metan, % 30-35 karbondioksit ve diğer gaz formlarından oluşmaktadır (WEF, 2009). Biyogazın tipik enerji içeriği 6.2 ile 6.6 kWh/m^3 arasında değişmektedir (OECD, 2004). Biyogaz elde edimi çamurun içerisindeki organik madde miktarına bağlıdır, bu sebepten çamur organik madde açısından ne kadar zengin ise biyogaz elde edim verimi de o kadar iyi olmaktadır. Çamur miktarı biyogaz üretimini arttıran bir diğer faktördür. Bu sebeple tesiste çamur miktarını arttırmak için ön çökeltme tankı kullanılabilir. Ayrıca düşük çamur yaşı ile işletilen tesislerde çamur miktarının fazla olması biyogaz üretimini olumlu etkileyen faktörlerden biridir.

Atıksu arıtma tesislerinde enerji elde edimi için kullanılan diğer bir yöntem yakma prosesidir. Yakma prosesinde çamurun organik içeriğini temsil eden uçucu askıda katı madde (UAKM) parametesi yakıt olarak kullanılır, ve çamurun ısıl değerini temsil eder. Çamurun kalorifik değerini içerisindeki su miktarının azaltılması ile mümkndür. Çamurun içerisinden suyu uzaklaştırabilmek için iki temel yöntem vardır. Bunlar susuzlaştırma ve kurutmadır. Susuzlaştırma yöntemi ile anaerobik özümlemeden çıkan çamurun su yüzdesi % 70-75 (WEF, 2009b) civarına getirilebilir. Kurutma prosesi ise bu oranı suyu buharlaştırarak % 5-10 civarına çekebilir. Susuzlaştırma ve kurutma proseslerinden geçen çamurun yakılması ile birlikte yaklaşık olarak % 60-65 ısı enerjisi ve % 20-25 elektrik enerjisi elde edilebilir (Worldbank, 1999).

Son zamanlarda, atıksu arıtma tesislerinde uygulanan metodların optimizasyonuna ve maliyetlerinin düşürülmesine tasarlanan işletme senaryolarını modelleme araçları ile test etmek mümkün hale gelmiştir. Model bazlı inceleme yaklaşımı farklı tesis yüklerinde çıkış suyu standartlarını tutturarak atıksu arıtma tesislerinde sürdürülebilir bir enerji döngüsünü yakalayabilmek için en uygun yaklaşımdır.

Bu çalışmada, genel aktif çamur modeli kullanılarak Türkiye'nin en büyük atıksu arıtma tesisinin çıkış suyu kalitesi, biyokütle üretimi ve biyogaz üretim potansiyeli simulasyonu yapılmıştır. Model bazlı yaklaşımın kullanılması gerçek bir tesisin çalışma performansının içerisine girip mümkün olabilecek senaryoları değerlendirme imkanı sunmaktadır (İnsel, 2004).

İnceleme yapılan atıksu arıtma tesisi sadece organik karbon giderimi için tasarlanmış olup azot giderimi dahilinde sistem enerjisi üzerinde oluşacak değişiklikler incelenmiştir. Ayrıca teorik olarak belirlenen değerlerle tasarlanan çamur yakma sisteminin hem organik karbon gideren sistemde hemde organik karbon ve azotu birlikte gideren sistemde enerji geri kazanımı nasıl etkilediğine bakılmıştır. Bu yaklaşımların tümü mümkün olabilecek dört senaryo altında incelenmiştir.

İlk olarak atıksu arıtma tesisinden enerji kullanımı ve üretimine, genel işletme parametrelerine ve fizikel özelliklerine dayalı veri alınmıştır. Alınan veriler değerlendirilip mevcut sistemin enerji dengesi kurularaktan Case 1.a olarak adlandırılmıştır. Ayrıca mevcut sistemin kütle dengesi kurulduktan sonra, konfigürasyonu seçilen yazılıma adapte edilmiştir. Seçilen model gerçek verilerle uyumlu olacak şekilde kalibre edilmiştir. Kalibrasyondan sonra elde edilen simulasyon sonuçları gerçek verilerle karşılaştırılıp onaylanmıştır. İkinci aşamada sistem hem karbon hemde nütriyent giderimi yapacak şekilde tasarlanmış ve yazılıma uygun bir konfigürasyon seçerek yerleştirilmiştir.

Biyolojik nütriyent giderimi için uygulanan simulasyondan elde edilen veriler ile Case 2.a adı altında yeni bir enerji dengesi kurulmuştur. Üçünc aşama olaraktan her iki sisteme de yakma ve kurutma proseslerinin eklendiği varsayılmıştır. Yakma ve kurutma prosesleri için gerekli kabuller ve hesaplamalar yapıldıktan sonra, Case 1.b ve Case 2.b adı altında enerji dengeleri kurulmuştur. Enerji dengeleri atıksu arıtma tesisinin elektrik ve isi enerji dengeleri olaraktan ayrı ayrı değerlendirilmiştir.

Değerlendirmenin sonucunda organik karbon ve azotu birlikte gideren sistemdeki enerji tüketiminin artan oksijen ihtiyacı ve eklenen birimlerin karıştırma ihtiyacına bağlı olaraktan sadece organik karbon gideren sistemdeki enerji tüketiminden 36% fazla olduğu bulunmuştur.

İlaveten önceki çalışmalarda bahsedildiği gibi konvansiyonel atıksu arıtma tesislerinin en çok enerji harcayan birimi olan havalandırma sistemlerinde yapılan iyileştirmenin tesisin elektrik enerjisi kullanımını azalttiği görülmüştür. Bu sebepten dolayı mevcut sistemde bulunan mekanik yüzey havalandırıcıları yerine, daha fazla oksijen ihtiyacı olan organik karbon ve azot giderimli sistemde ince difüzörlü havalandırıcılar kullanılmıştır. İnce difüzörlü havalandırmanın organik karbon ve azot gideren sistemin enerji ihtiyacını 30% azalttığı görülmüştür.

Biyogaz oluşumunda sadece karbon gideren konvansiyonel sistemin hem nütriyent hemde karbon gideren biyolojik arıtma sistemine oranla daha fazla çamur üretmesinden dolayı biyogaz üretiminin fazla olduğu görülmüştür. Çamur üretiminin fazla olması her iki sistemde de ön çökeltme tankı bulunduğundan dolayı düşük çamur yaşına bağlı olarak gelişmiştir. Nutriyent gideren sistemin çamur yaşının konvansiyonel sistemin yaklaşık 4-5 katı olmasından dolayı çamur üretimi de azdır.

Elde edilen elektrik enerjisinin Case 1.a ve Case 2.a da tesisin enerji ihtiyacını %100 olarak karşılamadığı ve bunun yanısıra Case 1.b ve Case 2.b de elde edilen elektrik enerjisinin tesisin ihtiyacınında yukarısına çıktığı gözlemlenmiştir.

Elde edilen ısı enerjisi tüm senaryolarda ihtiyacın üzerinde olarak bulunmuştur, fazla ısı enerjisi çevrede bulunan konutların ısınmasını karşılayabilecek kapasitedir.

Bununla birlikte çamur yakma sistemi her iki sistemin enerjisinin geri kazanımı açısından değerlendirilmiştir. Yapılan değerlendirme olumlu bir sonuç vermiş ve her iki tesisinde enerji geri kazanımını 60% oranında arttırmıştır.

Sonuç olarak konvansiyonel atıksu arıtma tesislerini biyolojik nütrient giderimi yapan tesislere dönüştürmek enerji üretim kapasitesini düşürüken enerji ihtiyacını fazlalaştırmaktadır. Eğer tesisin enerji harcaması enerj açısından verimli ekipmanlar kullanarak düşürülmezse ve enerji kazanımı için yakma prosesi gibi ek prosesler eklenmez ise, bu durum tesisin enerji verimliliğini olumsuz etkileyecektir. Yakma sisteminin tesise eklenmesi ile olumsuz olan bu durumun tesisin ihtiyacından fazla enerji elde etmesiyle olumlu bir hale çevrilebilmesi mümkündür.

1. INTRODUCTION

1.1 Aim of The Thesis

Today, natural water resources are in danger due to increasing pollution, they need to be strictly protected. Wastewater treatment plants (WWTPs) are important to meet discharge standards in order to avoid eutrophication problems in natural water bodies. The discharge standards are enforced by “Water Pollution Control Regulations” in Turkey. Eutrophication problem occurs due to discharge nutrients (nitrogen and phosphorus) to receiving water bodies. For this reason, nitrogen and phosphorus removal with organic carbon removal is so important in WWTPs. On the other hand, our world is in straits regarding the energy, and the wastewater treatment plants, which are necessary to preserve the natural water resources, consume a noticeably high amount of energy. The main goal of this study is to evaluate energy balance of full scale wastewater treatment plant operated under low sludge retention time with different possible scenarios. The scenarios are based on the conventional system, which has only carbon removal process, and biological nutrient removal system. Energy consumption and production potentials of the two system were evaluated.

Many studies are currently being undertaken in an effort to render the wastewater treatment plants energy efficient. These studies are mainly directed towards the use of the efficient equipment and the systems capable of generating their own energy. For instance, from the point of view of energy consumption, the highest amount of energy is spent in the aeration tanks in the conventional wastewater treatment plants. The studies of improvement carried out on the issues like the assessment of the energy efficiency of the aeration units and the control of the oxygen levels will enable the total energy consumed in a plant to be reduced. Another approach towards the energy efficient plants involves obtaining the electricity and heat energy from the produced sludge, by way of anaerobic digestion and/or incineration technology. For this purpose, the amount of sludge and the calorific value of the sludge are important.

For an efficient energy production, the amount of sludge entering the digestion phase should be at reasonable levels capable of producing biogas. The methane content of the biogas represents the quality of the biogas, because it also determines the energy level to be obtained. Likewise, the calorific value of the sludge becomes important in the incineration process. The higher the calorific value, the higher the amount of energy that will be obtained. Therefore, implementation of the drying process prior to the incineration process will reduce the water content and increase the calorific value of the sludge once the same exits the dewatering step and will lead to the recovery of a higher amount of energy.

When the energy consumptions of a system that removes organic carbon and another system that removes organic carbon and also nitrogen are compared, it is observed that the system for the removal of both the organic carbon and nitrogen has a higher energy demand. The main reasons for this excess demand are the addition of the systems with the ability of anaerobic and nitrification-denitrification to the plant and the increase in the oxygen demand necessary for the removal of both carbon and the nutrient. Here, the difference caused by the aeration is at a considerable level. As a result, the selection of an energy efficient aerator for the aeration process will provide a reduction in the total energy consumption. Thus, although an examination of the total energies consumed for the system that removes only carbon and for the system that removes both nitrogen and carbon reveals that the system for the removal of nitrogen and carbon together has a higher energy requirement, the energy consumption significantly reduced owing to the efficient aerator will be at such an extent to eliminate the difference between the two systems.

Another issue from the point of view of energy production is that the sludge amount produced is reduced with an increase in the sludge age in the denitrification and this decreases the amount of biogas produced in anaerobic digestion. As a result, the amount of energy obtained from the anaerobic digestion will also decrease.

The approach of simulation is quite suitable for an assessment performed with the data obtained from a full scale wastewater treatment plant at different system configurations. By means of modeling simulation, it is possible to clearly determine the amounts of sludge production, effluent concentrations and obtained biogas amounts that vary according to the changing conditions.

1.2 Scope of The Thesis

This thesis composed of five chapters including conclusions and future works. General scope and content of each chapter is summarized as follows:

Chapter 1: *Introduction*

WWTPs are important to meet discharge standards in order to avoid eutrophication problems in natural water bodies. On the other hand, our world is in straits regarding the energy, and the wastewater treatment plants, which are necessary to preserve the natural water resources, consume a noticeably high amount of energy. For this reason, many studies are currently being undertaken in an effort to render the wastewater treatment plants energy efficient.

Chapter 2: *Literature review*

Increasing meaning of renewable energy sources like biomass energy cannot be rejected. The considerable biomass sources are known to be the feed stocks, manure and sludge generated from municipal wastewater treatment facilities. Aside from having high potential of biomass (sludge) generation, wastewater treatment plants account the considerable part of consumed energy. Hence, the process selection and control of energy utilization in wastewater treatment plants may lead energy self-sufficient plants.

Chapter 3: *Material and method*

The relevant approach for achieving to maintain energy efficient operation in wastewater treatment plants with the existence of different plant loads and to fix the effluent restrictions can be the model based evaluation approach. In this study, the effluent quality, biomass generation and biogas generation potential was simulated for the largest wastewater treatment plant in Turkey using general activated sludge model. The plant was designed only for organic carbon removal. Possible scenarios were built in order to analyze additional nutrient removal effects on the system energy, and how incineration system (IS) effect the energy efficiency in wastewater treatment plants.

Chapter 4: *Results and discussion*

The results were evaluated by making electrical and heat energy balances over the wastewater treatment plant under study.

Chapter 5: *Conclusion*

As a conclusion of the evaluation, nitrogen removal increase the energy consumption approximetely 36% due to additional oxygen demand and mixing energy needs of the new units. Furthermore changing the aeration process as the biggest energy consumer in conventional wastewater treatment plants from mechanical surface aeration to fine bubble diffusion system decreases 30% the total energy consumption of the upgraded-wastewater treatment plant. Incineration system as alternative energy source rises the energy recovery for both organic carbon removal system and nutrient removal system.

2. LITERATURE REVIEW

2.1 Energy and Environment

In the last decade, energy has become a major concern for the modern society due to its dependence on non-renewable energy sources such as fossil fuels (coal, natural gas and oil) with proven negative environmental impacts (IPCC, 2011). Depletion of existing non-renewable energy sources along with the socio-economic problems; and even more increasing effects of non-renewable sources on global climate change can be considered as examples for significant negative environmental impacts of non-renewable energy sources. Thus, the world environmental authorities have turned their interest to alternative energy sources. In any case, increased importance of renewable energy sources as hydro, geothermal, ocean thermal, wave, wind, solar and biomass energy cannot be rejected.

85-90% consumption of world energy is represented by fossil fuels (Cornea and Dima, 2010; IPCC, 2011). Renewable energy sources take part of around 13% of the chart involved (Figure 2. 1). According to the research of Intergovernmental panel on climate change (IPCC), (2011), it is clearly seen that the biomass has a big part among renewable energy sources (Figure 2.2). Solar 0.1%, hydro-power 2.3%, geothermal 0.1% and wind energy 0.2% are other highlighted sources of renewable energy. On the other hand, it is important to emphasize that the percentage relating with the renewable energy sources are varied according to the country and region (IPCC, 2011). Energy consumption rates according to the sources are distributed as 18% oil, 27% coal, 23% natural gas, 7.5% renewable energy sources in Turkey (Soydan, 2009). The estimated capacity of the potential biomass energy of Turkey is 135 Mtoe (million ton of oil equivalent), while 65 Mtoe is technically and economically possible and 7.9 Mtoe is the used quantity (Acaroglu and Aydogan, 2012). Hence the capacity of different renewable energy sources of Turkey is listed in Table 2.1. Furthermore, Turkey's recoverable biomass energy potential is reported as 1,300 Ktoe for municipal wastes and human extra (kilo tones of oil equivalent) (Gokcol *et al.,* 2009; Kaygusuz and Aydogan, 2002).

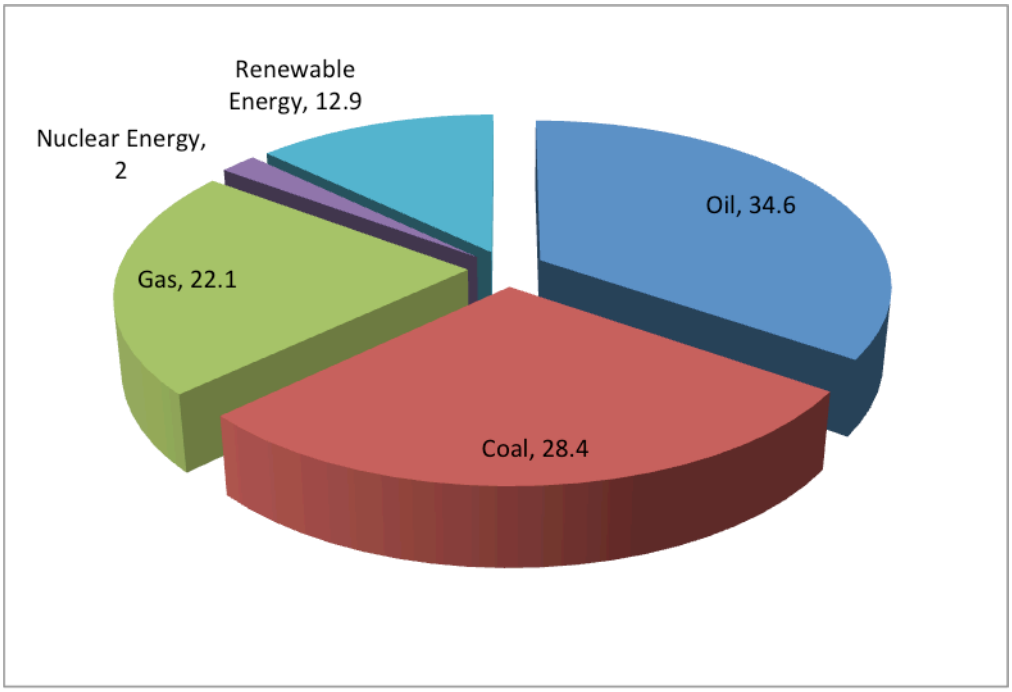

Figure 2. 1 : Global energy sources in 2008 adapted from (IPCC, 2011).

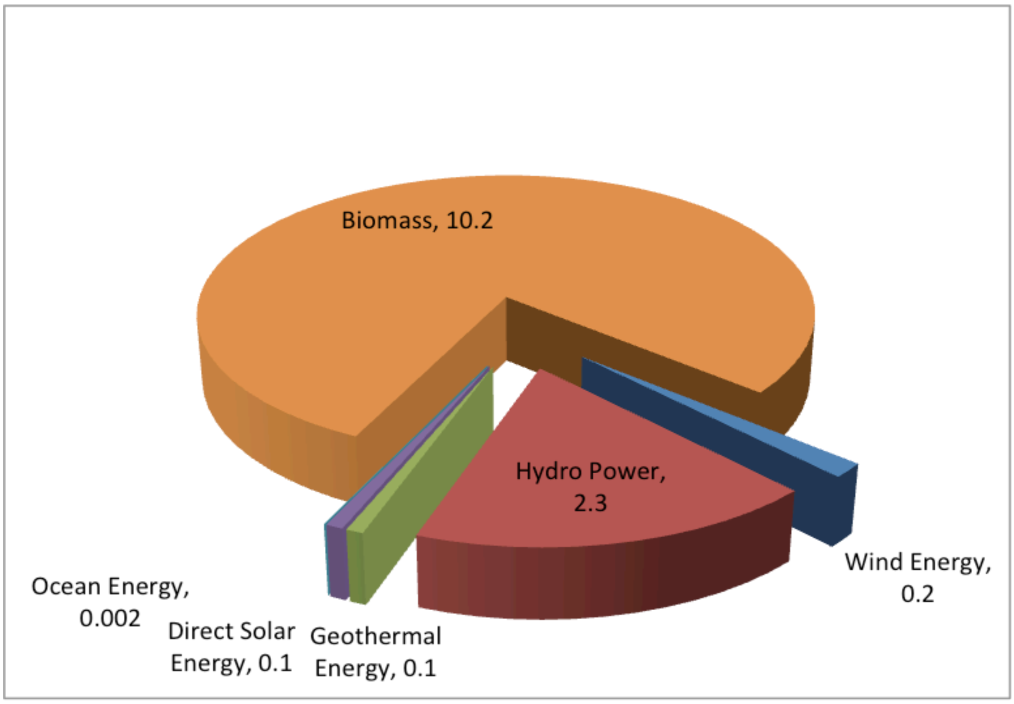

Figure 2.2: Global renewable energy sources in 2008 adapted from (IPCC, 2011).

Biomass energy is concerned with biodegradable parts of products, wastes and residuals from agriculture (e.g. vegetal or animal materials), industrial and municipal wastes (Cornea and Dima, 2010).

Table 2. 1 : Turkey's renewable energy potential (Acaroglu and Aydogan, 2012).

Renewable Energy Source	Estimated Capacity(Mtoe)
Solar Energy	1,300
Hydro Power Energy And Geothermal Energy	40
Wind Energy including land, offshore	200
Sea Wave Energy	21
Biomass Energy	135

In other words, the considerable biomass sources are known to be the feed stocks, manure and sludge generated from municipal wastewater treatment facilities. Conversion of the biomass to bioenergy has been carried out by thermo-chemical processes like combustion, or biochemical processes like anaerobic digestion (Cornea and Dima, 2010). Tucu et al. 2007 is stated that bio-fuels (e.g. biodiesel, biogas, bioethanol) can be replaced to natural gas or petroleum products (Cornea and Dima, 2010). Although local and regional fuel providing availability is a key point, latest developments demonstrate that there is increasing concern globally in bio-fuels (IPCC, 2011).

Biomass energy is the main concern of this study. Biomass (sludge) generation in municipal wastewater treatment plants makes these facilities remarkable energy producers. Aside from having high potential of biomass (sludge) generation, wastewater treatment plants account for a considerable part in energy consumption. Hence, the process selection and control of energy utilization in WWTPs may lead to energy self-sufficient plants. Additionally thermo chemical and bio-chemical processes are both investigated for energy conversion of biomass in the scope of this study.

2.2 Energy Requirement in Conventional Wastewater Treatment Plants

Energy consumption generally means electricity consumption, because most commonly electrical energy is used as source energy in wastewater treatment plants. Energy consumption in wastewater treatment plant may change according to the size of the plant, the type of treatment process (Hobus *et al.,* 2010), strength of wastewater, level of treatment and in plant energy recovery (WEF, 2009a).

Typical wastewater treatment plants consume large energy, which can represent 50% or more the facilities variable with operating and maintenance costs (Ataei, 2010). According to report of the environmental protection agency (EPA) named as "Water and Energy: Leveraging Voluntary Programs to Save Both Water and Energy"in 2008; America wastewater treatment plants accounts for 30-40% of total energy used within local governments (McLean, 2009). The electrical energy required for the treatment of municipal wastewater per capital is given in the range of 20-50 kWh/ca.year (WEF, 2009a). Electricity consumption wastewater treatment plants in China were 0,1% of the total national electricity consumption (Yang *et al.,* 2010). Energy needs of typical conventional activated sludge wastewater treatment plant average 0,4 kWh/m^3 (Habernkern *et al.,* 2006) – 0,6 kWh/m^3 (McCarty *et al.,* 2011). Approximetely 0.7% of total power consumption is used in wastewater treatment plants in Germany (Haberkern *et al.,* 2006; Mauer *et al.,* 2011). Energy equivalence of WWTPs in Holland is approximately 27 kWh/(PE.a) (Geilvoet *et al.,* 2010). At this point it is appropriate to emphasize that monitoring the wastewater treatment plants plays an important role for energy efficiency. Energy consumption in WWTPs concerns not only the wastewater treatment but also the sludge treatment processes. Comprehensive energy analysis of water and sludge treatment lines are essential in order to estimate energy efficiency in WWTPs.

According to literature review, the majority of the energy utilized in wastewater treatment systems are the same same; they are pumping actions, aeration and mixing processes, utilization of produced biogas, sludge dewatering and operating the engines (Mauer *et al.,* 2011; Mizuta and Shimada, 2010).

Biogas production and necessary modifications in plant might be a useful way to save energy in WWTPs. The possible achieved energy saving in wastewater treatment systems is around 20 -40 % of total consumption; and 20 % is possible for the biological treatment (Jones *et.al.,* 2007; Hobus *et al.,* 2010; Mauer *et al.* 2011; Wett *et al.,*2007). Although obtaining biogas with anaerobic treatment from organic material in wastewater is an efficient way to capture energy, extra costs are probably required to complete the reduction of energy utilization. The additional expenses may be related with monitoring, operational or construction costs. Renewing the existing plants is a costly action. Although more cost may be deterrent at first look; it seems that better to apply anaerobic systems to new facilities.

On the other hand, it could be beneficial in long term for existing plants, following effective feasibility analyses. In this part of the thesis, energy consumption and possible precautions in wastewater treatment systems have been briefly explained. Overall effected energy points in the wastewater treatment process have been organized under the titles as primary treatment, biological treatment and sludge treatment.

2.2.1 Primary treatment

Screens, grit/grease removal and primary settling can be listed as the main units of primary treatment at municipal wastewater treatment facilities. Screens, which are generally used at the first stage treatment in WWTPs, can be mechanical or manual Typically, energy use in screening is the minor portion of total WWTP. Energy saving can be possible by decreasing water flow for rinsing screens, and reduction of energy requirement for screening can be beneficial in energy use of following part of the plant (WEF, 2009a). Furthermore, pumping plays an important role in energy circulation of WWTPs. Energy requirement of influent wastewater pumping alone represents 15-70 % of total the WWTP, and energy requirement of whole pumping system of the WWTP may represent 90% of the total energy used (WEF, 2009a). Determining the best efficient point for operation of the pumps, and using efficient pumps and motors can be effective. At the design stage of a WWTP, minimize the pumping height together with recycling and side streams can be an advantage. Additionally, a well designed configuration for WWTP will decrease hydraulic energy loss to a minimum (Geilvoet et. al., 2010). However the best way to obtain high level energy efficiency for pumping can be variable frequency drives (VFD) where the flow rate is highly variable (EPA, 2010), Hence this mechanism provides the optimum efficiency for entire flow range (WEF, 2009a). VFDs control the motor speed of pumping according to the variable flow conditions, which inturn makes electrical power input to reach a good match with hydraulic power needed to pump the water (EPA, 2010).

Grit/grease removal unit does not have much energy requirement, but its efficient use can positively affect the other parts of the WWTP. If the treatment of grit chamber is not properly cleaned, it can accumulate in anaerobic digesters and reduce production of digester gas (WEF, 2009a).

Aerated grit chambers use blowers, which creates turbulence to suspend lighter organic material and to settle heavier grit particulates (WEF, 2009a). Optimal operation and correct setting in this type grit chambers is an important key-point to use in this treatment step efficiently. Geilvoet *et al.* (2010) also reported that correct setting of the equipments up to desired range, enables energy saving.

Using primary settling process provide a benefit for unwanted accumulations in aeration units, and floatation in aeration tank and final clarifier (FC). In addition primary settlement reduces the biological oxygen demand for five days to total kjedahl nitrogen ratio (BOD_5:TKN) and it has a positive effect on denitrification process (Wang et. al., 2009). Efficiency in primary settling much depends on the influent settleability, composition and local conditions (Puig, 2010). The performance of the activated sludge process is highly effected from primary settling. Primary settling increase the chemical oxygen demand total suspended solids (COD:TSS) ratio; and COD has more biomass after settling process; increasing biomass concentrations have positive effect to activated sludge process (Takacs and Vanrolleghem, 2006). Furthermore, primary settling reduces aeration requirements due to decrease in BOD_5 concentration. Furthermore, primary settling process gives an advantage with increasing sludge production of the plant, hence performance biogas of production from anaerobic digestion is higher with primary sludge which is rich in BOD_5.

Removal of settleable solids and floating material from wastewater is the main purpose of the primary treatment. Good performance of the primary treatment positively affect the overall plant such as requiring less use of energy in aeration tank, and in solids handling, while increasing the digester performance to obtain gas for energy recovery (WEF, 2009a).

2.2.2 Biological treatment

The basic idea of biological treatment is to treat wastewater by using microorganisms. Microorganisms use organic matter in wastewater to perform their metabolic activities. After primary treatment, high organic matter is left in the wastewater. In other words, convenient atmosphere is ready for sustaining metabolic activities of microorganisms productively.

In this part of the thesis; biological treatment is focused on solely organic carbon removal plus carbon and nutrient removal processes combined.

Organic carbon removal :

The characterization of wastewater takes a substantial place in activated sludge systems. The classification of the characteristic is the initial considerable point, and includes physically (soluble or non soluble, settleable colloidal or suspended), biologically (biodegradable or non-biodegradable) parts (Henze et al., 2008). Though they have basically same principles, all aerobic biological systems are distinguished from each other in the conditions under system constraints related to biological reactions, (Henze et al., 2008).

Important issues for activated sludge system are mixing, aeration, separation activated sludge (final clarification), recycling and disposal of the excess sludge. Among these operations, mixing is necessary for contact between microorganisms and substrate (organic material). Aerators for the aeration process are usually employed during the mixing process. Aerators are also necessary to supply oxygen for the biochemical reactions. Aeration process requires the maximal energy in wastewater treatment system (EPRI 2000; WEF, 2009a; EPA, 2010; Li *et. al*., 2010; Mauer *et al.* 2011), it consumes approximately 50- 75% of the total process energy (Gori *et al.* 2011; Yang *et al*. 2010; Geilvoet *et al.* 2010; Hobus *et al*. 2010).

EPA (2010), reported that energy consumption in aeration systems is related with several key factors; diffuser type; oxygen transfer rate (OTR); oxygen transfer efficiency; mixed liquor dissolved oxygen (DO) concentration.

Generally, DO concentrations in suspended growth systems should be between 0.5 to 2.0 mg/l reported by WEF (2009); 1.0 to 2.0 mg/l reported by EPA (2010). If the expected dissolved oxygen value is decreased, aeration rate would also decrease.

Slow aeration rate does not affect the system negatively, and yet helps to save energy (Geilvoet *et al.,* 2010). By the way monitoring the aeration systems can play significant role for energy recovery in WWTPs.

Importance of aeration process by energy efficiency perspective makes the first evaluation related with aerators in WWTPs. Aerators generally can be listed as mechanical aerators, coarse bubble, and fine bubble diffusers (WEF ,2009a).

Common type of mechanical aerators are low speed mechanical aerators, direct drive surface aerators, and brush type surface aerators (EPA, 2010). Mechanical aerators are placed at the centre of activated sludge tank and mix the wastewater. In the surface aerator systems, the immersion level is important, thus, when it is submerged, the dissolved oxygen concentration and electrical load decrease (WEF, 2009a). For situations where adjustment of liquid level is not possible, VFDs may be used. VFDs arrange automatically the operation of the aerators on exact time intervals (WEF 2009a).

The most efficient aeration system is the coarse bubble diffuser, and fine bubble diffuser system (Ataei, 2010; WEF, 2009a). Although additional mixing equipments are mostly needed, the bubbled aerators are more efficient than surface aerators. Hence, oxygen transfer capacity of bubbled aerators is much more than surface aerators,along with more energy saving (Geilvoet *et al.,* 2010). Ataei (2010), reported that surface aerators transfer 1.4 to 1.45 kgO_2/kWh, and fine bubbled diffusers transfer 2- 3 kgO_2/kWh.

Secondary clarifiers are mostly used for settlement of sludge part of the wastewater following the aeration process. Secondary clarifiers do not consume so much energy, and there is no energy savings for this unit of the system (WEF, 2009a). Sludge settleability is the first key point for final clarifying process.

Sludge volume index (SVI) is an indicator to show settlement capacity, and SVI values higher than 120 g/ml are considered as bulking sludge in activated sludge process (Orhon *et al.,* 2009). The recycle from secondary settling tank is the second key point; a part of this sludge return to the aeration tanks in order to keep concentration of activated sludge in the aeration tank sufficiently. Excess sludge has to be removed from the cycle; otherwise it can result in the death of microbial community at the bottom of the tank due to lack of oxygen.

There are many factors to determine the achievement of the activated sludge process. The sludge retention time (SRT) as being one, is the time which represents the residence period in the entire system. Oxygen and energy demand of the system can be decreased by using low SRT. Hence sludge production would increase (Geilvoet *et al.,* 2010) and more organics in sludge are converted to the biogas (McCarty *et al.*, 2011).

Moreover, if a facility is not required to nitrify the stream, and sludge disposal costs are not high, then reducing SRT may provide a cost effective way to reduce the total volume of suspended solids in the mixed liquor or reduce the number of aeration tanks in service (Ataei, 2010). Upgrading the existing equipments to energy efficient equipments can be useful to reduce energy requirements. The monitoring of aeration systems is also an advantageous method to control any variation in settings of the equipments, and avoid the system delivering oxygen more than that is absolutely needed. By this way, it is easier to avoid energy wastage (Geilvoet *et al.,* 2010).

Biological nutrient removal process :

Discharge over concentrations of nutrients can cause negative effect to natural water bodies. Ammonia has toxic effect to aquatic environments. Hence nitrogen and phosphorus cause eutrophication problems. Thus, nutrient removal has a significant importance to protect ecosystems and human health. Related to this discharge standards are enforced by Urban Wastewater Treatment Regulation of Turkey (2004) to protect sensitive water bodies. Biological nutrient removal (BNR) systems in WWTPs enable sustainable decrease in discharge concentrations of the nutrients.

Nitrogen exists in the wastewater through the forms of ammonia, nitrate, nitrite and organic nitrogen form. Nitrogen removal is completed with the nitrification and denitrification processes (Figure 2.3). Nitrification is based on ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB). AOB and NOB are autotrophic bacteria.

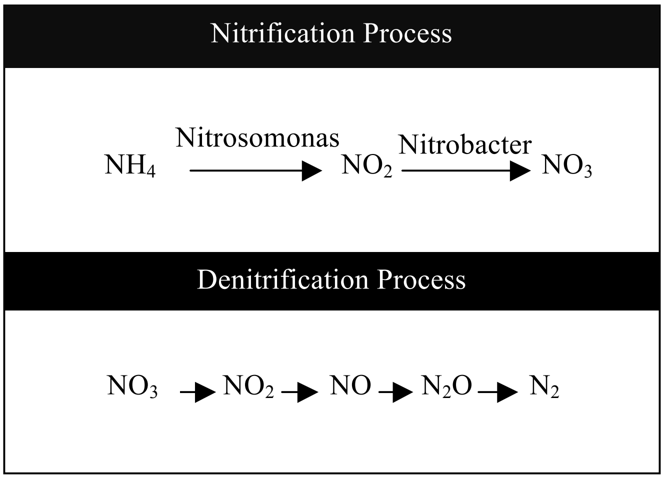

Figure 2. 3: Nitrification and denitrification processes schematic seen.

Nitrification process is the oxidation of ammonia to nitrate; and denitrification process is a reduction of nitrate to nitrogen gas (Metcalf and Eddy, 2003). Removal of particulate organic nitrogen is done by settling the solids. Nitrification is strongly affected from SRT, temperature, DO concentration, pH and inhibitory compounds (Jeyanayagam, 2005). Growth rate of autotrophic bacteria is slower than heterotrophic bacteria, thus, autotrophic bacteria needs longer SRT than heterotrophic bacteria for growing. Nitrification rate tend to increase with rising temperature (Kim *et al*., 2006; Malone and Pfeiffer 2006; Maada and Saidu 2009), and the optimum nitrification rate have been obtained at 28-29°C (Fdz-Polanco *et al.,* 1994). Optimum pH range for nitrification is around 7.0 to 8.8 (Chen *et al.,* 2006). In addition, C:N ratio is important for nitrification process. High concentrations of the carbon can cause of the growing heterotrophic bacteria, which has faster growing rate, compared to autotrophic bacteria. Increasing heterotrophic bacteria population may decrease DO concentration and this would affect negatively autotrophic bacteria growth (Satoh *et al.,* 2000). Dobrzynska et al. (2003) found that high COD:N ratio increases biomass synthesis while decreases denitrification. Denitrification is essential to remove nitrate from wastewater. Denitrifiers are used organic matter for energy source, hence, amount of biodegradable organic matter in the wastewater becomes important in order to completely perform denitrification process. Jeyanayagam (2005) reported that at least 3 to1 ratio of BOD_5:TKN for certain denitrification. Additionally, higher temperature rates also increase the microbial activity in denitrification. Removal mechanism of TP comprises to remove particulate phosphorous and soluble phosphorous. Particulate part is taken away with solid separation, and soluble part is removed by microbial uptake of the phosphorous and/or chemicals (Figure 2. 4) (Jeyanayagam, 2005). Taking up process of phosphorous is carried out by phosphorus accumulating organisms (PAOs)(WEF and ASCE/EWRI, 2006).

PAOs convert the volatile fatty acids (VFAs) to poly-hydroxybutyrate (PHB) (poly-hydroxyalkanoets (PHA)) under anaerobic conditions. PAOs use the energy released during break down of poly- phosphates for creating the PHAs. Accordingly, phosphorous releases while poly phosphates is breaking down.

Later on PAOs use the energy stored in PHAs to catch the phosphorous under aerobic conditions (WEF and ASCE/EWRI, 2006). On the other hand, in anoxic conditions PAOs use nitrate instead of oxygen.

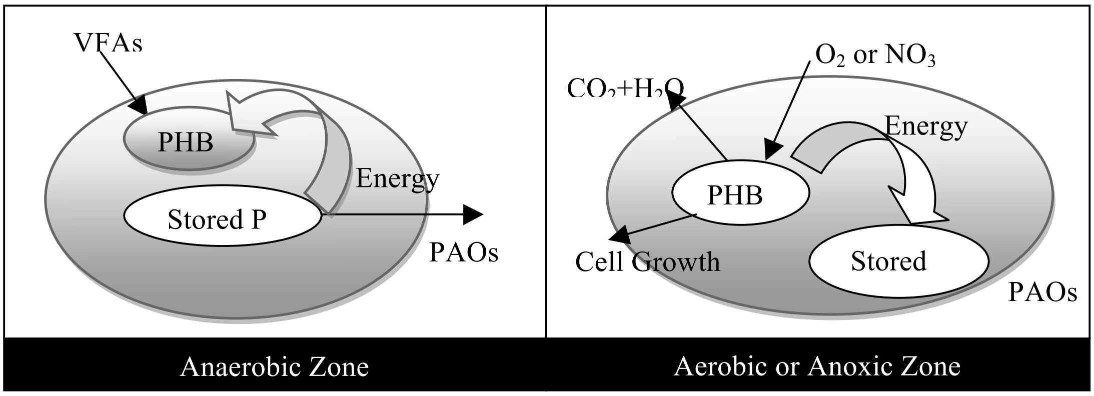

Figure 2. 4: Biological phosphorus removal (Jeyanayagam, 2005).

Another way to remove phosphorus from wastewater is chemical addition to wastewater. Aluminium, iron coagulants or lime can be used to form phosphorus flocs, and settling process may be applied to remove these flocs from wastewater. BNR systems are designed to remove only TN, or only TP, or both TN and TP. The most common of these systems are listed in (Table 2.2).

Appropriate configuration depends on the limits on effluent concentrations, influent characteristics. To build BNR system on an existing plant is more difficult, so it needs to be considered that the nitrogen removal system chosen fits to current conditions in the existing plant. Energy demand in biological nitrogen removal depends on the oxygen demand. In addition oxygen transfer rate have to meet both carbonegeneous and nitrogeneous oxygen demand.

Theoretical oxygen demand for nitrification process is 4.6 kgO_2 per kg NO_3 formed, and for denitrification process is 2.86 kg O_2 per kg NO_3 converted to nitrogen gas. Hence the net oxygen demand is 1.74 kg O_2 per kg ammonia converted to N_2 (Maciolek and Austin, 2006).

2.2.3 Sludge treatment

Sludge term regarding the wastewater treatment system represents the residuals from the treatment of wastewater. The organic value is in the sludge is shown usually volatile suspended solids.

Sludge recycle stream originated from secondary clarifier is an important issue need to be considered. The aim of this is to control and minimize unwanted nitrogen, phosphorous, and organic acids, which can be joined to wastewater treatment process. Control and monitoring of return sludge stream protects the system from undesired efficiency decrease.

Gravity sludge thickening process:

Thickening process can be categorized as gravity thickening, flotation thickening and centrifugation. Separation of sludge and wastewater has been done by sludge thickening mechanism where operation consists of settling sludge. Excess sludge coming from activated sludge process and primary sludge coming from primary settling tank are thickened before going into anaerobic digestion process. Gravity thickening process gives a chance to avoid washout of solids in the recycle stream, and concentrate the sludge which is stabilized in anaerobic digester. Thus, the decreasing in sludge mass would also decrease the energy consumption related to heating the sludge for anaerobic digestion. Concentration of the sludge can be raised to 4-6% by the gravity thickening process (Metcalf & Eddy, 2003).

Anaerobic digestion process:

Anaerobic digestion (AD) process can be defined briefly that the breaking down of organic matter to gases as methane as the majority of the biogas, carbon dioxide, ammonia and water. Main advantages of this process are to produce energy and to reduce the mass of sludge to go to dewatering, other advantages and disadvantages of anaerobic digestion are shown in (Table 2.3).

Hydrolysis, acidogenesis, acetogenesis and methanogenesis as shown in (Figure 2.5) are the basic steps of AD (IWA, 2002; Appels *et al.,* 2008). Hydrolysis degrades complex insoluble organic materials (e.g. lipids, polysaccharides, proteins and nucleic acids) to soluble simple organic materials (e.g. fatty acids, simple sugars, aminoacids). Hydrolysis process has been carried out by facultative anaerobes and anaerobes. This step is recognized as a limiting rate step in literature in the case of participating slowly degraded particulate materials in hydrolysis (Gerardi, 2003; Appels *et al.*, 2008).

Table 2. 2 : Common BNR configurations and their TKN:COD, COD:TP ratios.

Process Name	**TN Removal**	**TP Removal**	**Stages**	**TKN:COD**	**COD:TP**
Modified Ludzack- Ettinger (MLE)	Good	None	Anoxic Aerobic	$0.10<^{+}$	n.a
$A^{2}O$	Good	Good	Anaerobic+Anoxic+ Aerobic	$<0.08^{+}$	20-25*
Step Feed	Moderate	None	Alternating+ Anoxic and Aerobic	n.a	n.a
Bardenpho (4 stage)	Excellent	None	Anoxic+Aerobic+Anoxic+Aerobic	$<0.09^{+}$	26 ≤*
Modified Bardenpho	Excellent	Good	Anaerobic +Anoxic+Aerobic+Anoxic+Aerobic	$<0.08^{+}$	n.a
Modified University of Capetown (UCT)	Good	Excellent	Anaerobic+Anoxic+Anoxic+Aerobic	$<0.12^{+}$	20-25*
Oxidation Ditch	Excellent	Good	Time sequenced looped channels with continuous flow among anoxic+ aerobic+ anaerobic zones.	n.a	n.a

*(MetCalf and Eddy ,2003), $^{+}$(Park *et al.,* 1997)

Table 2. 3 : Advantages and disadvantages of AD process (WEF,2009a).

Advantages	Disadvantages
High degree of stabilization	Slow growth rate of methanogens
Inactivates pathogens	Requires long SRT
Decreases the amount of waste sludge	May require auxiliary heating
Low nutrient requirements	Capital intensive
Low energy requirements	Maintenance intensive
Methane rich gas is a usable product	Generates poor quality side-stream
Stabilized sludge is a usable product	Methane is powerful Green House Gases (GHG_s) that requires collection
	Biogas is usually odorous

Acidogenesis, acidogenic bacteria or fermentative bacteria make the simple organic materials change to VFAs such as propionic acid, formic acid, lactic acid, butyric acid, succinic acid, and to alcohols such as ethanol, methanol, glycerol, acetone, and to CO_2, H_2 and acetate.

Acetogenesis, acidogenic bacteria produce mainly acetic acid, CO_2, H_2 from organic acids and alcohols.

Methanogenesis process has been carried out by methanogenic bacteria. There are two type methanogenic bacteria. While one splits acetate to methane and carbon dioxide, another of uses hydrogen as an electron donor and carbon dioxide as acceptor to produce methane (Appels *et al.,* 2008).

Anaerobic digestion is affected from many factors such as solid content of sludge, biodegradability of organic material, retention time, temperature (Nouri *et al*., 2006), alkalinity and pH (Appels *et al.,* 2008) and Carbon: Nitrogen (C:N) ratio organic loading rate (OLR) (Buekens, 2005). Control of pH is very important, because microorganisms can be effective negatively which inturn fails the digestion process. Methanogenic bacteria are very sensitive for the variations of the pH range. The optimum pH range in the digestion process reported as between 6.5 to 7.2 (Buekens, 2005; Appels *et al.,* 2008). As a result of acidogenesis step, the pH range is reduced. pH reduction causes an “acid accumulation” problem in the system.

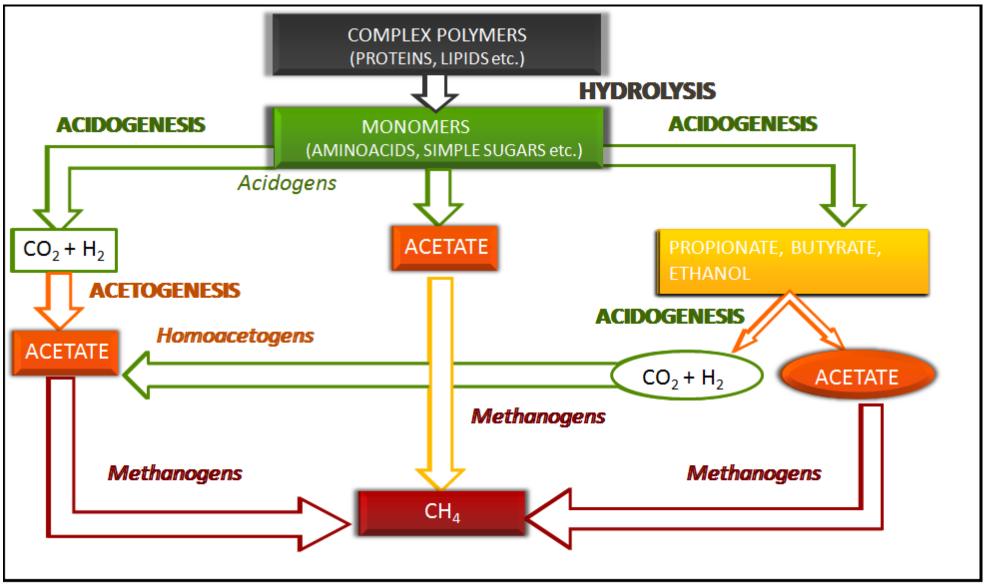

Figure 2. 5: Main steps of anaerobic digestion process.

The activity of methanogenic bacteria can respond to the pH reduction by producing carbon dioxide, ammonia and bicarbonate. In the WWTPs the system is controlled by carbon dioxide concentration and bicarbonate alkalinity of liquid phase. If there is a demand of alkalinity; bicarbonate can be added to the system in order to increase pH.

Another important parameter is temperature in the AD system. It needs to be controlled in order to avoid inhibition to the digestion process. Anaerobic digestion process can be operated in optimum conditions as mesophilic (32- 35°C) and thermophilic (54- 57°C) conditions (Nouri *et al.,* 2006; WEF, 2009a). Mesophilic sludge digestion is more preferable and prevalent condition type in worldwide, as its operating conditions is easier than thermophilic sludge digestion and optimal gas production occurs at 35°C (Nouri *et al.,* 2006). Although mesophilic sludge digestion is the most common technology used in water industry, thermophilic sludge digestion has higher potential to yield biogas and more solids destruction. On the otherhand, thermophilic digestion is usually unstable due to higher operating temperatures (Zupancic and Ros, 2003). In literature, it is accepted that thermophilic anaerobic digestion provides 4-8% more reduction of volatile solids at same SRT period (WEF, 2009a). Willis and Schafer (2006) reported that there are less differences between mesophilic and thermophilic conditions related with the reduction of volatile solids in high SRT.

Besides the disadvantages of thermophilic conditions are that, more energy is required for high temperatures and residual volatile fatty acids in digested sludge are much more than mesophilic conditions (WEF, 2009a).

The average time solids spend in the digester is called as SRT and the average time liquid sludge spends in the digester is called as hydraulic retention time (HRT). Low SRT decreases the grade of reactions (Appels *et al.,* 2008). Low HRT reduces the volume of the tank, and it results with cost saving. On the other hand low HRT also reduces degradation level and gas production (Buekens, 2005).

Patel and Madamwar (2002), investigated how the biogas production and treatment efficiency were effected with varying temperatures (25°C, 37°C, 45°C, 55°C), OLRs (3.60, 4.50, 6.00, 9.00, 18.10, 21.70 and 27.20 kgCOD/m^3.d) and HRTs (1.5, 2.5, 3, 6, 9, 12 and 15 days). In conclusion, they observed that the best performance of the reactor is at mesophilic conditions (37°C) with 21.70 kgCOD/m^3.d OLR and 2.5 days HRT, and CO_2 concentration in produced gas in mesophilic conditions is much more less than other temperatures.

When C:N ratio is high, it means that carbon content is high, and low nitrogen content unabling the methanogenic bacteria not to take enough nitrogen for producing sufficient amount of gas.

Heating and mixing processes in conventional digesters are the main energy consumers. Heating requirement is necessary to increase temperature for mesophilic and thermophilic environment. Commonly digester heating is supplied by boiler-heat exchanger, and it fuelled most efficiently with digester gas (WEF, 2009). Unless there are inner impeller mixers, mixing process is applied by using external pumps or compressors in order to re-circulate gas or liquid.

Dewatering :

Dewatering is a physical unit process which makes reduction in moisture content of the sludge. Dewatering can achieve dry-solids level between 10-45 % (IPCC, 2006). Sludge type, characteristic of dewatered sludge and space availibilty are the main factors to decide dewatering device selection. Small plants generally where land availability use drying beds or lagoons; on the other hand if there is no land available, mechanical devices would be preferable (Metcalf & Eddy, 2003).

The most common methods for dewatering process are centrifugal dewatering, belt-filter presses, drying beds and lagoons. Centrifugal force and sedimentation is used to separate solid and liquid in centrifugal type dewatering.

Effective parameters on centrifugal dewatering are feed rate, sludge characteristic, temperature and chemical additions. Increasing the temperature during dewatering process can accelerate the process necessarily (Falk and Wallin, 1987; Hulston *et al.,* 2004). Maximum 30-40% dry solid concentrations can be obtained by centrifugal type dewatering units. The aim of the filtration by belt filter pressure is the same with centrifugal type dewatering, separation of liquid and solid. It usually consist of belt-filter press, sludge containing tank, polymer feed equipments, sludge feed pump, sludge conditioning tank and sludge cake conveyor. Belt-filter press can only reach 20-25% dry-solid concentration. Belt filter press is sensitive for variable sludge characteristic, wide variations can cause decreasing in performance (Metcalf &Eddy, 2003).

Drying Processes:

Drying process after dewatering process can increase the dry solids level to 80-90% (IPCC, 2006). The waste sludge drying can be divided in three according to the type of heat transfer. These are (1) convection drying, (2) contact drying, and (3) radiation drying.

In convection drying process, hot air flows around the material to be dried. The heat is transferred to the material, and water in the material is evaporated by this method. Contact drying includes heat carrier, which heats the material, without coming into direct contact. Radiation drying is performed by electromagnetic radiation or infrared radiation.

Type of convection driers are (1) drum type, (2) fluidised bed, (3) belt and (4) cold air driers. Drum type driers increase the dry solid content to 80% and more (ATV, 2004). On the other hand, fluidized bed driers are combination of convection and contact driers, and employed the full drying. This type driers are condensed the dry matter concentration to 95% at 85°C (ATV, 2004). Therefore, belt driers can dry the waste sludge up to 90% at 120- 130°C (ATV, 2004). The main advantage of the belt driers is to transit to pasty phase without problem. On the other hand heating up the high degrees brings high risk for the fire.

The last type of the convection driers is cold air driers. These driers required initial dewatering process, and dry solid content can be increases to 70-90°C (ATV, 2004).

Common contact driers can be listed (1) disc type, (2) thin film and (3) revolving tubular driers. Combination of disc type and thin film driers is also used as contact drier. In this combination, thin film driers first increases the dry solid content to 55-60% (ATV, 2004) , then disc type drier is fed for full drying process. Revolving tubular driers use saturated steam to heat up rigid bank of tubes. The dry solid content increase 90- 95% with revolving tubular driers (ATV, 2004). Solar/ ventilation driers is processed with mechanisms both convection and infrared drying. This type of drying is depended the weather conditions. Therefore in the winter the sludge is needed to be stored. This system can achieve 80% of dry solid concentration.

Theoretical heating energy demand for evaporation of 1 tonne of water under normal pressure 627 kWh, and water heating from 20°C to 100°C is 93kWh, and heating of the solid matter 14kWh. Moreover, the electrical energy demand varies in the range of 70-110kWh/ton water (ATV, 2004). The most common way for energy recovery in wastewater treatment systems is the enhancement in self-supported energy production as kind of electrical and thermal energy.

Most common ways of self supported energy production are biogas production by anaerobic digestion of sewage sludge (McCarty *et al.*, 2011; Gurieff *et al.,* 2011; das Neves *et al.,* 2009; Shahabadi *et al.,* 2009; Mizuta and Shimada, 2010; Nouri *et al.*, 2006); and combustion of the sludge by incineration technology (EMEP/EEA, 2009; IPCC, 2006; McKay, 2001). Following part of this chapter briefly explains biogas and incineration process.

2.2.4 Biogas

Gas composition in digester is typically represented by 55-70 % methane, 30-45% carbon dioxide and other gas formations (Appels *et al.,* 2008; WEF, 2009a).

The possible cost reductions is around 42% (Mauer *et al.,* 2011) as the production of biogas increases while the amount of solids needed to be removed is reduced significantly (Gurieff *et al.,* 2011).

High portion of energy consumption in WWTPs can be covered with the energy potential of sludge digestion (Hobus *et al.*, 2010). Mizuta and Shimada, 2010, reported that digestion gas provided 50% of the energy consumed WWTP in Japan. McCarty *et al.* (2011) reported that 28% of the actually energy potential of wastewater can be produced as electricity, because 35% of the methane energy might be obtained as electricity, while the remaining part is kept as heat. He also reported that it is needed to increase this potential degree to higher. Thus, biogas can be used to generate power for producing electrical and heat energy.

In exchange for per kilogram of VSS destroyed, the produced gas is approximately between 0.75 to 1.25 m^3 (WEF, 2009a). Common usage areas of digester gas in wastewater treatment systems were reported in WEF (2009a), and it is shown in Table 2.4. Besides, produced heat energy can be used to recover heat demand of the anaerobic digester.

Table 2. 4: Common uses of digester gas from (WEF, 2009a).

Advantages	Disadvantages
Digester Heating	Boiler, Heat Recovery equipment,Heat Exchangers
Electric Power Generation	Gas Cleaning, Microturbine,Turbine, Fuel Cell, Steam Turbine
Building Heating	Heat Recovery Equipment, Heat Exchangers
Air Conditioning	Heat Recovery Equipment, Chiller
Biosolids Drying	Dryer, Heat Recovery Equipment
Biosolids Pasteurization	Boiler, Heat Recovery Equipment, Heat Exchangers
Thermal Hydrolysis	Boiler, Heat Recovery Equipment, Direct Heat Injection
Methane Gas Retail	Gas Treatment
Drive Pumps and/or Blowers	Gas Engine Driven Pumps and Blowers
Flaring	Flare

2.2.5 Incineration

Incineration is widely used thermal oxidation process in waste treatment in order to reduce the volume of waste sludge, save money, extend to life of landfills and recover electrical and/or heat energy from combustion process.

Average composition of dewatered sewage sludge in general and dewatered sludge composition of general domestic and sewage sludge of the investigated plant is shown in (Table 2.5). Basic means of combustion is chemical reaction between a fuel and an oxygen source.

Table 2. 5: Average composition of dewatered sewage sludge from (EC, 2006).

Component	Domestic Sewage Sludge
Dry Solids (% of sludge)	10-45
Organic Material (% of DS)	45-85

In WWTP sludge cake, volatile fraction of total solids is as fuel. The difference of sludge cake fuel from the other fuels (oil, natural gas etc.) is that there is higher heat needed to evaporate the moisture part of the cake by drying process. It is possible to use heat energy obtained by incineration process into the heating of dryer.

Table 2. 6: Typical analysis of digested biosolids from (WEF, 2009b).

Parameter	Dry Basis (%)	Moisture (%)
Carbon	29.64	56.12
Hydrogen	4.29	8.12
Oxygen	13.85	26.22
Nitrogen	3.66	6.94
Sulfur	1.37	2.6
Ash	47.19	0

To know the composition of sludge cake is a significant point in order to understand the incineration process (Table 2. 6). After dewatering process, the sludge cake composition includes moisture, ash and volatiles. Moisture (liquid) part of the cake is vaporized with the evaporation process and there is no change in its chemical composition. The ash part of the cake does not participate in any chemical reaction, so it is the chemically inert part of the cake. Hence, the changes in composition and releasing heat result from combustible (volatile) fraction, which reacts with air oxygen. As it is reported in WEF (2009b) that typical digested biosolids have 70% moisture, 14.16% ash, 14.98% volatile content, and remains 0.86% part represents fixed carbon.

Certainly, it is important to check thermo-dynamical validity of expected incineration process for a municipal sludge waste (WEF, 2009b; Channiwala, 1992). If the water loading can be decreased around 30%; incineration, which is a thermal process to gain energy, would be the potential energy converter from sludge (McCarty *et al.,* 2011).

Different types of incinerators are applied for various kind of wastes, however, sewage sludge incineration usually takes in rotary kiln or fluidized bed incinerators (IPCC, 2006). Sewage sludge normally has high water content, thus dewatering and drying processes before incineration might be guaranteed an efficient method of combustion. Commonly used incinerators in incineration of sewage sludge are listed in (Table 2.7).

Table 2. 7: Incinerator applications for sewage sludge combustion (IPCC, 2006).

Technique	Sewage Sludge
Rotary Kiln	Applied
Rotaty Kiln- water cooled	Applied
Fluid bed - bubbling	Applied
Fluid bed - circulating	Widely Applied
Fluid bed - rotating	Applied
Pyrolysis	Rarely Applied

Although there are various incineration technologies such as pyrolysis, gasification, and rotary kiln; fluidized bed incinerator technology is briefly explained here. Fluidized bed incinerators (FBI) are usually applied for homogeneous waste incineration. This kind of incinerator has a cylindrical combustion chamber, and there are inert material, sand and ash at the bottom of the cylinder (Figure 2. 6).The incinerator is fed by sludge continuously, from the side. Temperature in afterburner chamber is around 850-950°C (IPCC, 2006).

Fluidized bed incinerators can be divided into three different types. They are bubbling, rotating and circulating fluidized beds. Bubbling fluidized bed incinerator is generally used for sewage sludge, as well as industrial or chemistry sludge.

If sludge calorific value is not enough for combustion, additional fuel can be used to reach the target temperature. Typical target temperature for bubbling fluidized bed incinerator is 850°C (IPCC, 2006). Rotating fluidized bed system is an upgraded type of bubbling fluidized bed. The temperature control in the combustion chamber by flue-gas circulation is the important difference of rotating than bubbled fluidized bed incinerator. Circulating fluidized bed incinerator (CFI) is especially appropriate for dried sewage sludge, which can be burned to a higher temperature.

Incineration process operated to waste releases large volume of flue gases. Oxidation and volatilization of sulfur, nitrogen and chlorine in sludge cake, and incomplete combustion of hydrocarbons or other organic compounds cause some hazardous gases formation (WEF, 2009b; IPCC, 2006; World Bank, 1999).

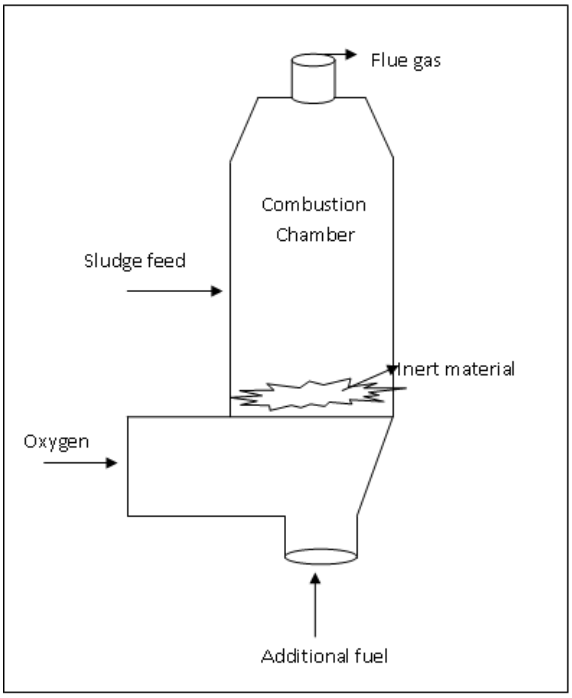

Figure 2. 6: Simple schematic diagram of fluidized bed incinerator.

Primarily hazardous gases are acid gases such as hydrogen chloride (HCl), sulfur dioxide (SO_2) and nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic carbons (VOCs), poly-cyclic organic matter (POM) and GHGs.

Composition of the waste and the condition of combustion establish which type of hazardous gases are released and their quantity (World Bank, 1999). Control of the emissions can be provided at basic, medium or advanced levels. The level of air pollution control might be determined by applying some measurements on waste characteristics before the incineration process.

Certainly, the best way to prevent a hazardous pollutant is to design the furnace in order to achieve complete burning of the waste. In addition, another important point is to cool down the flue gases in the boiler before flue gas treatment technology. The side product of flue gas treatment is a kind of dust.

The treatment of dust would be better, whether flue gas treatment is capable of removing dust as well. Today, variety of devices is used to control and reduce emissions (WEF, 2009b), basic types of these devices are listed below:

- Afterburners: They control VOCs, CO or odorous emissions. It is aimed to combust unburned organic materials in flue gas by increasing the flue gas temperature.
- Cyclones: Nowadays, they are rarely used, because there are devices that are more effective today. They used on FBI in order to supply reduction on particulate loading.
- Venturi Scrubbers: This kind of device is also responsible to control particulate loading, however it has more dominant specifications than cyclones. It provides condensation on the sub-micrometer and micrometer particulates, and their mass increase by this way. Thus, raised mass contribute to their removal by impaction mechanism (Perry and Chilton, 1973).
- Tray Scrubbers: They are used following venture scrubber, in order to complete wet scrubbing system and get better performance on removal of the particulates.
- Dry Electrostatic Precipitators: These devices are used on FBI. In this system negative charged particulates hold on the positively charged plates, and then let particulates removed by falling to bottom of the device.
- Wet Electrostatic Precipitators: These precipitators are similar to dry electrostatic precipitators; the difference is that there is a washing mechanism to prevent from accumulation of particulates on surfaces.
- Fabric Filters: The filters are used when maximum level of particulate matter exists. Particulate matter falls to the bottom of the unit and then they are collected.

The primary profit from waste incineration is the potential reuse of the waste as fuel for energy production. Waste incineration secures to get reduction in using fossil fuels and GHGs. Energy recovery from waste may require reducing process for size, shredding, and sorting. However, sludge waste from municipal treatment plant is pretreated and homogeneous in structure. In literature is reported using fluidized bed technology is theoretically proper for homogeneous municipal waste (World Bank, 1999).

2.2.6 Combined heat and power generation

Combined heat and power (CHP) is a valuable system to decrease external energy demand (McCarty *et al.,* 2011). According to the research done by the EPA (2010), if all wastewater treatment facilities, which have anaerobic digestion, in U.S. generate an electricity or thermal energy by CHP adaptation, the energy reduction would be equal to the removal of emissions around 430,000 cars per year (McCarty *et al.*, 2011).

Temperature of flue gases released from incineration furnace is around 1,000 – 1,200°C. Hence, the flue gases must be cooled to approximately 160- 200°C in a boiler in order to apply flue gas treatment regarding air pollution control. Cooling process of flue gases is done in a boiler and, here, the released energy is recovered as steam or heat. Boiler can be divided into three categories as the following:

1. Hot water boiler: This type of boiler only produces heat (hot water) with 80% efficiency.
2. Low-pressure (LP) boiler: It produces low-pressure steam only. Efficiency is about 80%.
3. Steam boiler: The boiler generates power, combination of power and steam/heat.

In this study, steam boiler is taken into consideration as a purpose of obtaining combined electricity and heat. Steam boiler consists of one to three radiation passes and a convection part. Initially, the flue gases pass through radiation part, and then the heat is converted to steam by super boilers. After all process, the flue gases are cooled for air pollution control system. Horizontal layout of steam boiler is shown in (Figure 2.7).

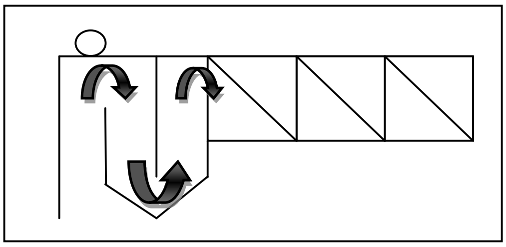

Figure 2. 7: Layout of a steam boiler (Worldbank ,1999).

Table 2. 8: Efficiencies of different energy recovery systems (Worldbank, 1999).

Energy Utilization	**Recovery**	**Efficiency**	**Equipment**	**Overall Efficiency**
Heat Only	Heat	80%	By using hot water boiler and heat exchangers	80%
Steam Only	Steam	80%	By using LP steam boiler	80%
Power Only	Power	35%	By using steam boiler and condensing steam turbine	35%
Combined steam and Power	Steam Power	0-75% 0-35%	By using steam boiler and extraction turbine	
Combined heat and power	Heat Power	60-65% 20-25%	By using steam boiler, back pressure turbine and condensing heat exchanger	80-85%

LP steam boiler is used to get steam with 80% recovery efficiency. If steam boiler and condensing steam turbine is used to produce power from the system, it is possible to recover 35% of total energy as power energy. Combined steam and power system can provide steam in the range of 0-75% and power 0-35% by using steam boiler and extraction turbine. Power and heat obtaining from CHP system can be around 20-25% and 60-65% by using steam boiler, back pressure turbine and condensing heat exchanger. The overall energy efficiency is in the range of 80-85%.

3. MATERIAL AND METHOD

3.1 Conceptual Approach

In recent years, expansion of activated sludge systems brings on more complex structure for design, operation and control of the system. Increasing number of biological reactions, compounds and variety of microorganisms augment the difficulty level of process. To use modelling for activated sludge systems gives a chance to get inside the plant performance, and to evaluate the possible scenarios for upgrading (Insel, 2004). Especially in full-scale plant operation, modelling plays an important role to expect the behaviour of the system under variable conditions (Barker and Dold, 1997a).

The relevant approach for achieving the energy efficient operation in wastewater treatment plants with different plant loads and fixing the effluent restrictions could be achieved with the model based evaluation. In this study, the effluent quality, biomass and biogas generation potential was simulated for the largest wastewater treatment plant in Turkey using general activated sludge model. Four possible scenarios were built to analyze system energy, and to understand how incineration system affects the energy efficiency in WWTPs. Energy efficiency of actual plant, which has conventional activated sludge system (CS), was evaluated under the name of Case 1.a. The effects of additional drying and incineration process on energy efficiency of CS were evaluated in Case 1.b. Case 2.a was built in order to analyze additional nutrient removal effects on the system energy, and called biological nutrient removal (BNR) system. Case 2.b investigates how drying and incineration systems effect to BNR system energy efficiency. The results were evaluated by making electrical and heat energy balances over the investigated WWTP. The following steps in this study are given in (Figure 3.1), and they explained briefly below:

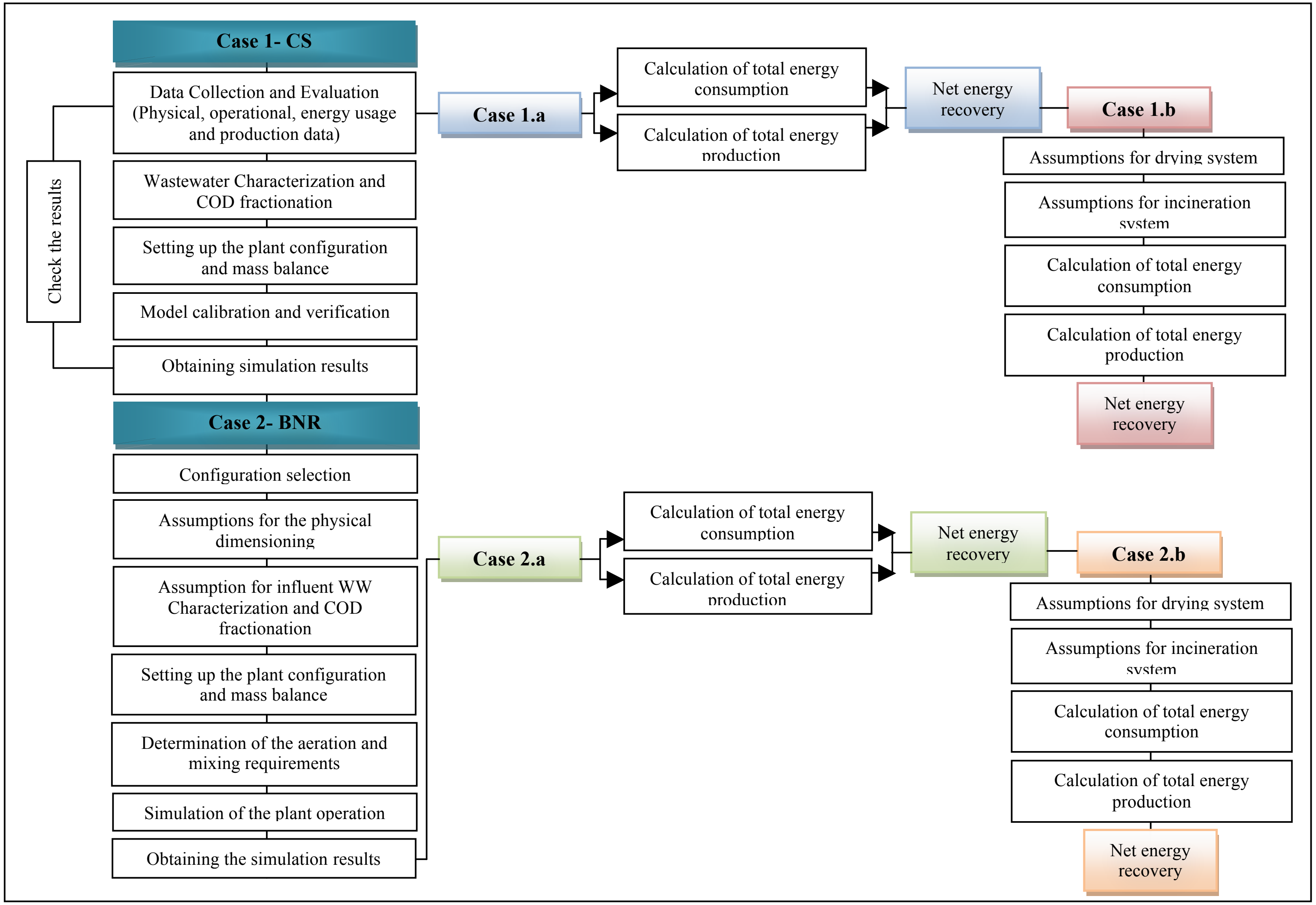

Figure 3. 1: Chart of the following steps in this study.

- Physical, daily average operations including energy consumption and production rates were collected belong to Ankara Central Wastewater Treatment Plant (ACWTP) in the year of 2009.
- Energy consumption and production data were evaluated. Energy balance of ACWTP was set up. Energy consumptions of the processes were evaluated. Net energy was obtained for Case 1.a.
- Influent and effluent wastewater characterization (COD, BOD_5, TSS, TN and TP) were set according to the operational data.
- COD fractionation was done according to literature review results.
- Plant configuration was set up based on the physical data.
- Material mass balance of the full scale WWTP were built according to the operational data.
- The facility was modelled with selected general activated sludge model (GASM) (Barker and Dold, 1997a) under steady state (yearly based average) condition. The model was calibrated based on adjustments on the parameters until getting the best fit with the actual plant data.
- The steady state simulation results were used to evaluate effluent quality, sludge and biogas generation, and compared with actual plant operation.
- A configuration was selected for BNR process and the proper dimensioning assumptions were made for the configuration.
- It is assumed that influent wastewater characterization and fractionation is same with the real plant data.
- After that selected configuration was set up on the simulator.
- Aeration and mixing requirement were determined and proper assumptions were set according to literature based data.
- BNR plant was simulated under steady state conditions with calibrated model parameters.
- The steady state simulation results were used to evaluate effluent quality, sludge and biogas generation.
- Biogas generation rate was used to establish the energy balance of Case 2.a.
- Assumptions were set for selection of drying and incineration process. Energy consumption rates for selected drying process and energy consumption- production rates for incineration process were determined.

- Total energy demand and energy production were calculated for Case 1.b and Case 2.b.
- Finally, energy requirements, consumptions and production rates of Case 1.a, Case 1.b, Case 2.a and Case 2.b were discussed (see Chapter 4).

3.2 Plant Information

3.2.1 Location

The location of ACWTP is 40 km away from the west of the city center and near Tatlar location. The topography of the location and the city allow the wastewater to enter the plant by gravity without pumping station. Figure 3. 2 shows the Location of the plant.

Figure 3. 2: Location of ACWTP at the map of Turkey.

3.2.2 Data collection

Evaluation of wastewater treatment plants are based on a detailed data collection, it is important to ensure the highest quality in data collection, correct base data would provide to reach the correct solution at short notice. Physical, design and daily based operational data are belong to ACWTP plant for year of 2009 with the contributions of Ankara Water and Sewer Administration (ASKI) and Bel-ka A.S. Obtained physical data include dimensioning data of each unit.

Besides, operational data contains process data as flows, COD, BOD_5, SS, TN, TP and VSS measurements, mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS) concentrations, sludge and hydraulic retention times, also data belong to design criteria of the wastewater treatment plant. In addition, average daily based energy consumption and production data were also collected.

3.2.3 Configuration and units

All wastewater of Ankara region had been discharged to Ankara River without any precaution, before the facility was established. The construction of plant was planned to be completed in three phase accordingly. Design criteria is given in (Table 3. 1). 1st phase: Construction and commissioning were completed in 2002. This phase was designed to get daily average dry weather flow, 765,000 m^3/d. 2nd phase: Expansion of the plant was planned to be completed in 2010. However, it has not been realized yet. This phase was designed to get daily average dry weather flow, 971,000 m^3/d. 3rd phase: Expansion of the plant was planned to be completed till 2025. This phase was designed to get daily average dry weather flow, 1,377,000 m^3/d.

Table 3. 1: Design flows of ACWTP with projected population equivalents.

Years	**Population Equivalent (PE)**	**Average Weather Flow (m^3/d)**	**Peak Storm Weather Flow (m^3/d)**	**BOD_5 Load (tonnes/d)**
2002	3,919,600	765,000	1,530,000	235.2
2010	4,883,300	971,000	1,942,000	290.0
2025	6,228,300	1,377,000	2,754,620	377.3

ACWTP was designed for removal of organic carbon and treatment of all domestic within Ankara province. It is expected that removal of nitrogen (N) and phosphorous (P) will be considered in the future. The main parts of treatment process and sludge treatment are consist of (1) coarse and fine screens, (2) grit chambers, (3) primary clarifiers (PC), (4) activated sludge tanks, (5) final clarifiers, (6) sludge thickeners, (7) anaerobic tanks, (8) digested sludge thickeners (DST), (9) dewatering unit and (10) biogas power stations. Brief explanations of configuration units of ACWTP (Figure 3. 3) are as following:

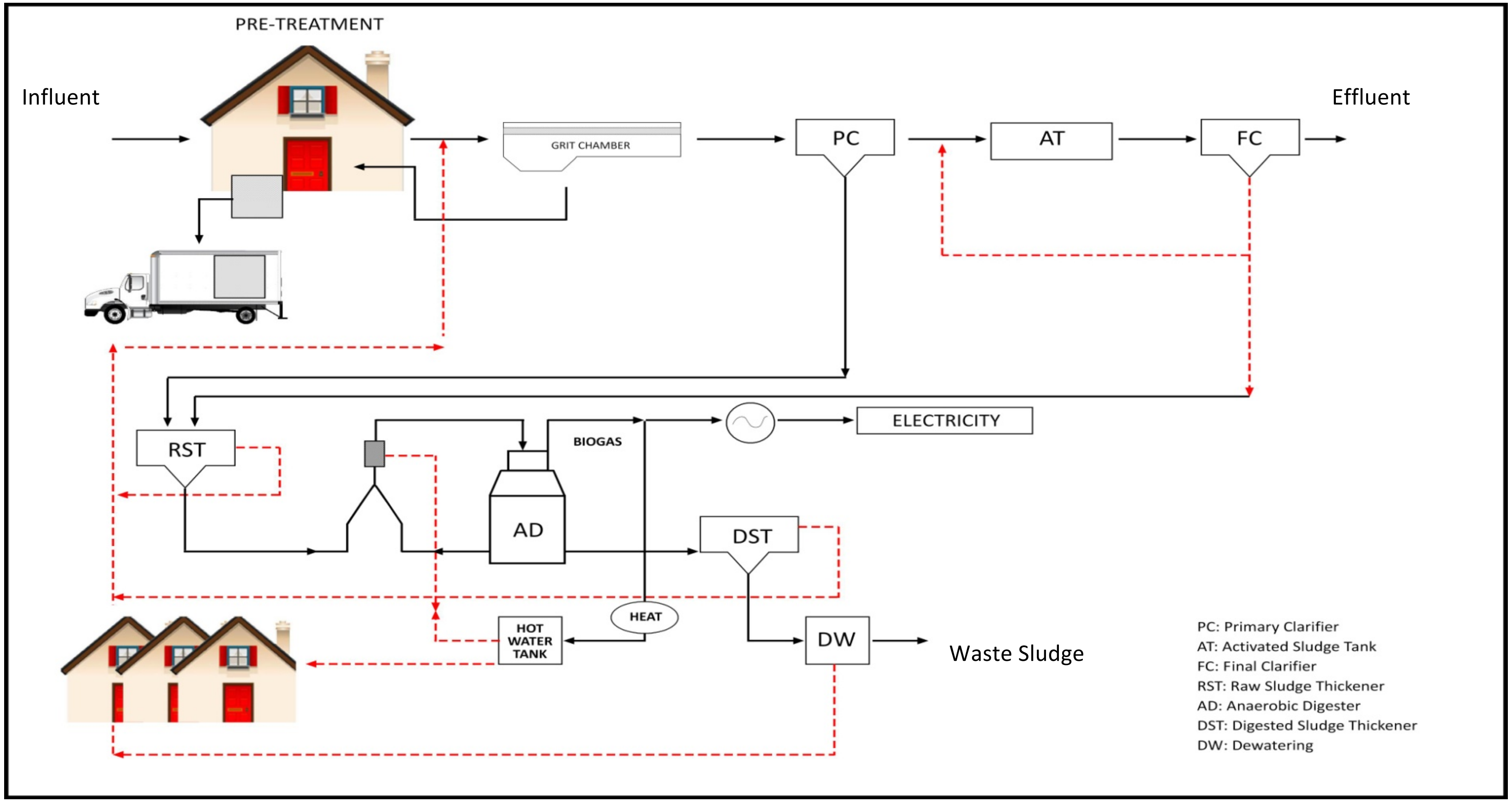

Figure 3. 3: General configuration of ACWTP.

1. Pre- treatment: The main purpose of the pre-treatment is to prepare wastewater for treatment. Pre- treatment process mainly consists of coarse screens, fine screens and aerated grits/scum chamber. First, coarse screen separate the matters larger than 40 mm, and then fine screen separate the solid matters greater than 15mm (Table 3. 2) from influent wastewater. The separated solid matters are kept in the containers in order to be sent to the storage area. After all, the wastewater goes into the two set big grit tanks (Table 3. 3). Sand, oil, grease are also separated from wastewater here. In addition, iron-chloride solution ($FeCl_3$) is added to decrease hydrogen sulfur (H_2S) dosage coming from biogas units for avoiding corrosion problem in biogas motors or the system, itself.

Table 3. 2: Design parameters of screens.

Unit	Number of Screens	Size	Unit
Coarse Screen	5	40	mm
Fine Screen	5	15	mm

Table 3. 3: Design parameters of grit chamber.

Unit/ Equipment	Size	Unit
Number of tanks	10	#
Volume of each pool	584	m^3
Surface Area	209	m^2

2. Primary clarifier: This unit has been used for settling the matters as suspended solids, which cannot be settled during pre-treatment. Settled matters are sent to the primary sludge thickener.

Table 3. 4: Design parameters of primary clarifier.

Unit/ Equipment	Size	Unit
Number of tanks	10	#
Volume	7,100	m^3/each
Surface Area	1,963	m^2
Diameter	50	m
Retention Time	1.5-2	hrs

Primary clarifier tanks are designed in circular shape and the settled pre-sludge is transferred to primary sludge thickeners by gravity (Figure 3.4). Average TSS removal efficiency range of primary settling process is 60-70 %, and the average hydraulic retention time varies between 1.5-2 hrs. The water coming from primary clarifier (Table 3. 4) is mixed with activated sludge and sent to aeration tanks.

Figure 3. 4: Photograph of primary clarifier.

3. Activated sludge basins: In this part the active microorganisms use the soluble organic matter in wastewater as their substrate. Aerator type used in ACWTP is mechanical surface aerators (Figure 3. 5). The oxygen needed by heterotrophic microorganisms is supplied by surface aerators. Mechanical surface aerators also mix activated sludge and wastewater, and it keeps solids in suspended situation, and makes easy to contact microorganisms with substrate. There is also recycle system in order to stabilize the microorganism population. Design parameters of activated sludge basin is given in (Table 3. 5).

Table 3. 5: Design parameters of activated sludge basin.

Unit/ Equipment	Size	Unit
Number of tanks	10	#
Volume	13,005	m^3/each
Surface Area	2,601	m^2
Depth	5	m
Retention Time	4	hrs

Figure 3. 5: Photograph of mechanical surface aerators.

4. Final clarifiers: The activated sludge in aeration tanks is settled in the final clarifiers (Table 3. 6). Part of this sludge recycled to aeration tank in order to stabilize activation of microorganism in the activated sludge basin. Recycled sludge ratio is average 24.5 % of main flow. Treated water is discharged to Ankara River.

Table 3. 6: Design parameters of final clarifier.

Unit/ Equipment	Size	Unit
Number of tanks	20	#
Volume	8,400	m^3/each
Diameter	55	m
Retention Time	3	hrs

5. Sludge thickeners: It is used to thickening of the sludge coming from primary clarifier and final clarifier. The uniform thickening is provided by slow speed mixers in the thickeners. The water at the surface of the tank is recycled back to head of the system. Photograph and design parameters of sludge thickeners are given in (Figure 3. 6) and (Table 3. 7).

Table 3. 7: Design parameters of sludge thickener.

Unit/ Equipment	Size	Unit
Number of tanks	7	#
Volume	1,964	m^3/each
Surface Area	491	m^2
Diameter	25	m

Figure 3. 6: Photograph of primary sludge thickening tank.

6. Anaerobic sludge digesters: Thickened sludge is heated by passing through heat exchanger. Anaerobic digestion process takes two or three weeks in temperature condition of 35 °C (mesophilic conditions) and pH value of 7.0 - 7.5(Table 3. 8), (Figure 3. 7).

Table 3. 8: Design parameters of anaerobic digesters.

Unit/ Equipment	Size	Unit
Number of tanks	8	#
Volume	11,250	m^3/each
Diameter	25	m
Height	35	m
Retention Time	14	d

Table 3. 9: Design parameters of biogas storage tanks.

Unit/ Equipment	Size	Unit
Number of tanks	2	#
Volume	4,000	m^3/each
Diameter	22	m
Height	17	m

The last products of this process are the solid matters. The produced gas is stored in the gas storage tanks (Figure 3. 8). Design parameters of gas storage tanks is given in Table 3. 9. The biogas consist of approximately 65% methane, 31% carbon dioxide and 4% other gases (Ozalp, 2005).

The biogas is used for producing electricity and heat in anaerobic digester.

Figure 3. 7: Photograph of anaerobic digesters.

Figure 3. 8: Photograph of biogas storage tanks.

7. Digested Sludge Thickener: Sludge is become more condensed in digested sludge thickener (Table 3. 10), and outlet dry solid concentration is varied from 3 to 4 %. The working principle of the digested sludge thickener is the same with primary sludge thickeners. Thickened sludge is sent to mechanical dewatering unit while the water in the surface is recycled to the head of the system.

8. Dewatering Unit: In this part, sludge has been flocculated by using cationic polyelectrolyte, and dewatered by using belt- filter press system (Table 3. 11).

Table 3. 10: Design parameters of digested sludge thickeners.

Unit/ Equipment	Size	Unit
Number of tanks	5	#
Volume	1,964	m^3/each
Surface Area	491	m^2
Diameter	25	m

Design parameters shows that 3 x 10^{-3} kg polyelectrolyte is added per kg of dry solids. Dry part increases from 3-4% to 20-25%. Filtered water in belt- filter press system is sent to head of the system, and solid part is also stored in biosolid storage area. Even though it is intended to use biosolid more efficiently, yet there has not been any decision for choosing the way of biosolid usage (Gizlice, 2011).

Table 3. 11: Design parameters of dewatering unit.

Unit/ Equipment	Size	Unit
Number of tanks	6	#
Max Total Capacity	180	m^3/hrs
Area	1,450	m^2

9. Biogas power station: Installed capacity of biogas power station is 13.72 MW. Maximum total efficiency of the motors is between 65-70 %. The electricity and thermal energy efficiency of the station are between 25-30% and 60-70% , respectively. The plant has recovered 80% of its electrical energy demand.

3.3 Modelling Approach

3.3.1 Influent wastewater

Influent wastewater characteristic can be a function of factors such as water usage, socio-economic factors. Hence, understanding the nature of wastewater means also to know how the materials in the wastewater behave in activated sludge process. As having significant effect on system performance, influent wastewater characteristics should be determined carefully.

The photo of mixing point of recycle stream and influent of ACWTP is shown in Figure 3. 9.

Figure 3. 9: Mixing point of recycle stream influent at ACWTP.

Characterization:

Influent wastewater characterization has a significant effect on effluent quality (Insel *et al.,* in press). The influent wastewater characterization of ACWTP belong the year 2009 is summarized in Table 3. 12. The mean values are calculated from daily collected data and standard deviations obtained as a result of statistical analysis. Collected daily average COD, BOD_5, TSS, and VSS data was used for wastewater characterization. There is no available TKN and TP measurement data, there is only NH_4 and PO_4 measurements. Hence TKN and TP values were assumed, according to range of TKN:NH_4 and COD:TP ratios from various domestic wastewaters (DWW) in Turkey (Table 3. 13 and Table 3. 14). Secondly, the proper ratios were selected as 1.43 for TKN: NH_4 and 44 for COD:TP. Afterthen these values were compared with the literature. Necessary calculations were done, annually average TKN concentration has been set to 23.6 mg/l and TP set to 7.4.

Table 3. 12: Average influent wastewater characterization.

Parameter	**COD (mg/l)**	**BOD_5 (mg/l)**	**TKN (mg/l)**	**TP (mg/l)**	**TSS (mg/l)**	**VSS (mg/l)**
Mean	326	188	23.6	7.4	150	137
Std.Dev.	48	29	5.45	1.72	18.4	16.7

Table 3. 13: COD:TP and TKN:NH_4 ratios.

Wastewater	COD:TP	TKN:NH_4
Kadikoy*	54.00	1.66
Fethiye*	41.73	1.50
Marmaris*	47.93	1.43
Bodrum*	49.09	1.38
Tuzla*	59.32	1.50
Pasakoy#	62.35	1.27
Range	41.73-65.35	1.27-1.66

*(Cokgor, 1997), # (Insel *et al.,*2011)

As a result of comparision with Cokgor's (1997) research COD, TSS, TKN, TP and VSS concentrations of ACWTP are within the ranges of literature.

Table 3. 14: Variation of wastewater characteristics in Turkey.

Wastewater	TKN (mg/l)	COD (mg/l)	TP (mg/l)	TSS (mg/l)	VSS (mg/l)
Istanbul*	61	530	8.5	315	220
Istanbul#	45-118	315-870	7-11.6	220-504	190-430
Fethiye	20-37	190-245	3.3-9	100-270	90-235
Marmaris	31-42	215-480	5.6-9	145-265	145-230
Bodrum	32-57	335-530	7.0-11	140-290	120-230
Tuzla	60-120	485-715	2.0-23	240-400	200-360
General Range	20-120	190-870	2.0-23	100-504	67-430

*Pasakoy (Insel et al., 2011) , #Kadikoy and others (Cokgor, 2007).

COD fractionation:

Fractionation of the organic material is an important step to define wastewater characteristics. Soluble biodegradable COD (S_S) and particulate biodegradable COD (X_S) participates the biochemical reactions in the first place. Soluble inert COD (S_I) is non-biodegradable and never participates to biochemical reactions. As a result, S_I joins to effluent wastewater. Particular inert COD (X_I) never participates to biochemical reactions, and it is settled with sludge.

Achieving the correct wastewater characterization helps to get successful results to predict oxygen demand, organic material removal and MLSS concentrations (WERF, 2003).

Table 3. 15: Average COD fractionation of influent wastewater of ACWTP.

Unit	C_T	S_S	X_S	S_I	X_I
mg/l	326	54	215	15	42
% of C_T	-	16.4	66.0	4.6	13

COD fractionation was done by taking into account the literature review and verified with the simulation (Table 3. 15). In literature; S_S value range changes between 5 and 20.0 mg/l, X_S value from 60.0 to 84.0 mg/l, S_I value from 2.0 to 7.0 mg/l and X_I value from 7.0 to 18.0 mg/l according to various studies on domestic wastewater (Table 3. 16).

In addition COD fractionation of ACWTP was set to 16.4% for S_s , 66% for X_s, 4.6% for S_I, and 13% for X_I of total COD.

Table 3. 16: Variation of COD fractionation for different DWW.

Literature data for DWW		S_S (%)	X_S (%)	S_I (%)	X_I (%)
South Africa	**General***	20.0	62.0	5.0	13.0
Denmark	**General**[#]	20.0	60.0	2.0	18.0
Turkey	**General**[']	10.0	81.0	2.0	7.0
	Atakoy°	9.0	68.0	7.0	16.0
	Pasakoy[x]	5.0	84.0	4.0	7.0
Range		5.0-20.0	60.0-84.0	2.0-7.0	7.0-18.0

*(Ekama et al.,1986), [#](Henze, 1992),['] (Orhon et al., 1994),° (Tas et al., 2009), [x] (Sozen et al.,2008)

3.3.2 Configuration and operational parameters

Beside determination of influent wastewater characterization; setting up the configuration is also important in modeling studies. First configuration was built in simulator based on the actual plant data (Figure 3. 10).

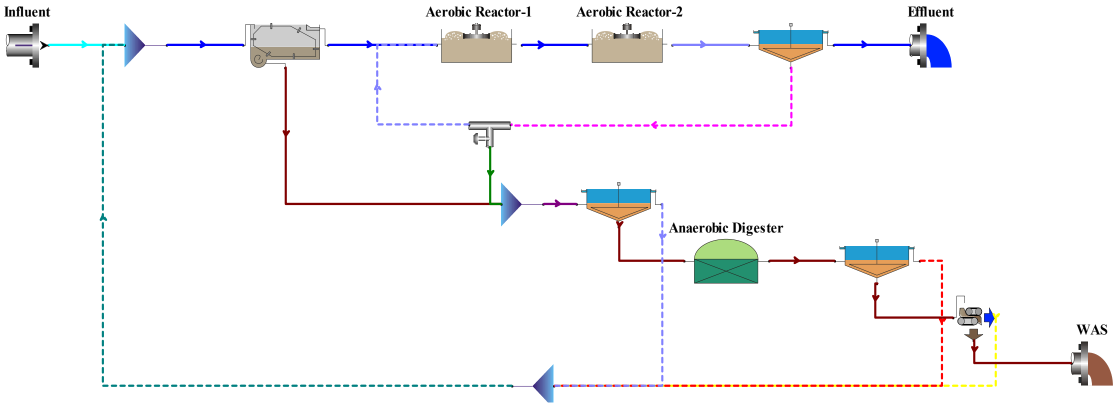

Figure 3. 10: Configuration of ACWTP figured in the simulator.

Actual plant operation data shows that average MLSS and MLVSS concentration in aeration tank recorded as 1340 and 1005 mg/l. These concentrations are reasonably low values when compared with the literature (Metcalf and Eddy, 2003). ACWTP operated under low SRT, mean SRT value is between 2.5- 3 days. DO concentration in aeration tanks is around 3-3.5 mgO_2/l (Gizlice, 2011). Recycle ratio was recorded as around 0.24 in actual operational data. In Case 1, SRT is determined as 2.72 days. It was observed that most of the time 2.72 days SRT can be enough to catch recorded MLVSS concentration data during operation, and effluent quality in actual plant operation data. MLVSS and MLSS concentrations are on average 1001 and 1342 mg/l respectively in simulation (Table 3. 17) . In addition, DO concentration is 3.4 mgO_2/l.

Table 3. 17: Summary of operational data of ACWTP at 16°C.

Parameter	Unit	Actual Plant Operation	Model Simulation
		Activated Sludge Parameters	
SRT	days	2.5-3	2.72
MLVSS	mg/l	1005	1001
MLSS	mg/l	1340	1342

3.3.3 Mass balance of the plant

Setting up of material mass balance was controlled by the simulation results, and shown in Figure 3. 11. 43% of inflowing COD to primary clarifier is removed by primary sludge, 18% of the COD is removed by excess sludge, and 12% of the COD is discharged to natural environment via effluent.

Sludge removal part of the system consists of raw sludge thickener, anaerobic digester, digested sludge thickener and dewatering unit. 29% of inflow COD, in other words 48% of total of primary sludge and excess sludge COD has been converted to biogas and removed from the system for energy utilization. 47% of total inflowing sludge has been removed from the system via dewatering operation.

3.3.4 Activated sludge modelling

The definition of a model concept can be a purposeful description of a system of interest (Wentzel and Ekama, 1997). Modeling has an important aspect “Time”. Aspect of time can be divided into two processes called as dynamic state and steady state (Henze *et al.*, 2008). Dynamic state, which is commonly used in modeling approach, means the variations occur as a function of time. Usually, the dynamics of wastewater is considered in hourly, daily sometimes yearly (Henze et al.,2008). In this part of the study the development of activated sludge model and how the model structures reported are briefly explained below:

First proposed model, which only deals with carbon removal under aerobic conditions, for activated sludge process was developed at the beginning of 1980s by a research group in University of Cape Town (Dold et al.,1980). In 1981, Van Haandel et al., incorporates the denitrification process to the model. However, the best known model for activated sludge system is known as Activated Sludge Model No.1 (ASM 1) (Figure 3. 12), which is published by International Association on Water Pollution Research and Control (IAWPRC) (Henze et al., 1987). ASM 1 includes carbon removal, nitrification and denitrification there is no biological enhanced phosphorous removal (BEPR) in this model (Barker and Dold, 1997a).

Illustrated schematic diagram in Figure 3.10 represents ASM 1 model components transformations under aerobic and anoxic conditions.

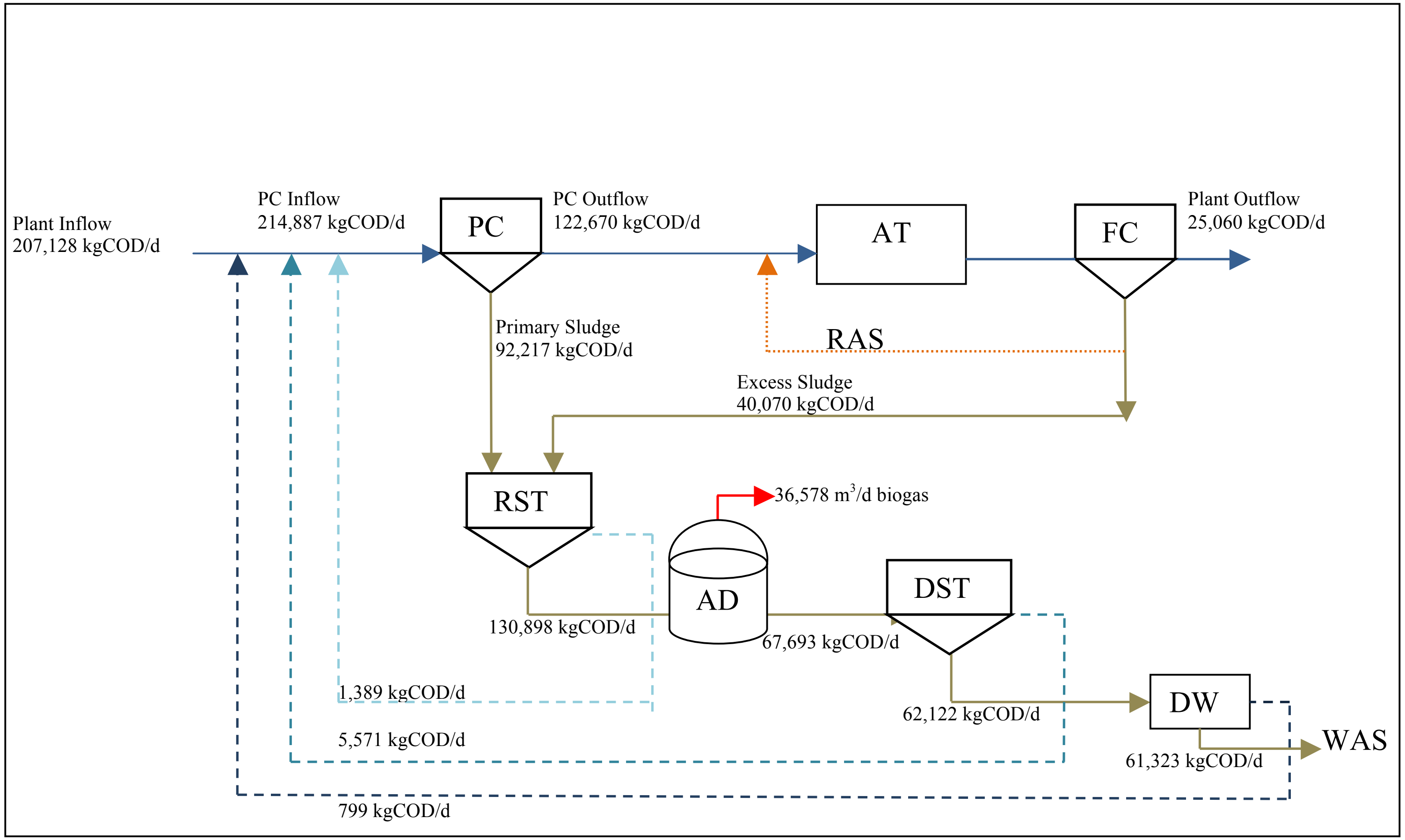

Figure 3. 11: Mass balance of ACWTP.

This simple process can be explained as S_s (readily biodegradable substrate) has been taken by X_H (biomass) for growth process, meanwhile they use O_2 (oxygen). Then the decay process cause the generation of X_P (particulate microbial product) with f_P fraction. Remained (1- f_P) fraction transferred to X_S (slowly biodegradable substrate) for aerobic hydrolysis process. Under anoxic conditions, the difference is that nitrate plays role as an electron acceptor instead of oxygen.

Later, IAWPRC task group has added the BEPR to ASM 1 and named as ASM 2 model. The phosphorus accumulating organisms (X_{PAOs}) store acetate (S_A) as polyhydroxyalkanoate (X_{PHA}) at the expense of VFA. In addition nitrogen components can be derived from COD components with a fraction.

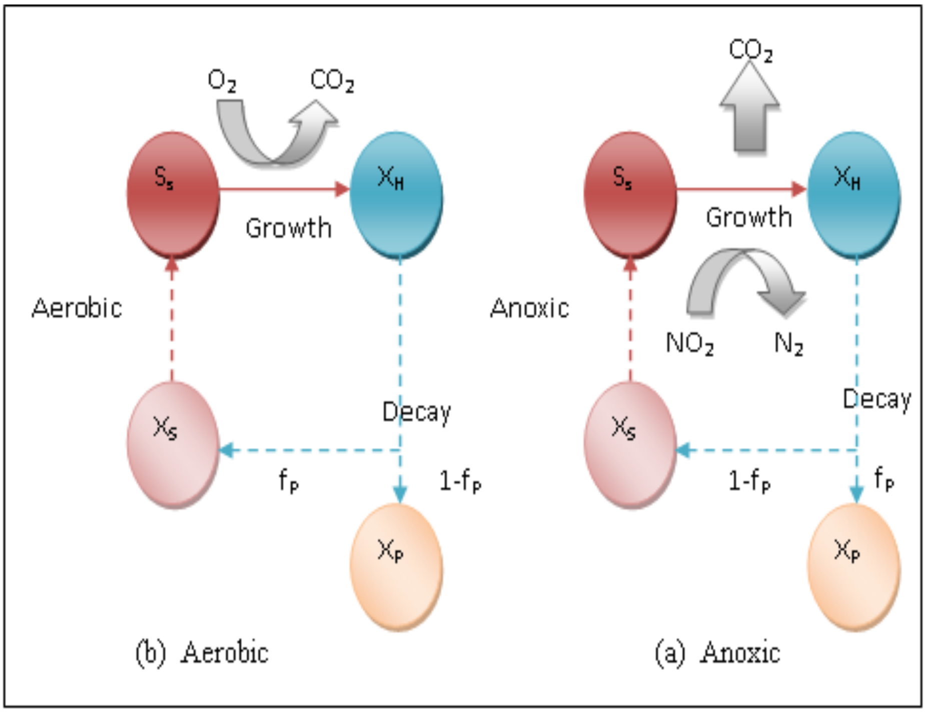

Figure 3. 12: Schematic diagram of ASM1 components under (a) aerobic, (b) anoxic conditions from (Henze et al., 1987).

The most important feature of this model is to emphasize aerobic phosphorus uptake. ASM 2d model builds on the ASM 2 model (Figure 3. 13); it includes also denitrifying activity of phosphorus accumulating organisms (PAOs). ASM 3 model (Figure 3. 14) was later developed for N removal, this model built also for supplying the deficiency of ASM 1 (Gujer *et al.,* 1999).

General activated sludge model (GASM) issued by Barker and Dold (1997a), has been developed for general model of biological nutrient removal.

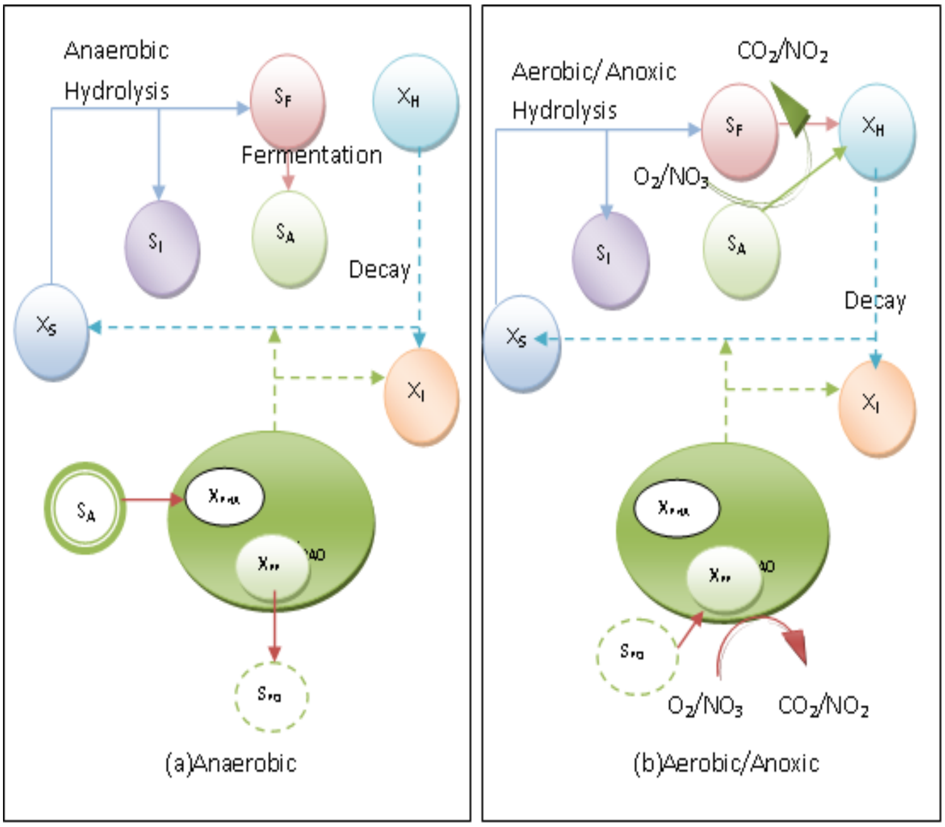

Figure 3. 13: Schematic diagram of ASM2/2d components under (a)anaerobic, (b) aerobic (ASM2/2d) and anoxic (ASM2) conditions from (Henze et al., 2000).

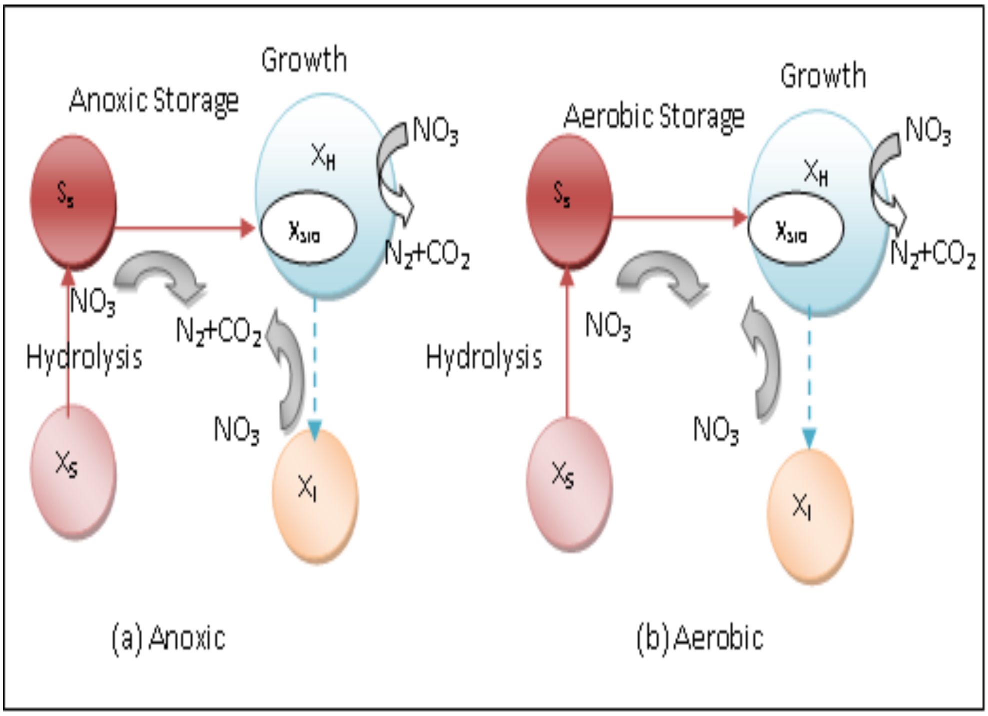

Figure 3. 14: Schematic diagram of ASM3 components under (a)anoxic,(b)anaerobic conditions from (Henze *et al.,*2000).

There are some differences between GASM model and ASM 2 model, they are listed as following:

- Number of the components in both models is the same, 19, but only 14 components are the same.
- A number of the processes are modelled differently in the two models; therefore, the parameter values may not be directly comparable.
- The ASM2 model divides all parameters into particulate (X) and soluble (S). The differences from the more definitive nomenclature system used here: (Z), biomass concentration (COD units); (S), substrate concentration (COD units) and oxygen concentration (COD units); (N), nitrogen concentration; (P), phosphorus concentration.
- The ASM2 model also excludes the processes such as anoxic growth of poly-P organisms and ammonification.
- In a number of cases, the ASM2 model uses the same parameter name for different purposes, for instance the switching function parameter (K_p) has two different values in ASM2 model, depending on whether it is used in the growth process or polyphosphate storage process.

GASM (Barker and Dold, 1997a) consist of two additional processes to previous studies; these are the COD loss and denitrification with anoxic P-uptake by PAOs. According to the Barker and Dold (1995), COD loss is expected during anaerobic hydrolysis, aerobic hydrolysis, fermentation and acetate uptake by Poly-P organisms. The considerable point in this model is decay of Poly-P organisms. Poly-P organisms consume oxygen during their decay process, so the decay process has been formulated with 13 reactions related to electron acceptor conditions. After the fermentation of COD to VFAs (S_{bsa}), VFAs is taken up by Poly-P (Z_P) organisms and stored as PHB (S_{PHB}) (Figure 3. 15). Stored PHB is used later for growth and P-uptake under aerobic and anoxic conditions. If bulk phosphate becomes limiting, growth of Poly-P organisms and P-uptake rates are affected. Thus, there is high $P_{PP\text{-}HI}$ and low $P_{PP\text{-}LO}$ weighted components within Poly-P organisms.In spite of there is various kind of model used for WWTP optimization, model selection should express the purpose (Vanrolleghem *et al.,* 2003).

For this reason, GASM model proposed by Barker and Dold (1997), which include organic carbon removal and nutrient removal processes, was selected for this study.

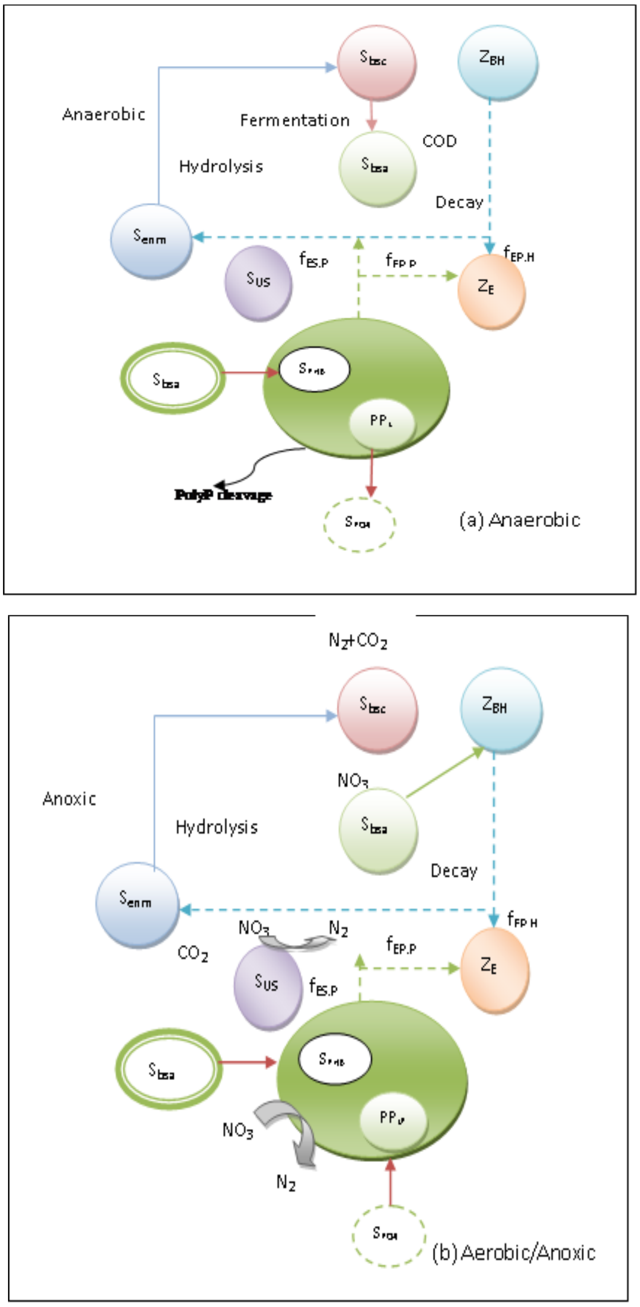

Figure 3. 15: Schematic diagram of B&D components under(a) anaerobic (b)aerobic/ anoxic conditions from (Barker and Dold, 1997a).

3.3.4.1 Software selection

Software selection was done among seven major activated sludge simulator. These simulators are summarized in (Table 3. 18).

In this study BIOWIN simulator program was used to control effluent standards, efficiency of the plant, biogas production potential; and to make a plan for decreasing plant facility costs.

Table 3. 18: Seven major AS software.

Simulator	Offered Models	Location	Website
ASIM	ASM1 adapted,ASM2d, ASM3	Switzerland	www.eawag.ch
BIOWIN	Barker & Dold (1997), substitution with ASM 1-3	Canada	www.envirosim.com
EFOR	ASM1, modified ASM2d and ASM3	Denmark	www.dhi.com
GPS-X	IWA models ASM1-3 and models attributed to Dold	Canada	www.hydromantis.com
SIMBA	ASM1, ASM2d,ASM3, ASM3biop	Germany	www.ifak-system.com
STOAT	ASM1, ASM2d, unmodified ASM3	U.K.	www.wreple.co.uk
WEST	ASM1	Belgium	www.hemmis.com

BIOWIN is Microsoft based software used in analysis of wastewater treatment plants. It has lots of process units to build a specific treatment plant. Using BIOWIN simulator in this study was an advantage to get expected results under the guidance of GASM (Barker and Dold, 1997b).

3.3.4.2 Systematic calibration protocol

Computer based simulations is satisfactory tool to perform different unit operations linked to each other. Simplified task stages for simulation can be useful way to carry out the modelling process.

These stages can be listed as (1) build a configuration of the plant on the simulation, (2) data gathering use for calibration, (3) calibrating the simulator, (4) verifying the calibrated simulator, (5) applying the simulator for intended purpose (WERF, 2003). Due to its simplicity WERF protocol was applied to ACWTP for model calibration.

Step 1 includes setting up the plant configuration by collecting of physical plant data, influent loading data and plant performance data.

After establishment of the configuration, Step 2 is placed for setting assumptions and collecting additional data based on historical operational plant data, or new full scale and laboratory scale measurements.

Step 3 has four different levels; basic definition of the levels can be seen in (Figure 3. 16). After all of these steps, the model validation is the last step of the protocol.

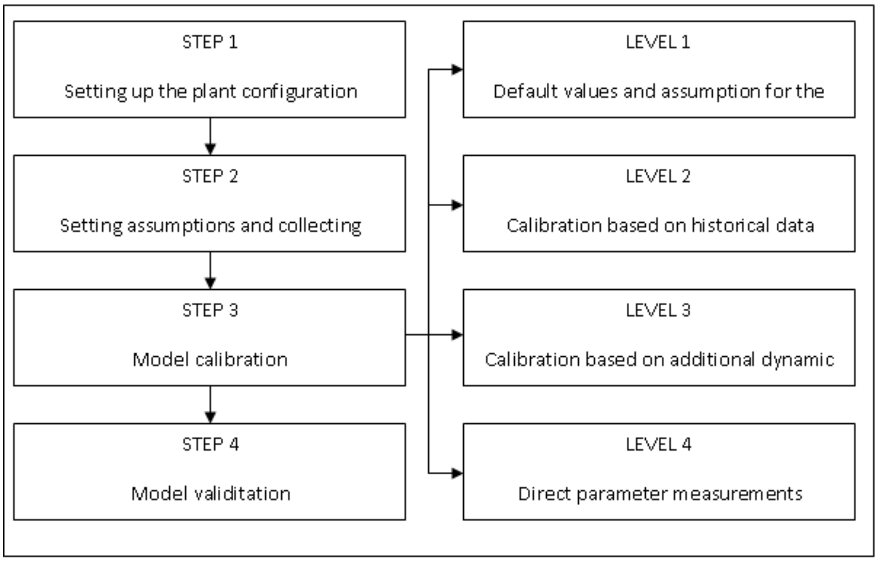

Figure 3. 16: Summary of WERF protocol (Melcer *et al.,* 2003) based on the study of Sin *et al.,*2003.

3.3.4.3 Model calibration

In this part of the study, the model was calibrated to fit the average effluent concentration and sludge waste data. Initially, the steady state model was run for activated sludge model with default parameters and average influent characterization of the wastewater. Aeration rates, recycle streams etc., and highest the biomass concentrations in aeration tank were controlled. Another imported issue to be taken into account is that the sludge production and the mass balance of the system should be fit with actual data (Roeleveld and van Loosdrecht, 2002; Vanrolleghem et al., 2003; Petersen et al., 2003). The effluent ammonia nitrogen ($NH_4.N$), nitrate nitrogen ($NO_3.N$) and phosphate phosphorus ($PO_4.P$) were used to calibrate the model. The model parameters were manually tuned according to (Insel et al.,2006) by comparing the daily average $NH_4.N$, $PO_4.P$ and COD, TSS concentrations for the year 2009. After getting verification good fit for yearly average data, the verification was repeated for mean values of each month belong to year 2009.

Solid production, digester gas production and sludge wasting was checked with simulator under steady state conditions. Nitrification is accomplished by two group of autotrophic bacteria ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB). Nitrogen is removed from wastewater by nitrification and denitrification process where NH_4 oxidized to NO_2 and then N_2.

Table 3. 19: Calibrated DO half saturation parameters.

Parameter	Unit	Default	Calibrated
Heterotrophic	mgO_2/l	0.05	0.01
Aerobic Denitrifiers	mgO_2/l	0.05	0.01
Ammonia Oxidizers	mgO_2/l	0.25	0.05
Nitrite Oxidizers	mgO_2/l	0.50	0.05

According to Beck (2007), low DO levels can achieve to reduce aeration requirement. As a result of steady state simulation with default parameters, DO half saturation levels were found considerably high for heterotrophic microorganisms, aerobic denitrifiers ammonia oxidizers and nitrite oxidizers. Thus, DO half saturation levels calibrated accordingly (Table 3. 19). In addition, max specific growth rate for AOB and NOB were also adjusted based on the best fit the actual plant data (Table 3. 20).

Table 3. 20: Calibrated kinetic parameters and kinetic parameters from literature.

Parameter	Unit	Default	Calibrated	Literature*
Ammonia Oxidizing Bacteria (AOB)				
Maximum Specific Growth rate	day^{-1}	0.90	0.80	0.76,0.32,1.4, 0.8
Nitrite Oxidizing Bacteria (NOB)				
Maximum Specific Growth rate	day^{-1}	0.70	0.85	0.81,0.9

*(Rittmann and McCarty, 2001),(Jang et al., 2005),(Hunik et al.,1994),((Insel *et al.,* in press).

3.4 Upgrade Options for BNR

3.4.1 Configuration and operational data

The simulation was used to build BNR system for Case 2. Initially, COD: TKN ratio after primary settling was considered during selection of the configuration. It was seen that the ratios are not significantly enough to investigate the feasibility of BNR process. One of the reasons that only total COD evaluated, and it cannot be ensure sufficient soluble biodegradable substrate will be available in the anaerobic zone. Another reason is that they do not indicate the effect of internal recycles. Thus, computer simulation was used to choose configuration which is expected to provide the feasible nitrogen removal by setting the best results on dicharge concentrations. As a result of this evaluation A^2O configuration was selected to carry out BNR process. Dimensioning for anaerobic/anoxic/aerobic tanks were done by taking account of ratio $0.2 \le V_D / V_{AT} \le 0.5$ and ratio $V_{ana}/(V_{ana} + V_A + V_D) \le 0.15$ (ATV, 2000). Hence, $V_D / (V_A + V_D)$ ratio and $V_{ana}/(V_{ana} + V_A + V_D)$ ratio were selected as 0.38 and 0.10. Dimensions for other units of the plant (anaerobic reactor for biogas utilization, settling tanks, thickeners etc.) were assumed to be same as actual plant data. A^2O configuration was applied on simulation (Figure 3. 17).

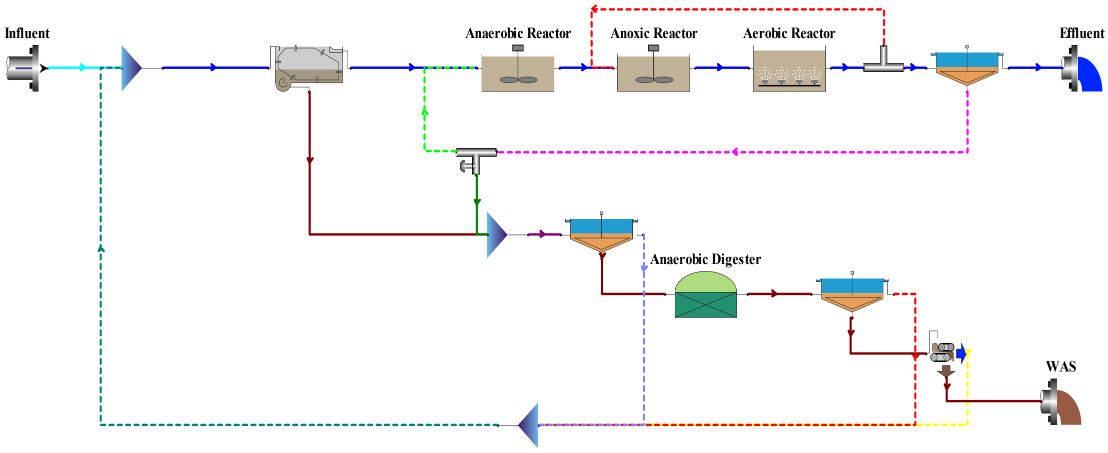

Figure 3. 17: Configuration of BNR system figured in the simulator.

SRT for BNR system was chosen 10.5 days due to nitrifiers (autotrophic bacteria) need more time than hetetrophic bacteria for their metabolic activities. Average MLVSS and MLSS concentrations in aeration tank are recorded 1883 and 1017 mg/l as a result of simulation (Table 3. 21). In addition DO concentration was taken 2 mgO_2/l.

MLSS and MLVSS concentrations are significantly low when compared with literature (Metcalf & Eddy, 2003). The reason of taking low concentrations is to be close actual plant data with aiming the best comparision.

Table 3. 21: Summary of operational parameters for BNR system.

Parameter	Unit	Model Simulation
SRT	days	10.5
DO_2	mg/l	2
MLVSS	mg/l	1017
MLSS	mg/l	1883

3.4.2 Aeration requirements

In BNR system, energy consumption is expected to be more than conventional system due to oxygen demand. Oxygen transfer rate (OTR) is actual mass of oxygen transferred per day and it is key for the design of activated sludge plant (ASP) (Stenstrom and Rosso, 2010). OTR have to meet both carbonegeneous and nitrogeneous oxygen demand. Theoretical oxygen demand for nitrification process is 4.6 kgO_2 per kg NO_3 formed, and for denitrification process is 2.86 kg O_2 per kg NO_3 converted to nitrogen gas. Hence, the net oxygen demand is 1.74 kg O_2 per kg ammonia converted to N_2 (Maciolek and Austin, 2006**)**. Simulated OTR value of BNR is 89,701.2 kgO_2/d.

Additionally, type of aerator has also significant impact on energy consumption rates. According to the efficiency calculations different aerator types (Appendix A), fine bubbled diffuser is the best choice for feasible aeration energy consumption rates (Ataei, 2010). It is assumed that disc shaped fine bubble diffusers were adapted to the system. Standard aeration efficiency of surface aerator and fine bubbled diffuser were determined as 1.40 kgO_2/kWh and 2.00 kgO_2/kWh according to the Ataei (2010).

3.4.3 Mixing requirements

Anaerobic and anoxic tanks added to existing system for BNR system. These tanks need additional mechanical mixing energy. On the other hand, it is accepted that the air flow mixing supplied by fine bubble diffuser is enough to meet mixing energy requirement of aerobic tank.

Power dissipation for mechanical mixing of anaerobic and anoxic tanks were assumed $5W/m^3$, and mixing demand were calculated accordingly (see Appendix A).

3.5 Upgrade Options for Energy Recovery

Drying and incineration processes were assumed to be added on CS and BNR system in order to see upgrading options for energy recovery. Assumptions made for additional units were given in following subsections.

3.5.1 Drying process

Belt drier as a convection drier was selected to carry drying process. Its process efficiency is approximetely 90% (ATV, 2004). The total dewatered sludge is 250 t/d, and its content is 74.4% water and 25.6% TSS for CS. The calorific value of sludge is 2,500kcal per kg sludge. It is assumed that the drying process reduce the water content of sludge 10% while TSS content increases to 90%. Aiming of increase the TSS content in sludge, it is needed to evaporate approximetely 179 ton water per day. The calorific value of the dry solid was calculated (see Appendix B), and it is found as 9,765.6kcal per kg dry solid.

Theoretical thermal energy demand for evaporation of 1 tonne of water under normal pressure 627 kWh, and water heating from 20°C to 100°C is 93kWh, and heating of the solid matter 14kWh. Theoretical electrical energy demand varies between 70-110kWh/ton water; it is assumed that 100kWh is needed per ton water evaporation (ATV, 2004). Then the total energy requirement is average 834 kWh/t for this study.

3.5.2 Incineration process

Almost 85% (IPCC, 2006) of energy recovery is possible by utilizing heat and power. World Bank (1999) reported that using steam boiler, back pressure turbine and condensing heat exchanger together with fluidized bed reactor gives the excepted performance of energy recovery (Figure 3. 18). It is assumed that 20% of the dry matter energy content is turned electricity and 60% of it is turned to heat energy (see Appendix B). Typical value for energy consumption including all processes in incineration system is between 8-14 % of total energy produced electricity (Ozturk, 2010).

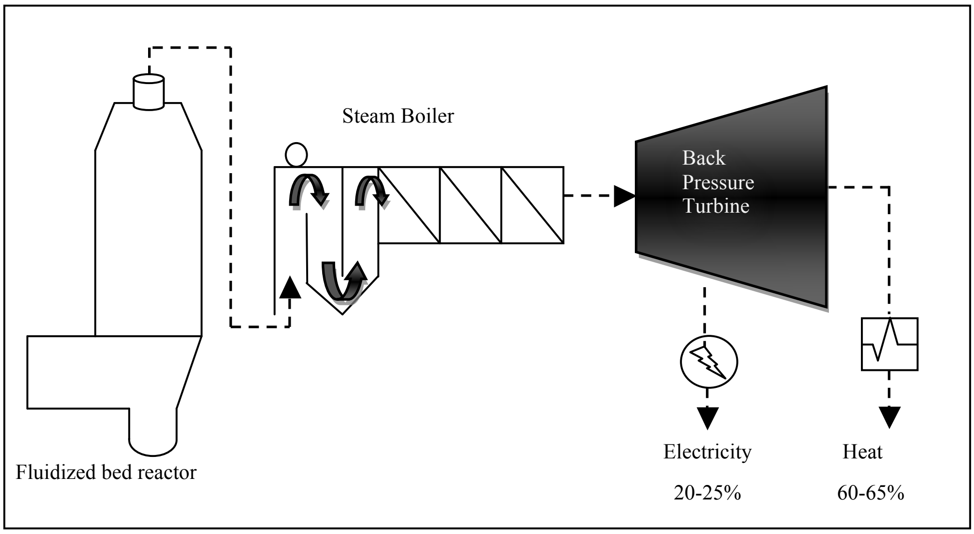

Figure 3. 18: Simple CHP generation system.

Assumed that 14% of produced electricity used for all incineration process including steam boiler, extraction turbine and condensed heat exchanger. The simple illustration of CS with additional drying and incineration system can be seen in (Figure 3. 19).

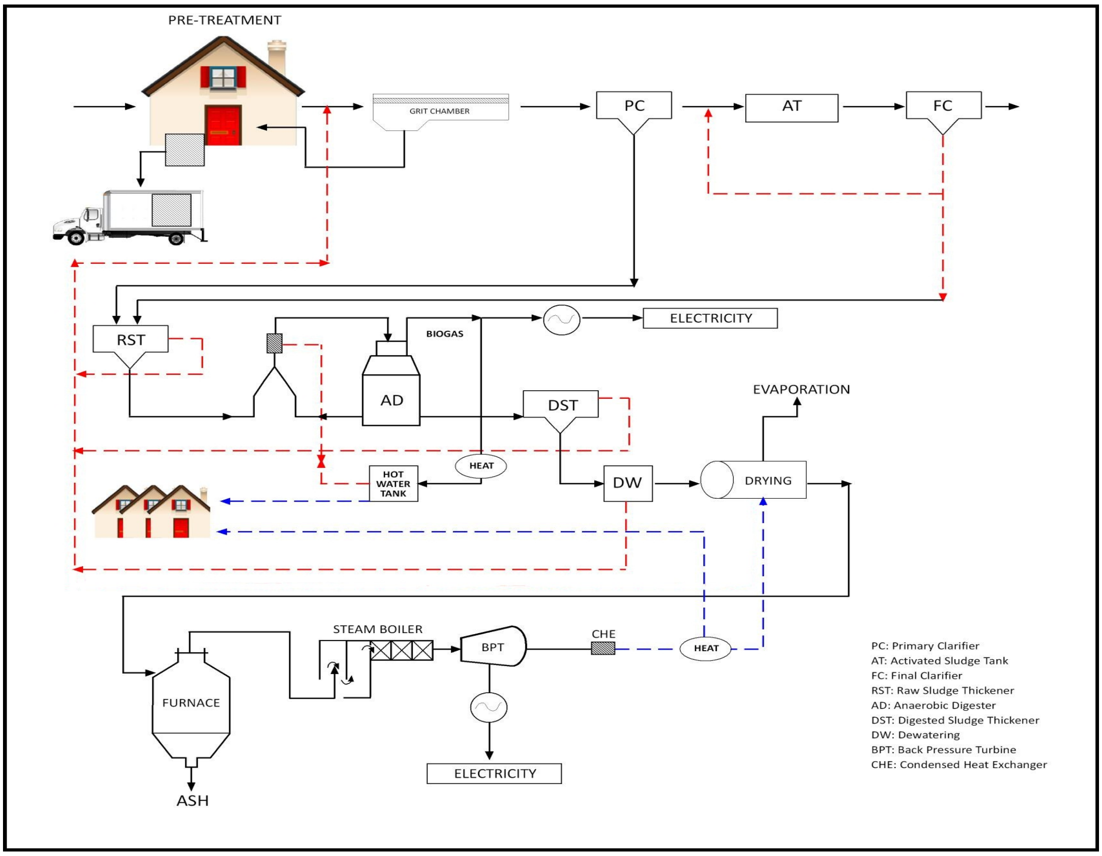

Figure 3. 19: Illustration of upgraded energy recovery option.

4 RESULTS AND DISCUSSION

4.1 Case 1: Model Based Evaluation of Actual Plant Data

4.1.1 Effluent quality

The main concern in this part of the study is the effluent quality of the actual plant operational data and the data obtained from simulation results. Total suspended solids (TSS) and chemical oxygen demand (COD) concentrations in the effluent, which were based on measurements on 24hrs composite sample (Gizlice, 2011), is given in (Table 4. 1) below:

Table 4. 1: Daily average effluent TSS and COD of ACWTP.

MONTH (2009)	TSS (mg/l)	COD(mg/l)
January	19	44
February	17	48
March	16	47
April	17	50
May	18	38
June	18	47
July	19	43
August	21	40
September	19	44
October	18	44
November	22	47
December	21	43
Max	**22**	**50**
Min	**16**	**38**
Mean	**18.8**	**44.6**
Std.Dev.	**1.8**	**3.4**

Actual plant data shows that average TSS concentration is 18.8 mg/l and COD concentration is 44.6 mg/l. Maximum concentrations for TSS and COD are 22 mg/l and 50 mg/l. Besides, maximum TSS and COD concentrations for steady state simulation results are 23 mg/l and 44 mg/l, respectively. In addition, average concentrations are calculated as 20 mg/l for TSS and 40 mg/l for COD.Comparision graphics are given in (Figure 4. 1) and (Figure 4. 2).

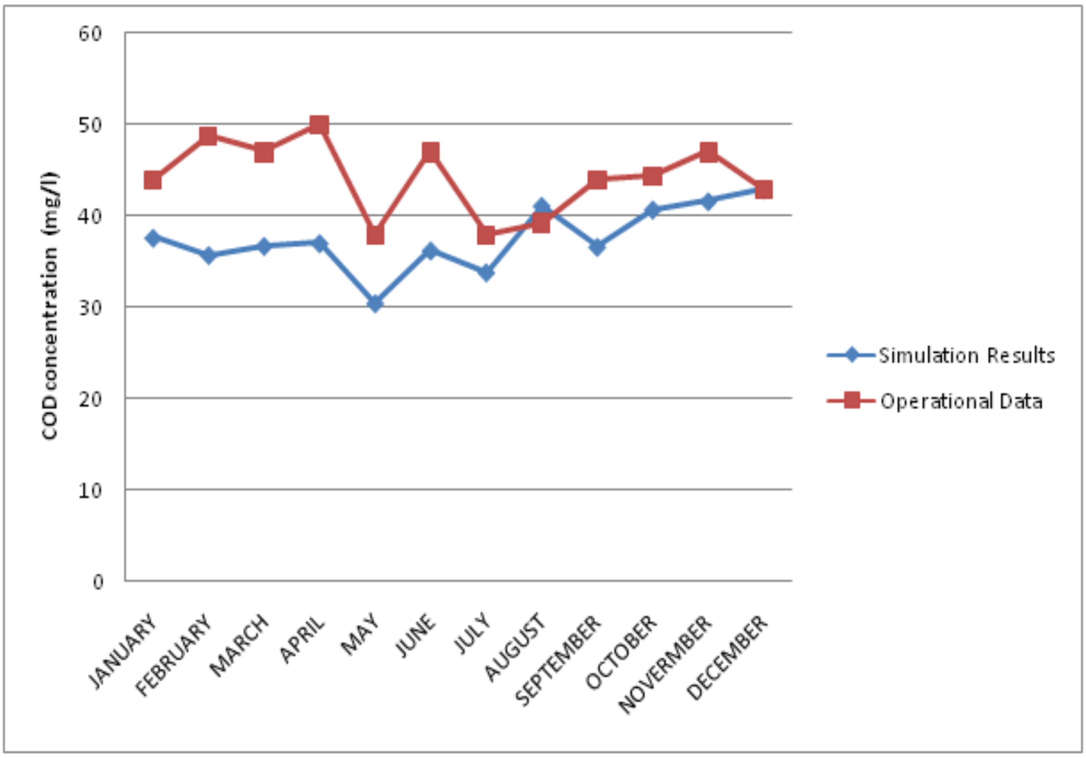

Figure 4. 1: Comparison graphic between monthly average effluent COD belong to actual plant data and simulator results.

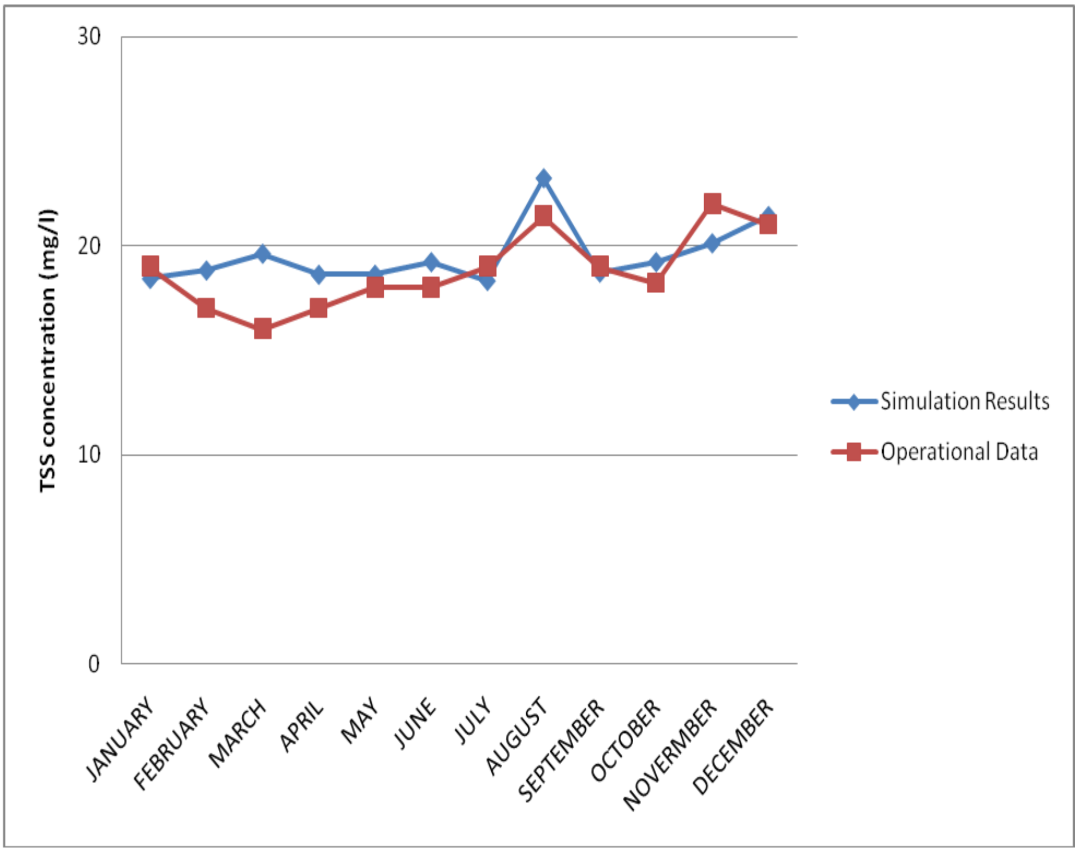

Figure 4. 2: Comparison graphic between monthly average effluent TSS belong to actual plant data and simulator results.

Related with the nutrient removal, mean values of NH_4 and PO_4 concentrations of actual plant data is reported as 13.3 mg/l and 3.9 mg/l. Simulation results gives the average value 14 mg/l and 3.3 mg/l for NH_4 and PO_4, respectively.

According to the Table 21.4 (Class 4: Domestic wastewaters, raw BOD_5 load more than 6000 kg/d and population more than 10000 people) in "Regulation on Water Pollution Control" of Turkey (2004) discharge standards for the 24 hrs composite sample measurements must be as following;

- COD must be under 90 mg/l,
- TSS must be under 25mg/l

Maximum operational data and simulation data for the COD value is 50 mg/l and 44 mg/l; they are less than 90 mg/l, so it can be said that the effluent quality of ACWTP is suitable for the standards. Additionally, maximum TSS data is also under the discharge standards for both the actual plant data and the simulation results. Efficiency averages in physical treatment unit are 68% for TSS, and 40% for COD, these values are compatible with the ranges 50-70% for TSS, and 25-40% for COD (Metcalf & Eddy, 2003). Total average removal of COD is 86% and TSS is 87%.

4.1.2 Energy balance for Case 1.a

Relationship between energy consumption and production of ACWTP were analyzed in this part of the study. Energy consumption values are based on the actual daily plant energy usage data (Figure 4. 3). Plant investigation was done by classification of the units as primary treatment stage (PT), activated sludge treatment stage (AT) and sludge treatment stage (ST). PT expressed in energy balance mainly contains screening, grit removal and primary settling processes. AT includes aeration and mixing processes. ST implies thickeners, anaerobic digestion process and dewatering process energy consumption. Another approach for energy usage in WWTPs is to find unit energy consumption, which is based on kWh per m^3 flow. Calculation results are given in (Table 4. 2). In literature, some research reported that the energy intensity per flow for the small inflow rates is higher than higher inflow rates (Ast *et al.*, 2008,). The average population equivalent reported as 2,660,729 in real date of ACWTP. Total electricity consumption in ACWTP is 27,651,602 kWh/a and 74,246 kWh/d, additionally the specific energy consumption calculated as 10.39 KWh/P.E.a.

ACWTP is in the class of the treatment plants of which served the population more than 100.000 P.E., the total consumption of WWTPs in this class is more than the smaller plants but unit flow energy consumption is less than the smaller plants (Hobus *et al.,* 2010).

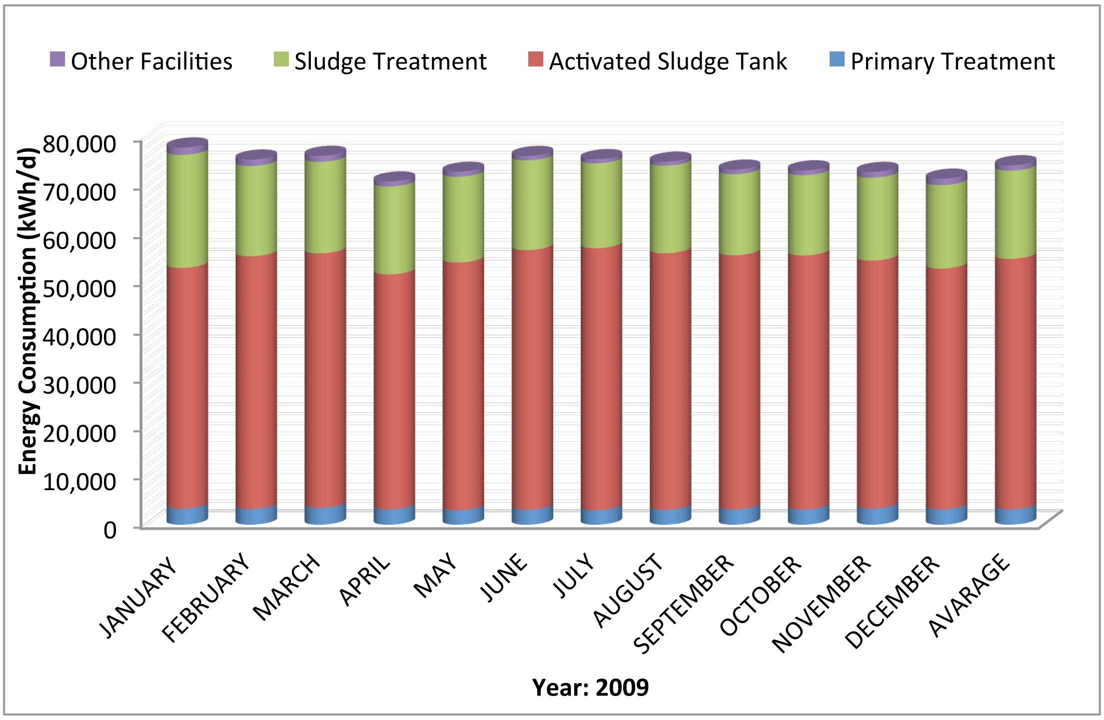

Figure 4. 3: Energy consumption rates according to the units of ACWTP.

Table 4. 2: Daily average energy consumption values calculated as kWh/m^3.

Month (2009)	Flow (m3/d)	Unit Energy Consumption (kWh/m3)
January	563,058	0.132
February	577,181	0.134
March	652,562	0.123
April	570,965	0.127
May	656,847	0.114
June	667,628	0.116
July	677,172	0.115
August	695,191	0.111
September	655,684	0.114
October	646,334	0.116
November	653,969	0.114
December	607,747	0.120
Mean	**635,362**	**0.120**
Std.Dev.	**44,239**	**0.008**
Min	**563,058**	**0.111**
Max	**695,191**	**0.134**

Investigation of ACWTP energy usage related with the inflow capacity is compatible with the literature. Average energy used to treat 1 m^3 wastewater in ACWTP is 0.12 kWh. Wastewater treatment plant, which has $150m^3/d$ inflow capacity, needs $0.42KWh/m^3$ (225MJ) electricity to treat wastewater (Metcalf, 2000). Figure 4. 4 represents the unit energy use graphic of average daily flows for ACWTP. The graphic shows that the unit energy consumption decreases per unit flow while the flow rate increases. It can be seen that energy needed to treat 1 m^3 wastewater decreases while the flow increases. As mentioned in the previous chapters in this study, ACWTP produce its own energy by anaerobic digestion process. High portion of the power consumption is supplied with the energy capacity of sludge digestion. Digestion gas of the ACWTP has 65% methane content. Annual investigation of 2009 shows that average biogas production is 36,578 m^3/d (see Appendix D), and methane production 23,776 m^3/d. Average electricity production is 59,400 kWh/d (Table 4. 4). Hence, approximately 2.49 kWh electricity is produced from 1 m^3 methane and 1.62 kWh electricity is produced from 1 m^3 biogas in the investigated plant.

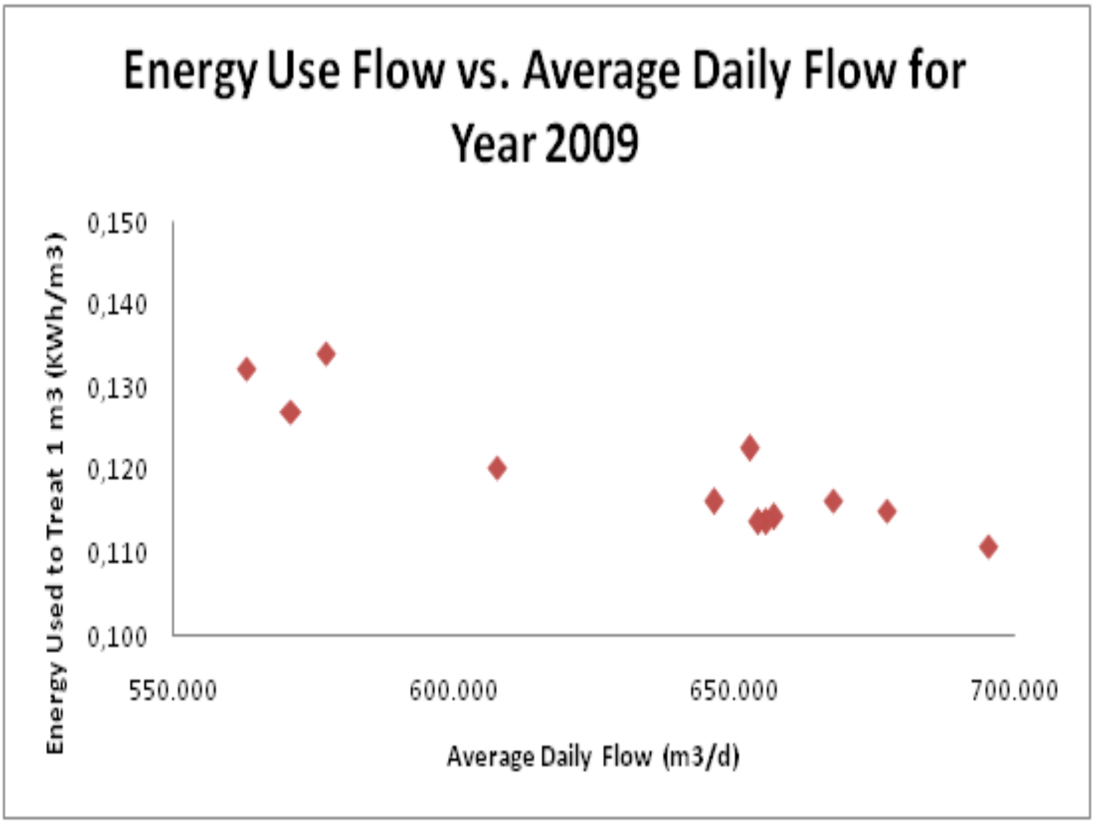

Figure 4. 4: Energy use flow vs. avarage daily flow.

Heating value of the biogas is approximetely 6.2 kWh for ACWTP.

In literature, heating value of biogas was given as 6.6 kWh (23.7 MJ/m^3) by Stafford *et al.*, 1980; DOE (n.d.) reported that 65% methane containing biogas has 6.8 kWh (24.0 MJ/m^3) heating energy; Organization for Economic Co-Operation and Development (OECD, 2004), also found that 1m^3 biogas has 6.2 kWh (22.32 MJ/m^3) heat energy and 2.2 kWh electricity. In ACWTP, biogas power station has 329,280kWh/d (13.7MW) energy potential.

The efficiency of biogas power station is 68.9%, and its thermal energy potential and electrical energy were estimated 74 % and 26 % respectively(see Appendix E). Hobus (2011) estimates that 57% of energy potential of biogas turned into thermal energy, and 33% of energy potential of biogas is turned into electrical energy, and remained part 10% is the lost energy. The actual biogas production rates and simulation biogas production rates are given in Figure 4. 5.

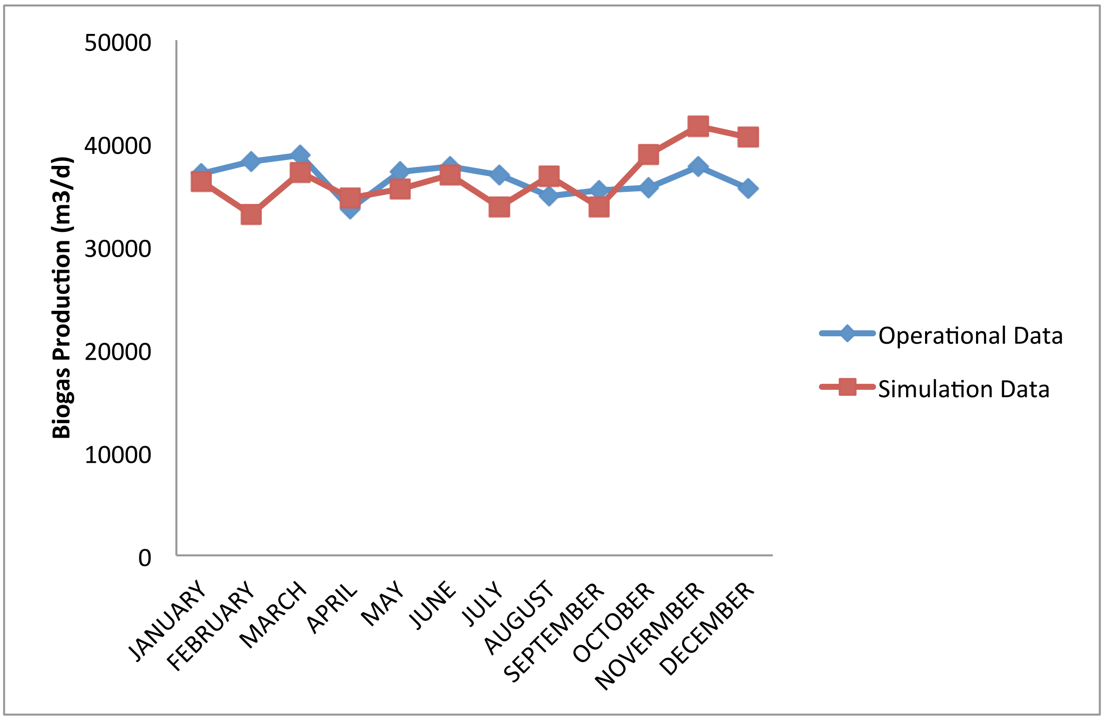

Figure 4. 5: Comparision chart of biogas production rates of ACWTP.

Comparison of existing production and consumption rates for each month was given in (Figure 4. 6). It is seen that range of energy self sufficiency of the plant is efficient, however it could be better. Existing system average energy recover is 80%. The recovery performance of the plant is in the range of 68% - 89%. All the information above were used to establish the energy balance of the existing system, and showed in (Table 4. 3).

The results of evaluation of the daily average electrical energy consumption of ACWTP show that utilizations are 3,155 kWh for primary treatment (PT), 52,761 kWh for activated sludge treatment (AT), 6,230 kWh for sludge recycling (SR) and 11,993 kWh for sludge treatment (ST). The total electricity consumption was recorded as 74,246kWh and electricity production from biogas was as59,400kWh.

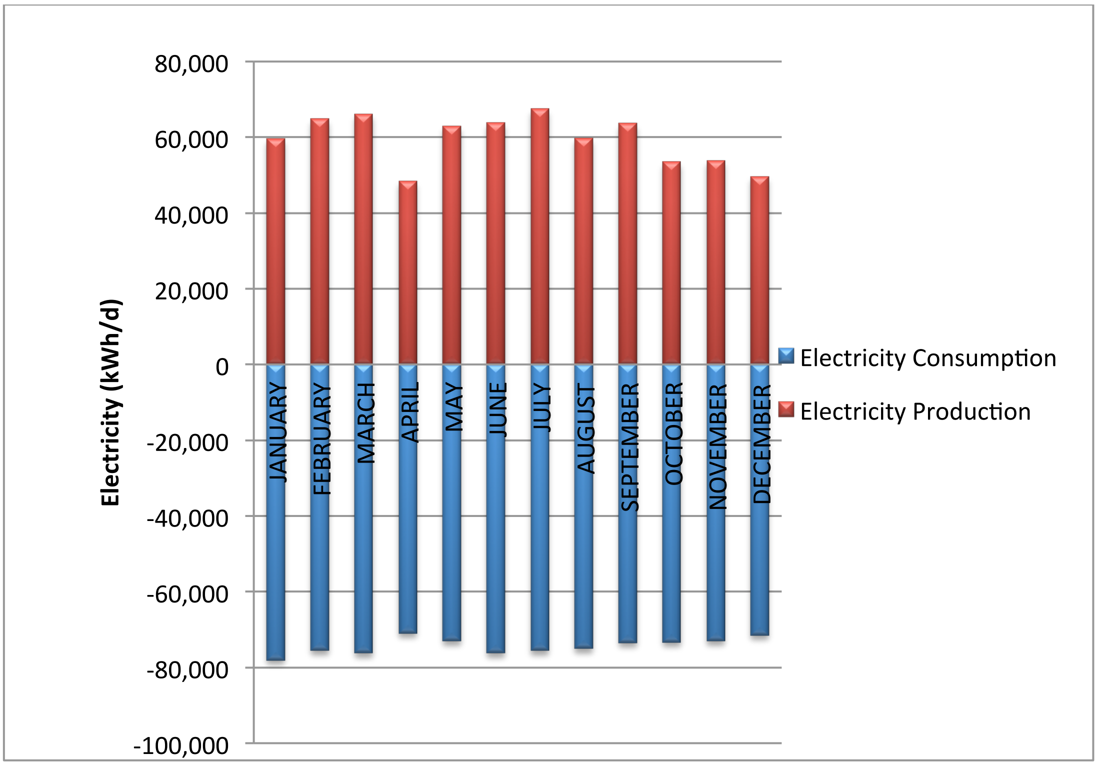

Figure 4. 6: Comparision chart of electricity production and consumption of ACWTP.

Results of the calculation of the net electricity energy shows that 14,486kWh electrical energy needs to be supplied from external sources.

Percentages of the units are as 4.2% for the primary treatment (PT), 70 % for the aerobic treatment (AT), 8.3% fot the sludge recycling (SR), 16% for the sludge treatment (ST), 1.5% for the other facilities (OF) ,(Figure 4. 7). Biogas utilization provide 80% of the electricity energy. Remained 20% is bought from “Turkiye Elektrik Dagitim A.S. (TEDAS) (Turkish Electricity Distribution Inc.)”.

The total heat energy requirement is calculated as 12,192 kWh/d for digester sludge and digester heating. (see Appendix E). Additionally, thermal energy production is found 167,384 kWh/d by anaerobic digestion (Table 4. 4).

Table 4. 3: Electrical energy balance of Case 1.a.

Process	**Energy (kWh)**
Electricity Consumption	
Primary Treatment (PT)	- 3,155
Aerobic Treatment(AT)	- 51,761
Sludge Recycling (SR)	- 6,230
Sludge Treatment (ST)	- 11,993
Other Facilities (OF)	- 1,107
Total Electricity Consumption	- **74,246**
Electricity Production	
Biogas	+ 59,400
Total Electricity Production	**+ 59,400**
Net Energy	
Net Electricity Energy	**- 14,846**

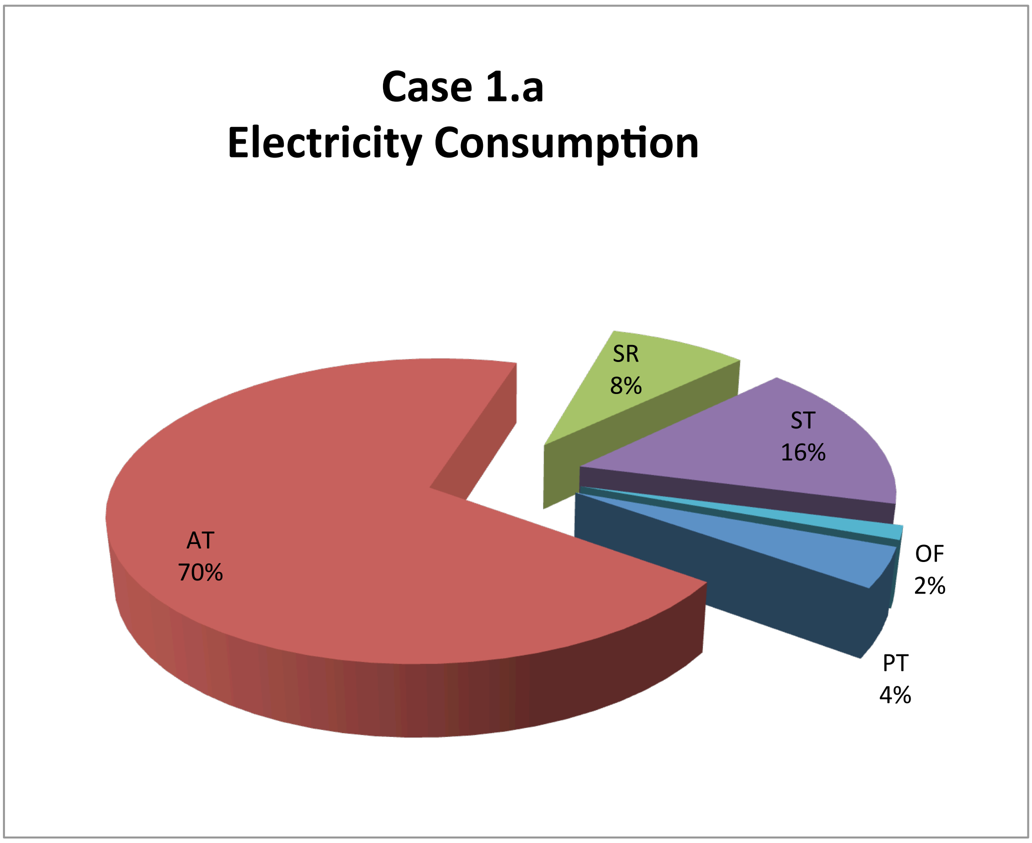

Figure 4. 7: Percentages of energy consumptions for Case 1.a.
(Total energy consumption is 74,246 kWh/d)

Table 4. 4: Heat energy balance table of Case 1.a.

Process	**Energy (kWh)**
Thermal Energy Consumption	
Anerobic Digestion(AD)	- 12,192
Total Heat Consumption	- **12,192**
Thermal Energy Production	
Anerobic Digestion (AD)	+ 167,384
Total Heat Production	**+ 167,384**
Net Energy	
Net Heat Energy	**+155,192**

4.1.3 Energy balance for Case 1.b

In this part of the study, the situation is evaluated whether drying and incineration processes are added to existing operation. Here, the drying process is only energy consumer, though incineration process is both energy producer and consumer. Incineration system (IS) was assumed to include furnace, steam boiler, extraction turbine and combined heat exchanger . The result of the recovery was determined as 80% for the actual plant. After addition of the IS and drying process, the recovery for Case 1.b is expected to increase up to 100%. Calculations of the energy production and consumption of the new units are shown in Appendix C.

As a result of the calculations, it is seen that incineration system energy recovery provide an energy efficient profile. Total electricity obtained is 205,004 kWh and total theoratical energy consumption is 112,519 kWh (Table 4. 5). Total produced electricity both by anaerobic digestion and incineration system is enough to cover 182% electricity demand of the plant. Furthermore 92,485 kWh extra electricity can be sold to outside.

According to the electrical energy recovery evaluation of the actual plant data with the assumed additional drying and incineration system, 46% of the total energy is used for aerobic tank. After aeration tank, the second energy consumer is IS with 18% of total electricity consumption. Other units are drying process (16%), sludge treatment (11%), sludge recycling (5%), primary treatment (3%) and other facilities (1%) in the order of highest to lowest percentages (Figure 4. 8).

Table 4. 5: Electrical energy balance table of Case 1.b

Process	Energy (kWh)
Electricity Consumption	
Primary Treatment (PT)	- 3,155
Aerobic Treatment(AT)	- 51,761
Sludge Recycling (SR)	- 6,230
Sludge Treatment (ST)	- 11,993
Other Facilities (OF)	- 1,107
Drying Process (DP)	- 17,889
IS electricty consumption	- 20,384.5
Total Electricity Consumption	**-112,519**
Electricity Production	
Incineration System (IS)	+ 145,604
Biogas Utilization	+ 59,400
Total Electricity Production	**+ 205,004**
Net Energy	
Net electricity	**+ 92,485**

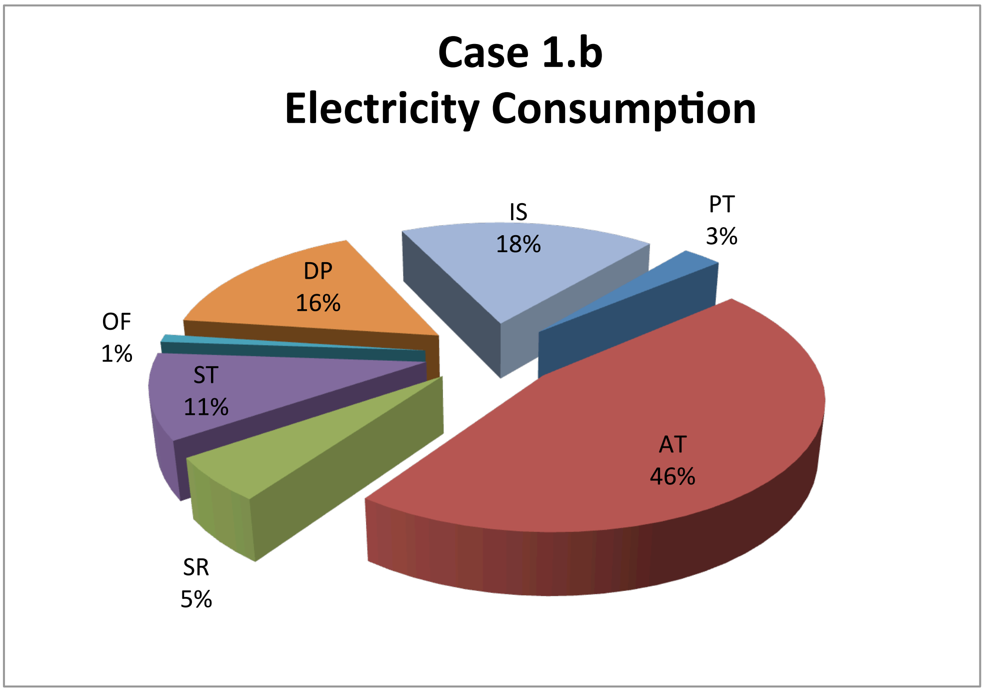

Figure 4. 8: Percentages of energy demand for Case 1.b.
(Total energy consumption is 112,519 kWh/d)

Table 4. 6: Heat energy balance table of Case 1.b.

Process	**Energy (kWh)**
Thermal Energy Consumption	
Anerobic Digestion	- 12,192
Drying Process	- 131,306
Total Heat Consumption	**- 143,498**
Thermal Energy Production	
Incineration Process	+436,812
Anerobic Digestion	+167,384
Total Heat Production	**+ 604,196**
Net Energy	
Net Heat Energy	**+460,698**

The total heat energy requirement for the drying process and anaerobic digestion was calculated 131,306kWh/d and 12,192kWh/d.

IS produces 436,812kWh/d heat energy while the heat from anaerobic digestion process is 167,384kWh/d. Heat requirement of the total plant is recovered by total heat production (Table 4. 6).

4.2 Case 2: Simulation of BNR Operations

4.2.1 Effluent quality

Simulation was applied for daily based annual average data, and compatible results obtained from simulation were given in (Table 4. 7). SRT for BNR system was choosen as 10.5days, organic carbon removal is close to actual plant data and it is around 87 % being close to actual plant data for both situation.

Table 4. 7: Summary of effluent concentrations of BNR system simulation.

Parameter	**Unit**	**Actual Plant Operation**	**CS Simulation**	**BNR Simulation**
COD	mg/l	44.6	40	39
TSS	mg/l	18.8	20	22.6
AmmoniaNitrogen-NH4.N	mg/l	13.3	14.4	1.03
Total Nitrogen	mg/l	n.a	18.5	7.84

n.a: not available

Total suspended solid removal is approximetely 85% obtained from simulation results. There is no available data for TN in actual plant operations due to the plant considers only CS.

However, results of the simulation shows that the discharge standards for TN only can be achievable where BNR system application is available. Ammonia nitrogen removed approximetely 93% in the simulation of BNR whereas it is not removed from the system in actual plant data and CS simulation.

Total phosphate and TSS did not significantly change. Phosphate ($PO_4.P$) is found 3.3 mg/l for CS and 2.5 for BNR system as a result of the simulation. In this study, it is thought that the phosphorus coming from the recycled streams after anaerobic digestion is interrupt the efficient phosphorus removal in BNR system.

The phosphorus amount recycled to the system is found 2,533kg/d. This value increases the influent phosphorus amount approximetely 39%. Metal addition was required to fit effluent phosphorus concentration with discharge standards. However, metal addition was not taken into account in this study due to its high cost effect to the system.

4.2.2 Energy balance for Case 2.a

This part of the study gives the calculation of energy production and consumption in upgraded BNR system.

Energy production calculations were based on the simulation results. Biogas utilization was reported as 28,648 m^3/d from simulation results. Here, energy consumption of PT, SR, ST and OF are assumed to be same with their actual energy demant in ACWTP.

Mechanical mixing requirement of anaerobic tank and anoxic tank are calculated as 4,681kWh, and 15,606kWh respectively (see Appendix B).

Aeration requirement for aerobic tank was calculated 44,851kWh when fine bubble diffusers are used. Total energy consumption is 93,853kWh, and production from biogas is 46,522 kWh. Net energy recovery is 49.5% of the total plant electrical energy demand (Table 4. 8).

Table 4. 8: Electrical energy balance table of Case 2.a.

Process	**Energy (kWh)**
	Energy Consumption
Primary Treatment (PT)	- 3,155
Anaerobic Tanks (AnT)	- 4,681
Anoxic Tanks (AnoT)	- 15,606
Aerobic Tanks(AT)	- 44,851
Sludge Recycling (SR)	- 12,460
Sludge Treatment (ST)	- 11,993
Other Facilities (OF)	- 1,107
Total Electricity Consumption	- **93,853**
	Electricity Production
Biogas Utilization	+ 46,522
Total Electricity Production	+ **46,522**
	Net Energy
Net Electricity	**-47,331**

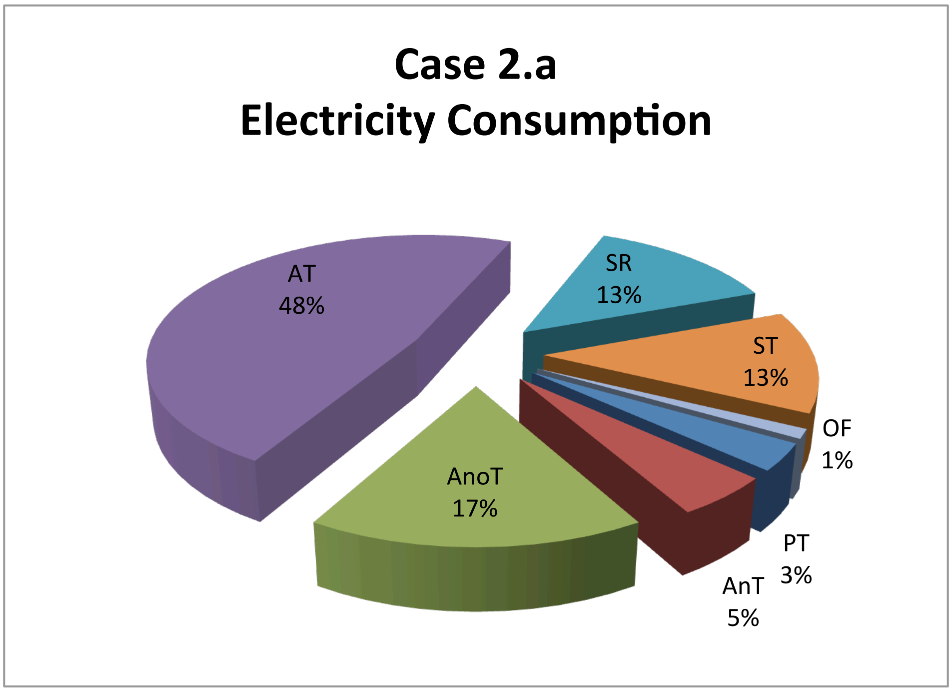

Figure 4. 9: Percentages of energy demand for Case 2.a.

(Total energy consumption is 93,853kWh/d)

Percentages of the energy usage in Case 2.a are 3% for primary treatment (PT), 5% for the anaerobic tank(AnT), 17 % for the anoxic tanks (AnoT), 48 % for the aerobic tanks (AT), 13 % for the recycle streams (SR), 13 % fot the sludge treatment (ST) and 1 % for the other facilities (OF), (Figure 4. 9).

Table 4. 9: Heat energy balance table of Case 2.a.

Process	**Energy (kWh)**
Thermal Energy Consumption	
Anerobic Digestion(AD)	- 12,048
Total Heat Consumption	**- 12,048**
Thermal Energy Production	
Anerobic Digestion (AD)	+ 131,780
Total Heat Production	**+ 131,780**
Net Energy	
Net Heat Energy	**+119,732**

Thermal energy balance of Case 2.a shows that anaerobic digestion process can produce neccesary heat energy for its own thermal process (Table 4. 9).

4.2.3 Energy balance for Case 2.b

This part of the study shows the energy production performance results (Table 4. 10) of the system which include the primary treatment, anaerobic tanks, anoxic tanks, aerobic tanks, sludge recycling, sludge treatment (sludge thickeners, anaerobic digesters, dewatering unit), drying process and incineration system with furnace, steam boiler, back pressure turbine and condensed heat exchanger.

Total energy consumption is 130,215 kWh and recovery is 141% of total electricity demand by obtaining 180,822 kWh electricity energy. Net electricity is 54,607 kWh.

Figure 4. 10 represents the percentages of energy demand for each processes in Case 2.b. It is seen that aeration tank uses 34% of the total electricity demand of the plant. Incineration system and drying system consume 15% and 13% of the total electricity respectively.

In addition, anoxic tanks, sludge recycling, sludge treatment, anaerobic tank, primary treatment are 12%, 10%, 9%, 4% and 2% respectively.

Table 4. 10: Electrical energy balance table belong to Case 2.b.

Process	**Energy (kWh)**
Electricity Consumption	
Primary Treatment (PT)	- 3,155
Anaerobic Tanks (AnT)	- 4,681
Anoxic Tanks (AnoT)	- 15,606
Aerobic Tanks(AT)	- 44,851
Sludge Recycling (SR)	- 12,460
Sludge Treatment (ST)	- 11,993
Other Facilities (OF)	- 1,107
Drying Process (DP)	- 17,000
Incineration System (IS)	- 19,362
Total Electricity Consumption	**- 130,215**
Electricity Production	
Incineration System	- 138,300
Biogas Utilization	+ 46,522
Total Electricity Production	**+184,822**
Net Energy	
Net Electricity	**+ 54,607**

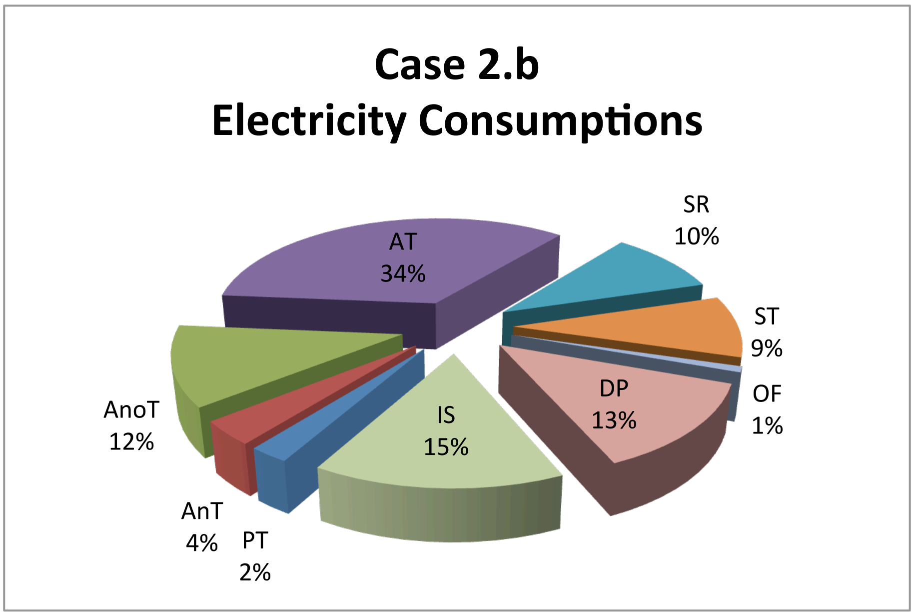

Figure 4. 10: Percentage cake of energy demand of Case 2b.

(Total electricity consumption is 130,215kWh/d)

Table 4. 11: Heat energy balance table of Case 2.b.

Process	Energy (kWh)
Thermal Energy Consumption	
Anerobic Digestion	- 12,048
Drying Process	- 124,780
Total Heat Consumption	**-136,828**
Thermal Energy Production	
Incineration Process	+414,901
Anerobic Digestion	+131,780
Total Heat Production	**+ 546,681**
Net Energy	
Net Heat Energy	**+409,853**

Total heat consumption is 136,828 kWh/d and production is 546,681kWh/d (Table 4. 11). Incineration process and anaerobic digestion is enough capacity to produce the thermal energy demand of the total plant.

4.3 Benchmarking on The Scenarios

4.3.1 Aeration

Aeration is the most effective process in WWTPs where looking from the energy demand perspective. In other words, oxygen requirement of the system determines the highest part of the energy consumption rate. Hence, type of aerator has significant impact on energy consumption rates. The comparision chart of aerator types effect on energy requirements of BNR is given in this part of the study (Figure 4. 11).

BNR system is designed to remove not only organic carbon but also nitrogen and phosphorus. Namely, BNR system needs more oxygen for efficient performance of the system. Thus, its oxygen demand increases in order to remove both organic carbon and nutrients.

There is significant additional load of TKN coming from recycled streams to head of the system. It is calculated as 1,617 kgN/d TKN added to the system from recycles, and its oxygen demand equal is 7,438 kgO_2/d.

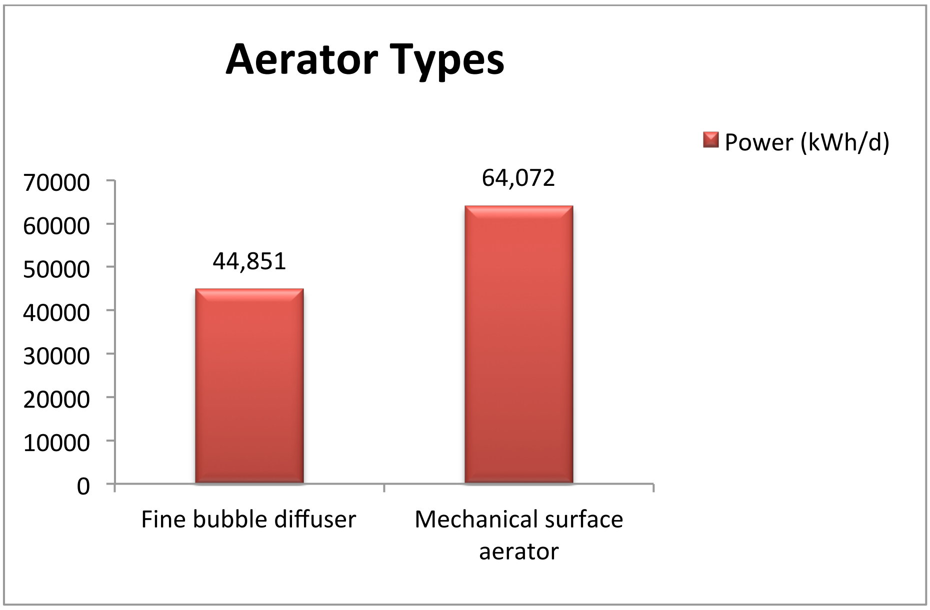

Figure 4. 11: Effect of aerator types on energy consumption.

In BNR plant 89,701kg oxygen is transferred in a day. In the situation of continuing to use existing mechanical surface aerators in Ankara Central WWTP, the electricity consumption for aeration process is 64,072kWh/d.

However, changing the aerator type to fine bubble diffuser decreases the electricity demand to 44,851kWh/d. Hence the fine bubble diffuser was choosen for aeration process in BNR system with aiming the energy efficiency.

As a result of this choice, the electricity consumption in aeration tank of CS (51,761kWh/d) seems more than electricity usage in aeration tank of BNR (44,851kWh/d), though BNR system needs more oxygen for removing both carbon and nutrients.

4.3.2 Mixing

In A^2O configuration of the BNR system, there is anoxic and anaerobic tanks different from CS. These tanks are needed to be mixed by mechanically. Mechanical mixing requirements are determined as 5 W/m^3, and total energy demand were calculated as 4,681 kWh/d for anaerobic tank and 15,606 kWh/d for anoxic tank (Table 4. 12).

Aerobic tank is assumed to be met necessary mixing requirement with fine bubbled air diffusion process. As a result, mechanical mixing requirements of anoxic and anaerobic tanks create more energy demand to BNR plant than CS plant.

Table 4. 12: Mechanical mixing requirements for BNR system units.

Parameters	Unit	Anaerobic Tank	Anoxic Tank
Mechanical mixing	W/m^3	5	5
Total Volume	m^3	39,015	130,050
Energy demand	kWh/d	4,681	15,606

4.3.3 Biogas production

Biogas production potential depends on the VSS destruction performance during anaerobic digestion. Anaerobic digester in investigated conventional system produces daily average 36,578 m^3 biogas whereas approximetely 28,648 m^3 biogas is obtained in BNR. Here, the most important effects on the biogas production rates are amount of TSS load to AD and VSS destroyed during anaerobic digestion process. TSS load decreases in BNR with increase in SRT to 10.5 days.

Likewise the VSS destruction decreases in BNR system when it is compared with CS. Table 4. 13 shows the main differences on effected factors to obtain biogas in CS and BNR plants.

Table 4. 13: Parameters for anaerobic digestion.

Parameters	Unit	CS	BNR
SRT	day	2.72	10.5
TSS load to AD	kgTSS/d	108,288	101,846
VSS destroyed	kgVSS/d	36,555	27,727
Biogas production	m^3/d	36,578	28,648
Energy production	kWh	59,400	46,522

4.3.4 Electricity recovery

Benchmarking on the possible scenarios is given in this part of the study. Electricity consuming, production and net electricity were shown in (Figure 4. 12 and Figure 4. 13). As it mentioned in previous parts of this thesis, summary of these scenarios are given below:

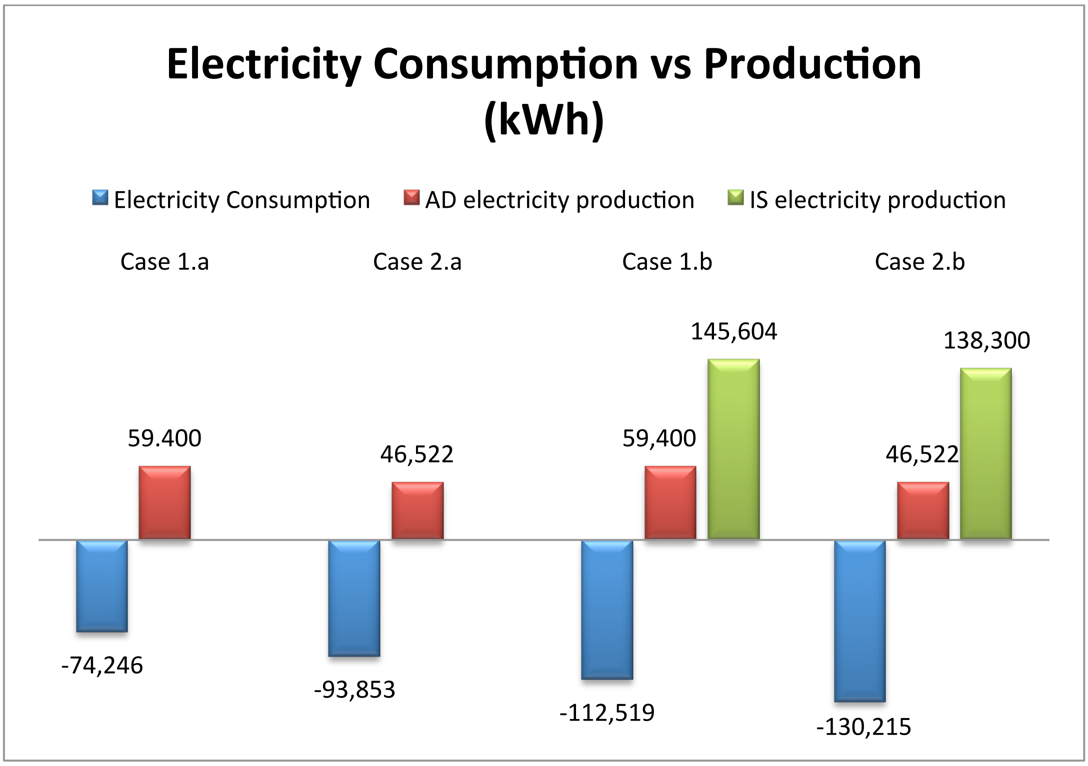

Figure 4. 12: Comparision chart of the possible scenarios for electricity.

- Case 1.a is a conventional activated sludge plant and it revocers 80% of its energy demand by producing electricity from biogas.
- Case 2.a is a biological nutrient removal plant, which has anaerobic digester as energy obtaining unit. Additionally, it recovers 50% of its energy demand.
- Case 1.b is a conventional activated sludge plant. It has anaerobic digestion and incineration processes for obtaining energy. It produces approximetely two times more energy than its total energy usage value.
- Case 2.b is a biological nutrient removal plant, and it obtain 141% of its electrical energy demand due to producing electric energy via incineration and anaerobic digestion.

The lowest energy consumer is Case 1.a. when compared with Case 2.a, the reason is that Case 2.a has additional anaerobic tank, anoxic tank and BNR system that has more oxygen requirement due to nutrient removal process. Moreover, BNR system has anoxic, anaerobic tanks which needs extra mechanical mixing units; accordingly, the energy demand of the system increases.

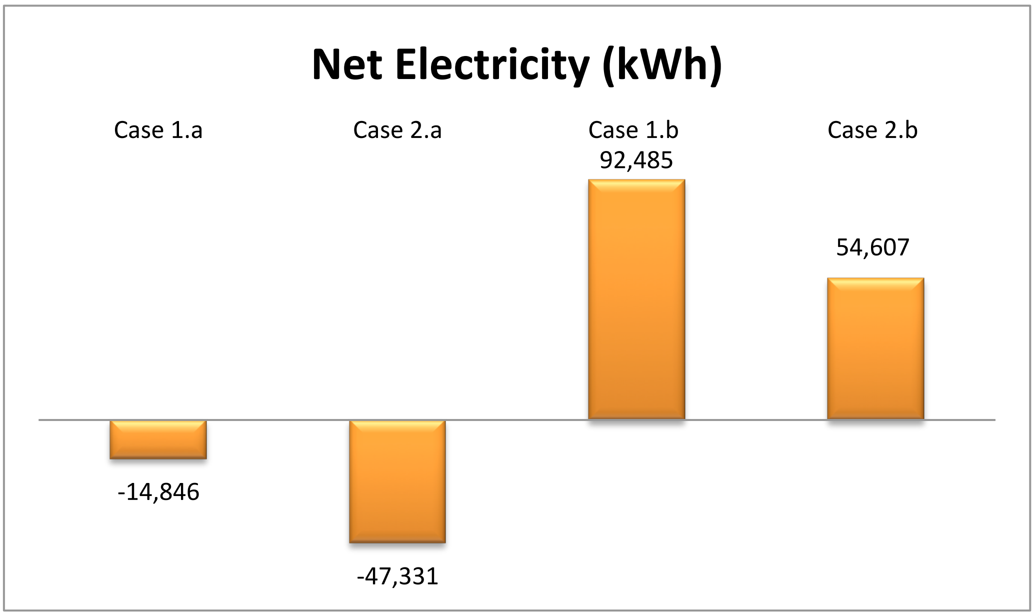

Figure 4. 13: Net electricity values of the possible scenarios.

Likewise Case 1.b and Case 2.b have additional drying and incineration systems,therefor these cases demand more electricity than Case 1.a and Case 2.a. Case 1.a and Case 2.a produces their electrical energy only from biogas production while Case 1.b and Case 2.b obtain electricity from both incineration and anaerobic digestion process. This situation results that Case 1.b and Case 2.b produces more electricity than Case 1.a and Case 2.a. Besides, the results shows that the energy obtained by anaerobic digestion is more in CS than BNR system due to change in SRT changing. Increasing SRT causes to decrease on sludge production; and this situation leads decreasing in biogas production rate (Patel and Madamwar, 2002). Same result is also effective for comparision of incineration system energy generation in conventional systems and BNR. Incineration system is more efficient for CS, because the sludge amount is more in Case 1.b than Case 2.b. Net energy for Case 1.a and Case 2.a, where there is no incineration system, is in negative side on the chart. On the other hand, net energy of Case 1.b and Case 2.b is higher them its energy requirement, and it is in the positive side of the char

4.3.5 Heat recovery

In this part of the study benchmarking on heat energy recovery is investigated. The heat consumption, production rates and net values is shown in (Figure 4. 14 and Figure 4. 15).

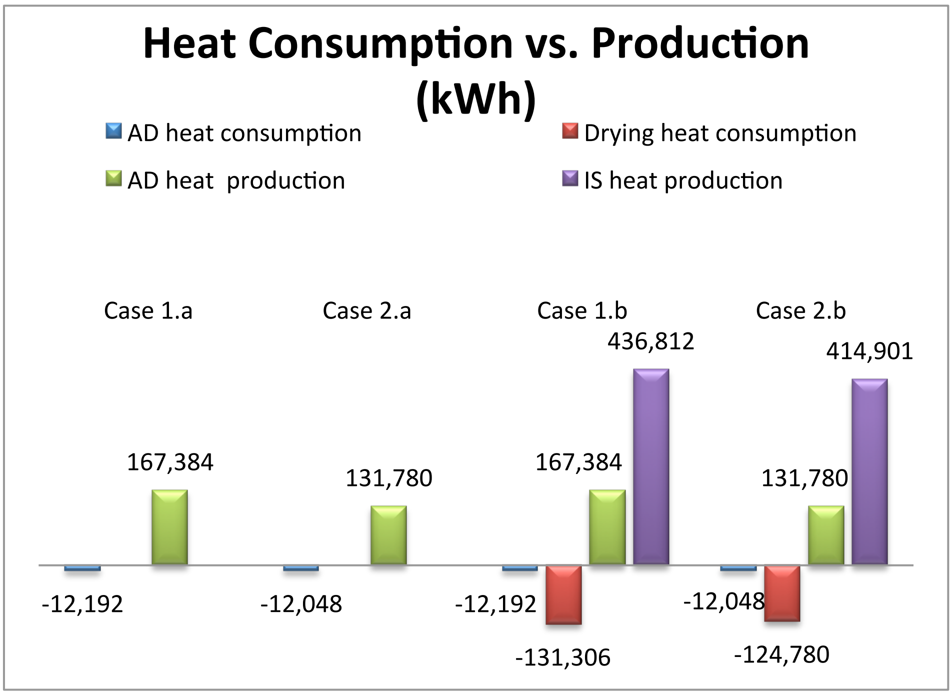

Figure 4. 14: Comparision chart of the possible scenarios for heat energy.

- All of the cases are enough to cover their heat energy demand.
- Low sludge production due to high SRT in BNR process, decreases to obtained energy rate of AD and IS.
- In Case 1.a; anaerobic digester needs 12,192 kWh/d thermal energy both sludge heating and digester heating, and it has a potential to produce heat energy as 167,384 kWh per day. There is 155,192 kWh/d remained energy for other purposes.

- Case 2.a; there is only anaerobic digester for heat consumption and heat production. AD produces 131,780kWh heat energy per day, and consumes 12,048kWh/d heat energy. The remained heat energy is 119,732kWh/d.
- Case 1.b; the thermal energy consumers are drying process and AD. The heat producers are AD and incineration system. Total heat consumption is 143,498kWh/d. The heat production can recover the heat demand of the system. Remained heat is 460,698kWh, and it can be evaluated for other purposes.

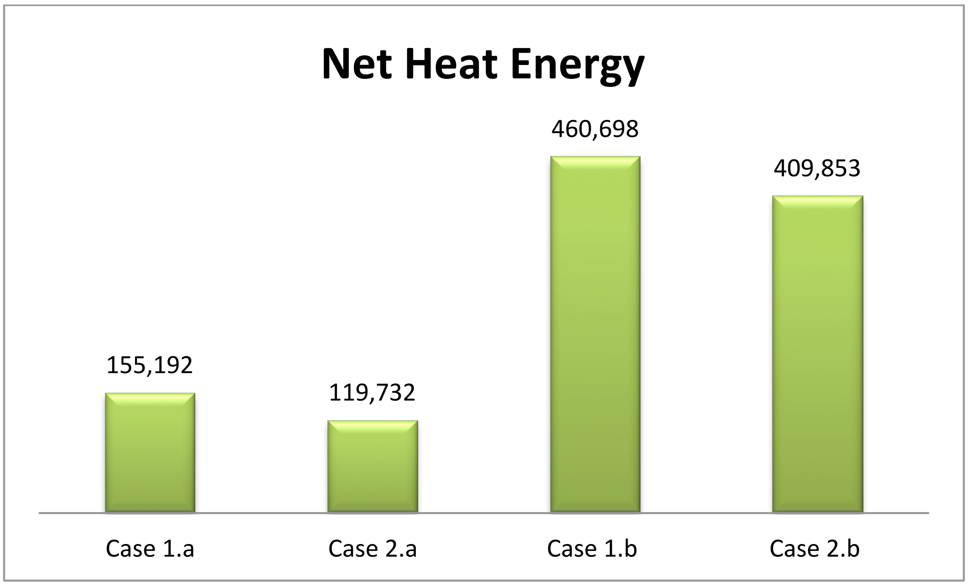

Figure 4. 15: Net heat energy values of the possible scenarios.

- Case 2.b; net energy recovery is less than Case 1.b due to sludge of Case 2.a is less than Case 1.b. AD and IS has a capacity to produce total 546,681kWh/d heat energy. Total of the consumption of drying and anaerobic digestion processes is 136,828kWh/d. The heat recovery for Case 2.b remains 409,853kWh/d energy.

5 CONCLUSION

In this thesis the related chapters within the model based evaluation of energy in full-scale WWTP, which is operated under low SRT: The first part of the thesis had provided a literature review related to general energy usage and production concepts in conventional and nutrient removal plants. The following part, third chapter, scenario and model based approaches were proposed. In addition, the content of four different scenario were explained, and the necessary assumptions made for the sceanrios that were set. Model calibration, upgrade options for BNR and energy recovery were also explained in the third chapter. Fourth chapter, the results of scenario based upgradings are given. In the final chapter, general conclusions derived during this study are summarized as follows:

- In this sudy, model based energy evaluation were done by collecting data from Ankara Central WWTP, which was designed for carbogeneous matter removal. Ankara Central WWTP is a conventional WWTP, which includes primary treatment, activated sludge process, sludge thickening, anaerobic digestion and dewatering processes. Full scale WWTPs are high energy consumers, and Ankara Central WWTP is one of them.
- According to the actual data (2009) of Ankara Central WWTP, its daily average electricity demand is 74,246kWh/d. Additionaly, its total heat demand for anaerobic digestion process is found as 12,192kWh/d.
- In Ankara Central WWTP, anaerobic digester produces daily based average 36,578m^3 biogas. Therefore, its electricity and heat generation capacities are 1.62kWh/ m^3 and 4.6kWh/ m^3 respectively. Regarding to these capacities, average electricity production is 59,400kWh/d and heat production is 167,384kWh/d. The existing plant recovers 80% of its electricity demand. Obtained heat energy is enough to warm up sludge incoming to anaerobic digester, anaerobic digester and buildings.
- The facility annually produces 8.15kWh electricity per person.

- The removal of the nutrients is important as much as removal of carbon from the wastewater in order to protect natural water resources and human health. Therefore, model based upgrading of Ankara Central WWTP from existing conventional system to BNR system were evaluated in this study. The evaluation shows that the upgraded system electricity and heat energy demand are 93,853kWh/d and 12,048kWh/d respectively. The electricity demand of the conventional system is 19,607kWh/d less than BNR system. In other words, BNR system needs approximetely 26% more electiricity for its daily operations.
- The difference of electricity consumption between conventional and BNR systems is taken root from increasing aeration and mixing requirements. Aeration process is the maximal energy consumer in WWTPs (EPA, 2010). In BNR plant 89,701kg oxygen is transferred in a day. In the situation of continuing to use existing mechanical surface aerators in Ankara Central WWTP, the electricity consumption for aeration process is 64,072kWh/d. However, changing the aerator type to fine bubble diffuser decreases the electricity demand to 44,851kWh/d. Hence the fine bubble diffuser was choosen for aeration process in BNR system with aiming the energy efficiency. As a result of this choice, the electricity consumption in aeration tank of CS (51,761kWh/d) seems more than electricity usage in aeration tank of BNR (44,851kWh/d), though BNR system needs more oxygen for removing both carbon and nutrients. In addition, recycled water from sludge treatement to head of the system brings additional TKN load to the influent. The oxygen equivalent of additional TKN load coming from recycled streams is 7,438 kgO_2/d.
- Another reason for changing of the energy amount of the BNR system is the mechanical mixing requirement for anaerobic and anoxic tanks. $5W/m^3$ power dissipitation in mechanical mixing results with 4,681kWh/d electricity consumption for the anaerobic tank and 15,606kWh/d for the anoxic tank.
- The electricity and heat generation from anaerobic digestion process in BNR system are 46,522kWh/d and 131,780kWh/d respectively. The obtained energy in BNR system is less than conventional system.

The reason for that is BNR system has longer SRT and the sludge production reduces at long sludge retention times. Reduced sludge amount causes decrease in biogas production in anaerobic digester, and the resulting gas production rate is 28,648m^3/d. The upgraded plant operations affect negatively the total energy recovery percentage of the plant. Namely, the upgraded plant would recover only 50% of the total energy demand. It is observed that the energy recovery is decreased 30% when the nutrient removal process added to the existing system. Heat generation also decreased due to low energy generation from biogas. However, the facility easily recover its own heat demand including buildings with 119,732kWh net heat per day, because of low heat requirement of the anaerobic digestion process. The upgraded BNR plant annually produces 6.38kWh electricity per person.

- Energy generation upgrading option is determined as combustioning of the waste activated sludge. Waste activated sludge derived after dewatering process includes 74.4% water and has 2,500kcal energy per kg sludge. Drying process make the water content of sludge decrease 10% by evaporation. Hence the calorific value of sludge became close to 9,765.6kcal/kg DS, which is calorific value of the dry matter in the sludge. This value is enough to combust sludge with the incineration process.
- Both conventional and BNR systems were evaluated with upgrading energy option above. In other words, drying and incineration systems were added to conventional and BNR systems. Additional drying process brings extra energy demand to both systems. In theory, total extra energy is 834kWh per ton evaporated water. Accordingly, calculated electricity and heat demand are 17,889kWh/d and 131,306kWh/d for conventional system, also, respectively 17,000kWh/d and 124,780 for BNR system respectively.
- Incineration system including furnace, steam boiler, back pressure turbine and condensed heat exchanger is capable of producing 20-25% electricity and 60-65% heat energy (Worldbank,1999) by combustion of the sludge. In this study the worst situation was evaluated, and it is assumed that 20% electricity and 60% heat energy obtained from incineration system.

As a result of the calculation, the electricity generation amounts of incineration process are 138,300kWh/d for CS and 414,901kWh/d for BNR system. On the other hand, the heat generation is 436, 812.6kWh/d for CS and 414,901kWh/d for BNR. The decrease in energy production of incineration system in BNR plant is related with decreasing in the amount of sludge.

- The scenarios combined with the incineration system produce more energy than the systems with only anaerobic digestion process. According to the results form the scenario (Case 1.b), which is designed for only carbon removal and includes both anaerobic digestion and incineration systems, annually produces 28kWh electricity per person. In addition BNR system with incineration and anaerobic digestion processes annually produces 25kWh electricity per person.

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APPENDICES

APPENDIX A : BNR system requirements

APPENDIX B : Energy calculations for drying and incineration processes

APPENDIX C : Electricity and biogas production of ACWTP

APPENDIX D : Energy calculations for anaerobic digester

APPENDIX A

Appendix A1: Aeration demand for BNR System

OTR: 3,737.55 kgO_2/h

Assumptions were made from (Ataei, 2010):

SAE of fine bubble diffuser: 2 kgO_2/kWh

SAE of mechanical surface aerator: 1,4 kgO_2/kWh

Table A.1: Calculation of possible energy consumption in aeration tank according to different type diffusers.

Aerator type	SAE* (kgO_2/kWh)	OTR (kgO_2/h)	OTR (kgO_2/d)	P (kWh/d)
Fine bubble diffuser	2.00	3,737.55	89,701.20	44,851
Mechanical surface	1.40	3,737.55	89,701.20	64,072

Appendix A2: Mixing Demand for BNR System

Energy need for mechanical mixing process of Case 2 were calculated accordingly:

V_{anox} : 130,050 m^3total volume for anoxic tanks

V_{an} : 39,015 m^3 total volume for anaerobic tanks

Power dissipation: 5 W/m^3

Mixing energy demand for anoxic tanks:

$$\begin{aligned} \mathrm{P} &= 5\frac{\mathrm{W}}{\mathrm{m}^3} \times 130{,}050\ \mathrm{m}^3 = 650{,}250\ \mathrm{W} = 650\ \mathrm{kW} \\ &= 15{,}606\ \mathrm{kWh/d} \end{aligned} \tag{A.2.1}$$

Mixing energy demand for anaerobic tanks:

$$\begin{aligned} P &= 5\frac{W}{m^3} \times 39{,}015\ m^3 = 195{,}075\ W = 117\ kW \\ &= 4{,}681\ kWh/d \end{aligned} \tag{A.2.2}$$

APPENDIX B

Appendix B1: Energy calculations for drying process

Case 1.b:

Total dewatered sludge : 250 ton/d

Total water in the sludge : 186 ton/d

TSS in the sludge : 64 ton/d

After drying, it is assumed that the sludge includes 10% water and 90% TSS.

The TSS as 90% of the total sludge: 64 ton/d

The water as 10% of the total sludge: 7.11 ton/d

Total evaporated water is:

$$186\text{ ton/d} - 7.11\text{ ton/d} = 178.89\text{ ton/d} \quad \textbf{(B.1.1)}$$

Theoretical thermal energy requirement is 734kWh/ton.

Total thermal energy requirement:

$$734\text{kWh/ton} \times 178.89\text{ ton/d} = 131{,}306\text{ kWh/} \quad \textbf{(B.1.2)}$$

Theoretical thermal energy requirement is accepted 100kWh/ton.

Total electricity requirement :

$$100\text{kWh/ton} \times 178.89\text{ ton/d} = 17{,}889\text{ kWh/d} \quad \textbf{(B.1.3)}$$

Case 2.b:

Total dewatered sludge : 238 ton/d

Total water in the sludge : 177 ton/d

TSS in the sludge : 61 ton/d

After drying, it is assumed that the sludge includes 10% water and 90% TSS.

The TSS as 90% of the total sludge: 61 ton/d

The water as 10% of the total sludge: 6.77 ton/d

Total evaporated water is:

$$177\text{ ton/d} - 6.77\text{ ton/d} = 170\text{ ton/d} \quad \textbf{(B.1.4)}$$

Theoretical thermal energy requirement is 734kWh/ton.

Total thermal energy requirement:

$$734\text{kWh/ton} \times 170\text{ ton/d} = 124{,}780\text{ kWh/d} \quad \textbf{(B.1.5)}$$

Theoretical thermal energy requirement is accepted 100kWh/ton.

Total electricity requirement :

100kWh/ton x 170 ton/d = 17,000 kWh/d **(B.1.6)**

Appendix B2: Energy calculations for incineration process

Case 1.b:

Calorific value of dewatered sludge is 2500kcal/kg sludge.

$$2500\ \mathrm{kcal/kg} = \frac{\text{Calorific value of dry solid}\times(100-74.4)}{100} \quad \textbf{(B.2.1)}$$

$$\text{Calorific value of dry solid} = 9{,}765.6\ kcal/kgDS$$

It is assumed that the calorific value of dry solid does not changed after drying process.

Dry solid loading to incinerator: 64,144 kgDS/d

Total energy obtained from incineration process:

$$64{,}114\frac{kgDS}{d}\times 9{,}765.6\frac{kcal}{kgDS} = 626{,}404{,}646\frac{kcal}{d} = 728{,}021\frac{kWh}{d} \quad \textbf{(B.2.2)}$$

It is assumed that 20% and 60% of the total energy is converted to electricity and heat.

Electricity production :

$$728{,}021\frac{kWh}{d}\times 0.20 = 145{,}604\frac{kWh}{d} \quad \textbf{(B.2.3)}$$

Heat production :

$$728{,}021\frac{kWh}{d}\times 0.60 = 436{,}812.6\frac{kWh}{d} \quad \textbf{(B.2.4)}$$

It is assumed that 14% of total energy production is consumed for incineration system.

Electricity consumption for incineration system:

$$145{,}604\frac{kWh}{d}\ \times 0.14 = 20{,}384.5\frac{kWh}{d} \quad \textbf{(B.2.5)}$$

Case 2.b:

Calorific value of dewatered sludge is 2500kcal/kg sludge.

$$2500\ \mathrm{kcal/kg} = \frac{\text{Calorific value of dry solid}\times(100-74.4)}{100} \quad \textbf{(B.2.6)}$$

$$\text{Calorific value of dry solid} = 9{,}765.6\ kcal/kgDS$$

It is assumed that the calorific value of dry solid does not changed after drying process.

Dry solid loading to incinerator: 60,926.5 kgDS/d

Total energy obtained from incineration process:

$$60{,}926.5\frac{kgDS}{d}\times 9{,}765.6\frac{kcal}{kgDS} = 594{,}983{,}828\frac{kcal}{d} = 691{,}503\frac{kWh}{d} \quad \textbf{(B.2.7)}$$

It is assumed that 20% and 60% of the total energy is converted to electricity and heat.

Electricity production :

$$691{,}503\frac{kWh}{d}\times 0.20 = 138{,}300\frac{kWh}{d} \quad \textbf{(B.2.8)}$$

Heat production :

$$691{,}503\frac{kWh}{d}\times 0.60 = 414{,}901\frac{kWh}{d} \quad \textbf{(B.2.9)}$$

It is assumed that 14% of total energy production is consumed for incineration system.

Electricity consumption for incineration system:

$$138{,}300\frac{kWh}{d}\ \times 0.14 = 19{,}362\frac{kWh}{d} \quad \textbf{(B.2.10)}$$

APPENDIX C:

Table C. 1: Electricity and biogas production values of ACWTP.

2009	PT		AT		SR		ST		OF		TOTAL	TEDAS	ELECTRICITY PRODUCTION	BIOGAS PRODUCTION
	kwh/d	**%**	**kwh/d**	**%**	**kwh/d**	**%**	**kwh/d**	**%**	**kwh/d**	**%**	**kwh/d**	**kwh/d**	**kwh/d**	**m^3/d**
JANUARY	3,285	4	49,763	64	11,543	15	11,807	15	1,521	2	77,919	14,577	59,568	37,058
FEBRUARY	3,200	4	52,240	69	5,770	8	12,888	17	1,330	2	75,429	12,692	64,718	38,244
MARCH	3,477	5	52,580	69	6,049	8	12,839	17	1,259	2	76,206	13,950	66,042	38,827
APRIL	3,121	4	48,565	68	5,613	8	12,557	18	1,052	1	70,907	24,135	48,400	33,632
MAY	2,966	4	51,185	70	5,598	8	12,141	17	1,020	1	72,911	12,250	62,871	37,255
JUNE	3,071	4	53,647	70	6,605	9	11,941	16	905	1	76,170	13,804	63,820	37,741
JULY	2,985	4	54,119	72	5,714	8	11,827	16	863	1	75,506	10,450	67,442	36,896
AUGUST	3,058	4	52,995	71	5,974	8	12,130	16	846	1	75,004	17,349	59,635	34,885
SEPTEMBER	3,133	4	52,525	72	5,183	7	11,562	16	952	1	73,354	11,031	63,523	35,422
OCTOBER	3,108	4	52,509	72	5,485	7	11,083	15	1,012	1	73,278	21,684	53,403	35,651
NOVEMBER	3,307	5	51,243	70	5,451	7	11,682	16	1,201	2	72,884	20,547	53,810	37,699
DECEMBER	3,143	4	49,765	70	5,779	8	11,461	16	1,321	2	71,470	23,534	49,568	35,627
AVARAGE	**3,155**	**4**	**51,761**	**70**	**6,230**	**8**	**11,993**	**16**	**1,107**	**1**	**74,246**	**14,846**	**59,400**	**36,578**

APPENDIX D:

Appendix D1:

Energy calculations for anaerobic digester

Energy Production:

Capacity of biogas power station :

$$13.7\text{MW} = 13{,}700\text{kW} = 329{,}280 \text{ kWh/d} \qquad \textbf{(D.1.1)}$$

Total energy of biogas : 6.2 kWh/m^3

1. **Case 1.a and Case 1.b**

Average biogas production of ACWTP (actual plant data): 36,578 m^3/d

Total electricity production (actual plant data) : 59,400 kWh/d

Total energy production:

$$6.2\frac{\text{kWh}}{\text{m}^3}\times 36{,}578\frac{\text{m}^3}{\text{d}} = 226{,}784\frac{\text{kWh}}{\text{d}} \qquad \textbf{(D.1.2)}$$

Electrical energy of biogas :

$$\frac{59{,}400\,\frac{kWh}{d}}{36{,}578\,\frac{m^3}{d}} = 1.6\ kWh/m^3 \qquad \textbf{(D.1.3)}$$

Thermal energy of biogas:

$$6.2\frac{kWh}{m^3} - 1.6\frac{kWh}{m^3} = 4.6\frac{kWh}{m^3} \qquad \textbf{(D.1.4)}$$

Total heat production:

$$4.6\frac{kWh}{m^3}\times 36{,}578\frac{m^3}{d} = 167{,}384\frac{kWh}{d} \qquad \textbf{(D.1.5)}$$

Efficiency of biogas power plant:

$$(226{,}784\frac{kWh}{d} \div 329{,}280\frac{kWh}{d})\times 100 = 68.9\% \quad \textbf{(D.1.6)}$$

26.2 % of 68.9 is for electricity, and 73.8% of 68.9 is for heat energy.

2. Case 2.a and Case 2.b

Average biogas production of BNR system: 28,648 m^3/d

Total energy production:

$$6.2\frac{kWh}{m^3}\times 28{,}648\frac{m^3}{d} = 177{,}617\frac{kWh}{d} \quad \textbf{(D.1.7)}$$

Total electricity production:

$$1.6\frac{kWh}{m^3}\times 28{,}648\frac{m^3}{d} = 46{,}522\frac{kWh}{d} \quad \textbf{(D.1.8)}$$

Total heat production:

$$4.6\frac{kWh}{m^3}\times 28{,}648\frac{m^3}{d} = 131{,}780\frac{kWh}{d} \quad \textbf{(D.1.9)}$$

Appendix D2:

<u>Thermal energy consumption for anaerobic digester</u>

1. Case 1.a and Case 1.b

Daily average treated sludge : 13,535.94 kgTSS/d

<u>Dimensions:</u>

Diameter = 25m

Side depth = 33m

Mid depth = 35m

<u>Heat transfer coefficients from (Metcalf and Eddy, 2003):</u>

Dry earth embanked for entire depth, U= 0.8 W/m^3.°C

Floor of digester in groundwater, U= 0.68 W/m^3.°C

Roof exposed to air, U= 1.6 W/m^3.°C

Temperature:

Air = 16°C

Earth next to wall= 20°C

Incoming sludge = 16°C

Earth below floor =20°C

Sludge in the digester =35°C

Specific heat of sludge = 4,200 J/kg.°C

Area

Wall area: 2590.5 m^2

Floor area: 496.5 m^2

Roof area : 490.6 m^2

Compute the heat required for the sludge:

$$\left(13{,}535.94\frac{kg}{d}\right).\{(35-16)℃\}.\left(\frac{4{,}200\mathrm{J}}{\mathrm{kg}}.℃\right)= 1{,}080{,}168{,}012\,\frac{\mathrm{J}}{\mathrm{d}}=\frac{300\mathrm{kWh}}{\mathrm{d}} \tag{D.2.1}$$

Compute the heat loss by conduction:

-Walls:

$$\left(0.8\frac{\mathrm{W}}{\mathrm{m3}}.℃\right).(2590.5\ \mathrm{m2}).\{(35-20)℃\}.\left(\frac{86{,}400s}{d}\right)= 2{,}685{,}830{,}400\,\frac{\mathrm{J}}{\mathrm{d}}=\frac{746\mathrm{kWh}}{\mathrm{d}} \tag{D.2.2}$$

-Floor:

$$\left(0.68\frac{\mathrm{W}}{\mathrm{m3}}.℃\right).(496.5\ \mathrm{m2}).\{(35-20)℃\}.\left(\frac{86{,}400s}{d}\right)= 437{,}566{,}536\,\frac{\mathrm{J}}{\mathrm{d}}=\frac{121\mathrm{kWh}}{\mathrm{d}} \tag{D.2.3}$$

-Roof:

$$\left(1.6\,\frac{\mathrm{W}}{\mathrm{m3}}.\,{}^{\circ}\mathrm{C}\right).\,(490.6\ \mathrm{m2}).\,\{(35-16)^{\circ}\mathrm{C}\}.\left(\frac{86{,}400s}{d}\right)= \\ 1{,}288{,}656{,}000\,\frac{\mathrm{J}}{\mathrm{d}}=\frac{357\mathrm{kWh}}{\mathrm{d}} \tag{D.2.4}$$

-Total energy lost:

$$\frac{746\mathrm{kWh}}{\mathrm{d}}+\frac{121\mathrm{kWh}}{\mathrm{d}}+\frac{357\mathrm{kWh}}{\mathrm{d}}=1{,}224\,\frac{\mathrm{kWh}}{\mathrm{d}} \tag{D.2.5}$$

Compute the total heat requirement for one digester

$$1{,}224\,\frac{\mathrm{kWh}}{\mathrm{d}}+\frac{300\mathrm{kWh}}{\mathrm{d}}=1{,}524\,\frac{\mathrm{kWh}}{\mathrm{d}} \tag{D.2.6}$$

Compute the total heat requirement for eight digester

$$1{,}524\,\frac{\mathrm{kWh}}{\mathrm{d}}\times 8=12{,}192\,\frac{\mathrm{kWh}}{\mathrm{d}} \tag{D.2.7}$$

2. Case 2.a and Case 2.b

AD dimensions and temperature conditions are the same with Case 1.a and Case 1.b above. Hence, only sludge heat requirement calculated as below:

Compute the heat required for the sludge:

$$\left(12{,}730.7\,\frac{kg}{d}\right).\,\{(35-16)^{\circ}\mathrm{C}\}.\left(\frac{4{,}200\mathrm{J}}{\mathrm{kg}}.\,{}^{\circ}\mathrm{C}\right)= \\ 1{,}015{,}909{,}860\,\frac{\mathrm{J}}{\mathrm{d}}=\frac{282\mathrm{kWh}}{\mathrm{d}} \tag{D.2.8}$$

Compute the total heat requirement for one digester

$$1{,}224\,\frac{\mathrm{kWh}}{\mathrm{d}}+\frac{282\mathrm{kWh}}{\mathrm{d}}=1{,}506\,\frac{\mathrm{kWh}}{\mathrm{d}} \tag{D.2.9}$$

Compute the total heat requirement for eight digester

$$1{,}506\,\frac{\mathrm{kWh}}{\mathrm{d}} \times 8 = 12{,}048\,\frac{\mathrm{kWh}}{\mathrm{d}} \qquad \textbf{(D.2.10)}$$

CURRICULUM VITAE

Dilvin Yildiz was born in Istanbul, on October 24th , 1980. She completed primary school at Dost College, and high school at Atakoy Cumhuriyet High School. In 2004, she graduated as a Geological Engineer from Geology Engineering Department of Istanbul Technical University (I.T.U.). After one year scientific preparation programme in Environmental Engineering department of ITU, she started her MSc study in Environmental Biotechnology Programme of ITU Environmental Engineering Department in 2010.