DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MINIMIZATION OF EXCESS SLUDGE PRODUCTION IN THE WASTEWATER TREATMENT PLANTS USING DIFFERENT TREATMENT MODIFICATIONS

by
Gizem BODU

February, 2020
İZMİR

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"MINIMIZATION OF EXCESS SLUDGE PRODUCTION IN THE WASTEWATER TREATMENT PLANTS USING DIFFERENT TREATMENT MODIFICATIONS"** completed by **GİZEM BODU** under supervision of **PROF.DR. AYŞE FİLİBELİ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

Excess sludge production is the main problem in biological treatment processes. Sludge minimization is important for transportation cost and disposal operation during the wastewater treatment. New wastewater treatment standards are resulting a rise in decracing of sludge production. Sedimentation, dewatering, treatment and disposal of solid matter during aerobic wastewater treatment is reguired high operational cost. Waste activated sludge (WAS) is a by-product which produced by microorganisms utilizing dissolved and organic pollutants in wastewater. The costs for sludge treatment is expensive, which has been forecasted to form 30-60% of the total operational costs of wastewater treatment plants. A principle approach to solve about sludge problems are to decrease the amount of sludge produced in biological process. So, the development of modern processes and technology for decreasing sludge production in biological treatment stage to need. All these strategies are modifications of the common activated sludge process for better results. This thesis summarized the strategies that is has been preffered to categorize different methods for the plant place where the minimization takes place. This study discusses the current sludge minimization technologies applied in the water line (such as lysis-cryptic growth, uncoupling metabolism, anaerobic treatment) or in the sludge line (physical, chemical and biological pre-treatment methods) and their advantages, disadvantages.

In this study, two different real-time biological wastewater treatment plant operating data obtained and the excess sludge amounts due to operational differences, spesific energy consumption rates, spesific sludge production rates and the amount and cost effects on sludge removal methods were explained in detail.

If the thermal hydrolysis process, which is the physical method application of sludge minimization processes, applied for two plants with comparison, the results will be examined and it is shown that sludge minimization will be possible and operating costs will be reduced.

Keywords: Activated sludge process, biological wastewater treatment plant, sludge minimization, excess sludge, sludge minimization technologies, thermal hydrolysis process

ATIKSU ARITMA TESİSLERİNDE FARKLI ARITMA MODİFİKASYONLARI İLE FAZLA ÇAMUR OLUŞUMUNUN AZALTILMASI

ÖZ

Aşırı çamur oluşumu, aktif çamur prosesinde gerçekleşen önemli problemlerden biridir. Çamur miktarının kaynağında azaltılması, nakliye bedelinin azaltılması ve uzaklaştırma faaliyetlerinin kolaylaşması açısından son derece önem taşımaktadır. Çamurun uzaklaştırılması ile ilgili mevzuatın sınırlamalar getirmesi, günümüzde çamur üretiminin azaltılmasının önemini daha da arttırmaktadır. Atıksuların aerobik olarak arıtılması sırasında çok miktarda oluşan katı maddelerin ayrılması, susuzlaştırılması, arıtılması ve uzaklaştırılması önemli bir işletim maliyeti getirir. Aktif çamur ve modifikasyonlarında, çözünmüş ve askıda katı maddelerin biyokimyasal reaksiyonlara bağlı olarak dönüşümü sonucu aşırı çamur adı verilen katı maddeler üretilmektedir. Fazla çamurun arıtımı ve sistemden uzaklaştırılması, klasik aktif çamur arıtma tesislerinin toplam işletme maliyetlerinin yaklaşık olarak yüzde 30-60 oranında bir kısmına karşılık gelen maliyetli metotları içermektedir. Fazla çamur ile ilgili sorunların çözümünde başlıca yöntem, biyolojik arıtma kademesinde meydana gelen fazla çamurun işlenmesi yerine, proseste fazla çamur üretimini azaltmaktır. Aktif çamur prosesi ve modifikasyonları gibi çeşitli biyolojik süreçlerde oluşan fazla çamur üretiminin minimize edilmesi için yeni prosesler ve teknolojiler geliştirilerek, gerçek ölçekte uygulanmaya başlanmıştır. Bu yeni yöntemlerin esası, klasik aktif çamur prosesinin daha iyi sonuçlar vermesi için yapılan modifikasyonlara dayanmaktadır. Bu tez kapsamında, atıksu arıtma tesislerinde oluşan çamurun minimize edileceği yere göre sınıflandırılarak uygulanan farklı yöntemler özetlenmiştir. Atıksu hattında uygulanan yöntemler (biyokütle parçalanması, enerji ayrımı, anaerobik arıtma) veya çamur hattında uygulanan yöntemler (fiziksel, kimyasal veya biyolojik ön arıtma sistemleri) aşırı çamur üretimini azaltmak için kullanılan bu yöntemlerin avantajları ve dezavantajları irdelenmiştir.

Bu çalışmada, gerçek ölçekli iki farklı biyolojik atıksu arıtma tesisi işletme verileri dikkate alınarak, işletmesel farklılıklarından dolayı oluşan fazla çamur miktarları, birim enerji tüketimleri, proses farklılıklarının birim çamur üretimi üzerine etkileri ve çamur uzaklaştırma yöntemleri üzerindeki miktar ve maliyet etkileri detaylı olarak incelenmiştir.

Çamur minimizasyon yöntemlerinden olan termal hidroliz prosesi kıyaslaması yapılan iki tesis için uygulandığında sonuçlarının ne olacağı irdelenmiş ve bu çalışma ile hem çamur minimizasyonunun mümkün olacağı hem de işletme maliyetlerinin düşürülebileceği tartışılmıştır.

Anahtar kelimeler: Aktif çamur prosesi, biyolojik atıksu arıtma tesisi, çamur azaltılması, fazla çamur, çamur azaltılmasına yönelik teknolojiler, termal hidroliz prosesi

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CHAPTER ONE
INTRODUCTION

The activated sludge process is a biological treatment method, which generally used in domestic and municipal wastewater treatment. The main function of this process is to oxidise organic pollutants into carbon dioxide, biomass and water.

The treatment and disposal of excess sludge has become difficult problem because of high rate of volatile solids (VS), large quantities of water, and harmful elements such as heavy metals, pathogens, and stable organic pollutant. The most important issue about that important increase in the carbon footprint and source consumption of the wastewater treatment proces because of treatment and disposal of excess sludge requires significant amounts of energy and chemical matters.

The methods used to decrease the production of excess sludge in biological processes examined in detail; some of the regulations that would be applied in plant operating conditions to reduce excess sludge production are discussed and various processes that are commonly applied in recent years are illustrated for this purpose. Sludge minimization methods advantages and disadvantages were discussed.

In this thesis, Adana Seyhan Wastewater Treatment Plant and Mersin Karaduvar Wastewater Treatment Plant operation parameters were examined in detail. The main purpose of this two plant selection is one of them only carbon removal with low sludge age and other one is C, N and P removal with high sludge age. In this study showed that differences between two types of conventional activated sludge plant with sludge production rates, spesific energy consumption rates, chemical consumption rates and final sludge cake production rates. Also detailed anaerobic digestion operation parameters examined and described according to volatile suspended solid degradation ratios, biogas production rates for making comparison better digestion performance effect on sludge minimization process.

With this operation, parameters thermal hydrolysis process (THP) was selected as excess sludge minimization process for each wastewater treatment plants. The most reason for choosing this process that sludge digestion capacity can be increased with THP. As a result of THP, biogas production can be increased, sludge dewatering process can work better with less VSS content and sludge disposal cost can be reduced with better dewatering process. The results described in detail if thermal hydrolysis process applied to these treatment plants.

CHAPTER TWO
SLUDGE MINIMIZATION EXAMPLES

2.1 Methods for Sludge Minimization

2.1.1 Processes Used in the Water Line

Processes used in the water line usually applied to the small wastewater treatment plants where anaerobic digester units do not occur. The method commonly used to decrease excess sludge in the wastewater line is to apply activated sludge treatment technologies to the return line.

Lysis and cryptic growth process and uncoupling metabolism methods are used for reducing excess sludge in the water line. The ozonation method seems good in wastewater treatment line, but the other side it has some disadvantages.

2.1.1.1 Lysis and Cryptic Growth

In applications based on the biomass disintegration principle, the bacterial content is dispersed. The bacterial content is a secondary feed source, which is used by microorganism, where the feed source is converted to carbon dioxide and the amount of feed used in biomass synthesis is reduced. In this way, the amount of sludge generated in the process is reduced. Lysis and biodegradation are as shown in Figure 2.1 (Chu, Yan, Xing, Sun & Jurcik, 2009). The reduction of excess sludge production by chemical (ozone, chlorine), thermochemical, mechanical and enzymatic methods is based on the principle of biomass disintegration.

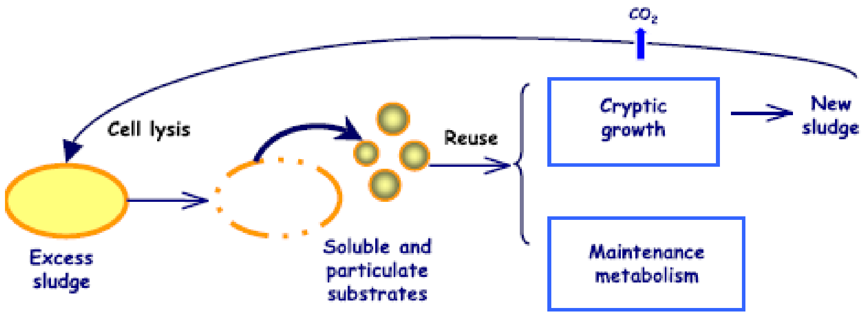

Figure 2.1 Schematic diagram of cryptic growth (Chu, Yan, Xing, Sun & Jurcik, 2009)

2.1.1.1.1 Ozone application. Ozone is a chemical oxidant and generally used in disinfection system. Ozone can oxidize wide variety of organic and inorganic compounds. Ozone has strong cell lytic activity, and can destroy the microorganisms found in activated sludge and additional oxidize the organic matters delivered from the cells (Cui & Jahng, 2004; Saktaywin et al, 2005). Yasui and Shibata developed activated sludge process with ozone application method. It contains two stage. They are ozonation stage and biodegradation stage as shown in Figure 2.2 (Low & Chase, 1999; Yasui & Shibata, 1994). This process consists of direct ozone oxidation or the formation of hdroxyl radicals (HO^- that is another strong oxidant). During ozone process, soluble nitrogen, phosphorus and COD concentrations inrease.

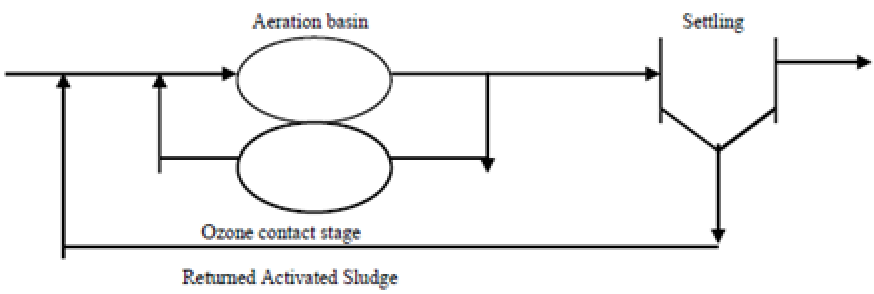

Figure 2.2 An ozone unit in the activated sludge process (Low & Chase, 1999; Yasui, & Shibata, 1994)

The ozonation method can be intermittent or continuous. Data from literature show that the percent of sludge reduced in the case of intermittent ozonation is high, when compared to continuous ozonation. The results of different studies carried out using ozone are summerized in Table 2.1. The ozonation process has been successfully used in the full-scale wastewater treatment plants.

Table 2.1 Ozonation data

Detail of Processes	Reduction of Sludge (%)	Explainations	References
Laboratory Scale, Domestic wastewater after primary sedimentation	70	İncreasig effluent COD, good sludge settling properties.	Deleris, Geaugey, Camacho, Debellefontaine, & Paul, 2002
Laboratory scale, Synthetic substrate, 30 mg-O_3/gMLSS/day. Y= 0.5 g/g Intermittently 11 mg O_3/g MLSS/day	50 70	Good sludge settling properties.	Kamiya, & Hirotsuji, 1998
Laboratory scale, 0.04 g O_3/g-SS, 4200 mgMLVSS/L in the aeration basin, 0.3/day, 1.0 kg-BOD/ m^3/d.	~ 100	In the influent 1.2 times biomass BOD for sludge yield to be zero	Yasui, & Shibata, 1994
Pilot Scale, Gwangju wastewater treatment plant in Gyeonggi 0.2 gO_3/g dissolved solids 0.5 gO_3/g dissolved solids	45[a] 34[a]	Good settleability and dewaterability	Ahn, Park, Maeng, Hwang, Lee, Song, & Choi, 2002
Laboratory Scale, 0.26g SS/gSCOD, 0.25 g SS/gSCOD.	40-60		Egemen, Corpening, Padilla, Brennan & Nirmalakhandan, 1999
Full scale plant operation of pharmaceutical wastewaters 20 to 30 g/Nm^3 (gas), 550 kg/d, 3 times recirculation aeration tank volume=1900 m^3	100	Enhanced SVI	Yasui, Nakamura, Sakuma, Iwasaki, & Sakai, 1996

Table 2.1 continues

Ful scale, Municipal wastewater Capacity 450 m^3/d 0.034 $gO_3/gTSS$	100	Period 9 months	Sakai et al.,1997
Full scale, Industrial wastewater Capacity 12700 m^3/d 3-4 kgO_3/h , 0.05-0.1 gO_3/gTS	40	Period 2 months	Vergine et al.,2007
Full scale, Slaughter-house Capacity 850 m^3BOD/d 0.45 kgO_3/h, 0.026 gO_3/gTS	60-80	Period 2 years	Wolff & Hurren, 2006
[a]The biomass residue in the system			

As shown in Table 2.2, because of important reduce in the disposal cost, the total cost of sludge treatment in 2004 using ozonation method reduced by €13000, compared with that in 2003 without ozonation method.

Table 2.2 Comparison of the total cost before and after ozonation method (Caffaz et al., 2005)

Items	Total operation cost (€)	
	2003 without ozonation	2004 with ozonation
Sludge treatment and disposal	24237	4485
Ozonation pilot plant		4749
Total	24237	11234

Ozonation method has advantages and disadvantages. Better SVI results creates efficient settling phenomena, sludge reduction is successful in full scale plants, the sludge settleability was highly enhanced and bulking and foaming could be decreased is advantages for ozonation. On the other hand, the disadvantages of ozonation method is that operation costs due to high electricity consumption, and ozone consumption for the degredation, which may be present.

2.1.1.1.2 Chlorination. Chlorination method is similar with ozonation method according to working principle. It is more cost effective than ozone method. However, chlorine is a weak oxidant; the amount used is higher than ozone. Saby et al. approached the excess sludge at a chlorine dose of 0.066 gCl_2/g MLSS (Pe´rez-Elvira, Diez, & Polanco, 2006).

The advantage of chlorination that low capital and operating costs check against ozonation method. The principal disadvantage of chlorination activated sludge process is constitution of trihalomethanes (THM), decreased sludge settleability, important remain of soluble COD in the discharge, only applied at lab scale.

2.1.1.1.3 Thermochemical. The destroyed of organic complexs can be succeed in by contents of mineral alkali or acids. Rocher et al. (1999) in a study conducted by 60 ^{o}C and 20 minutes. The thermochemical treatment has a higher productivity in sludge minimization when applied at the same temperature compared to the simple thermal treatment because of the effect of indicators. They stated that the maximum releasable carbon in the microorganism reached 80% at the end of the waiting period and sodium hydroxide was the most effective chemical in thermochemical hydrolysis.

Chemical addition can be applied common with thermal hydrolysis, thermal pretreatment, for the decomposition of sludge under normal pressures (Alsop et al. 1982; Hiraoka et al. 1984).

2.1.1.1.4 Purified Oxygenation Process. This is usually accepted that in biological treatment method, provide of dissolved oxygen performs a restricting role for developing loading ratios of treatment plant. It is probably that excess sludge generation at high dissolved oxygen concentration someway is a result of dissolved oxygen induced metabolic modifies of biological treatment.

It has been ascertained that the growth efficiency in this method may by decreased to 54% compared to usual method at high sludge loading ratios (McWhirter 1978).

The advantages for high purity oxgen process that remove dissolved oxygen activated sludge method can remove occurrence of filamentous organisms, capacity to continue a superior MLVSS concentration in the aeration unit, good sludge thickening and settling, more stable operation conditions, higher oxygen transfer efficiency. On the other side, high purity oxygen process has several disadvantages. There are high aeration cost, the process is unclear.

Wunderlich et al. (1985) revealed an important reduce in sludge generation from 0.38 to 0.28 mg VSS/mgCOD removed as the SRT increased from 3.7 to 8.7 days in high-purity oxygen activated sludge system. It shows that the pure oxygen aeration process operated at a relatively longer SRT is more effective in sludge minimization. Abbassi et al. (2000) informed that an increase in dissolved oxygen (DO) in the bulk liquid led to a deep diffusion of oxygen, which subsequently caused an enlargement of the aerobic volume inside the flocs. Consequently, when the hydrolyzed microorganisms in the floc matrix could be reduced, sludge amount is decreased in the system (Figure 2.2).

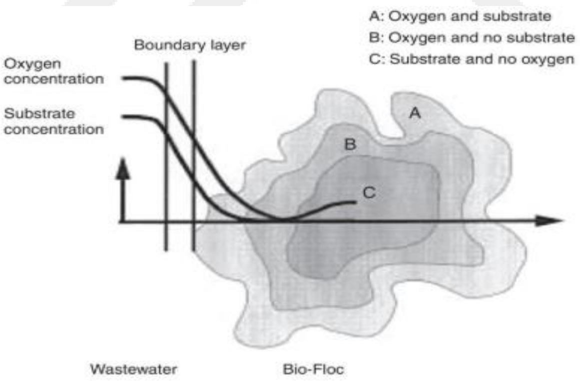

Figure 2.3 Oxygen and substrate concentration profiles within a biological floc (Abbassi, Dullstein & Rabiger, 2000)

2.1.1.2 Uncoupling Metabolism

Metabolism summarise of biochemical modifications that contains relation between anabolic and catabolic (Liu, 2003, Yang, Xie & Liu, 2003). Russell and Cook, 1995 have explained, “uncoupling” as the inability of chemiosmotic oxidative phosphorylation to produce maximum theoretical amount of metabolic energy in the form of ATP. For most of the aerobic bacteria the adenosine-5’-triphosphate (ATP) is produced by oxidative phosphorylation. In this process, electrons transported through the electron transport system (Figure 2.4) from a source of electrons at raised energy levels (substrate) to a final electron acceptor (oxygen) (Chudoba, Morel & Capdeville, 1992; Chudoba, Chudoba & Capdeville, 1992).

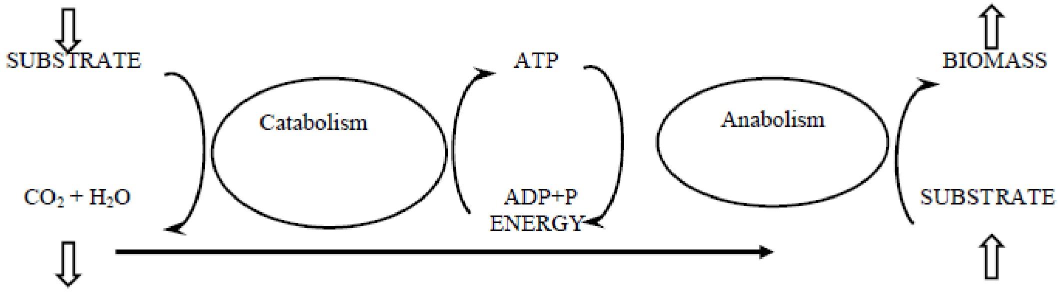

Figure 2.4 Relation between catabolism and anabolism (Chudoba, Morel & Capdeville, 1992; Chudoba, Chudoba & Capdeville, 1992)

Excess sludge generating directly depends on the amount of energy produced by catabolism. However, under certain conditions such as metabolic separators, heavy metal, abnormal temperature and anaerobic-aerobic cycle, energy transfer from catabolism to anabolism decreases (Liu & Tay, 2001). Thus, biomass synthesis and excess sludge production is reduced.

2.1.1.2.1 Oxic-Settling Anaerobic Process. The difference from the biological treatment is that an anoxic or anaerobic reactor is placed in the return line. Chudoba et al. (1992a, 1992b) OSA described the reducing of sludge minimization in the process according to the method of energy separation. Accordingly, microorganisms use their own energy reserves as energy sources since they cannot produce energy when exposed to anaerobic conditions that are not nutrients. When recycled to the aerobic reactor, microorganisms restore their energy spent in the anaerobic reactor before cell synthesis. In this case, the nutrient is used for catabolism and energy imbalance occurs between catabolism and anabolism. Thus, excess sludge production decreases. When the OSA method and the activated sludge method compared, biomass production found to be 0.13-0.29 kgSS / $kgCO_2$ and 0.28-0.47 kgSS / $kgCO_2$, respectively (Chudoba et al. 1992a, 1992b). Chen et al. (2001, 2003) have determined that energy separation, slow growing microorganism species and dissolved microbial products have no effect on decreasing excess sludge production in the OSA method. They argued that sludge production decreaes in the anaerobic or anoxic reactor due to low oxidation-reduction potential (ORP) compared to the biomass decomposition method. Saby et al. (2003) found that if the ORP value in the anaerobic reactor of the OSA process is -250 mV, the sludge minimization decreases by 36% compared to +100 mV and by 58% according to the activated sludge process. Lishman et al. (2000) argud that anoxic and aerobic sequential batch reactor in their study using the aerobic reactor 25-32% lower sludge formation and this is due to bacterial-fed protozoa and metaosa. Therefore, the mechanism that is efficient in decreasing excessive sludge production in the OSA method investigated. The OSA process has advantages such as reduced sludge production, COD removal and improved sludge settling capacity.

2.1.1.2.2 Chemical Uncouplers. Several different metabolic uncouplers tried to sludge minimization in the activated sludge unit.

The bacteria anabolism is combined with the substrate catabolism by ratio-restricted respiration. However, anabolism and catabolism are not nearly coupled occassionally, and coupled metabolism will occur when the biosysnthetic method is ratio restricting and rather than the respiratory control does not occur (Hao et al., 2010). It causes the differences the energy existing for anabolism. Thus, sludge efficiency will reduce. Chemical uncouplers addition would uncouple catabolism from their anabolism that has happened an efficient method to obtain sludge minimization (Chong et al., 2011; Feng et al., 2014; Guo et al., 2014; Xiao et al., 2016; Zuriaga-Agusti et al., 2016). Generally, chemical uncouplers contain TCP (2,4,6-trichlophrnol), DNP (2,4-dinitrophenol), mNP (m-nitrohenol) and THPS (hydroxy methyl phosphonium sulfate).

The chemical uncouplers have disadvantages such as being harmful to the environment, causing an increase in dissolved oxygen consumption, microorganisms considered to metabolic uncouplers, deterioration of sludge deposition characteristics and a decrease in chemical oxygen removal. The combining of pure oxygen aeration biological treatment and metabolic uncouplers may be an alternative solution for excessive oxygen consumption (Liu, 2003). In the studies performed, there is continuous dosing of metabolic separators. The effects of changes in dosage form needs to be investigated (Wei, 2003).

2.1.2 Methods in the Sludge Line

The sludge line methods are generally used in WWTPs with anaerobic digesters. Excess sludge minimization is reached including a sludge treatment process before anaerobic stabilization unit, that increased sludge minimization would be reached. In anaerobic stabilizations, the increased sludge minimization can be explained increased VS (volatile solids) or TS (total solids) elimination and recovered CH_4 formation.

There are two choices to increase sludge minimization in this method: sludge pretreatment before anaerobic digestion, or modified anaerobic units.

These decomposition systems are depend on biological, chemical and physical methods.

2.1.2.1 Physical Treatment Method

Physical treatment method comprise of thermal hydrolysis, ultrasonic pretreatment, freezing and thawing, mixer ball mills, high-pressure homogenization.

2.1.2.1.1 Thermal Hydrolysis. In thermal hydrolysis, the sludge dried to a certain solids content is hydrolyzed at a temperature of 130-175 °C. A full-scale study at 170 °C showed that the degree of sludge decay remained by 80% if the hydrolysed sludge was introduced into the aerobic digester (Kepp & Solheim, 2001).

In thermal treatment, the energy supplied to the sludge is usually provide by a heat exchanger or by steam application to the sludge. When the heat produced in the treatment plant is used for this purpose, the energy cost is significantly reduced (Müller, 2000b).

Cambi and Krepro processes are patented processes used for thermal hydrolysis of sludge. In addition to increasing the degree of stabilization by anaerobic degredation as a conclusion of thermal decomposition of sewage sludge, it has advantages such as advancing the quenching specialities of the sludge and decreasing the tendency of the sludge to form foam (Barjenbruch & Kopplow, 2003).

2.1.2.1.2 Ultrasonic Pretreatment. Ultrasonic pretreatment is applied both and in the wastewater line and the sludge line. Ultrasonic pretreatment is usually applied at 9-41 kHz (usually at 20 kHz) for many seconds to 2.5 h (generally < 1 h) with an increased 9-36% VS elimination and enhanced methane formation of 4-138%. Ultrasonic pretreatment method has been applied laboratory, pilot and full scale WWTPs.

2.1.2.1.3 Freezing and Thawing. Pre-treatment of freezing and thawing is one of the effective methods to decrease the level of pathogen in sludge. The characteristics of the sludge can change when left outside in cold weather. Thus, freezing and annealing in urban wastewater treatment plants is an effective dewatering method. The mechanism of this process involves the division of the solid and liquid phases in the treatment sludges, as ice crystals form, causing breakdown in the flock structure. Disadvantage for the freezing and thawing method is energy consumption is high.

As shown in Figure 2.5, a typical indirect freezing method is the “sludge freezer”. In this process, the sludge is pumped into a tank; a refrigerator is circulated inside tank walls, meltwater and conditioned sludge are separated. When the tank is emptied a new cycle of freezing/thawing can be happened. However, the forces aganist the tank walls generated by expansion of ice make this device inclined to break after few cycles.

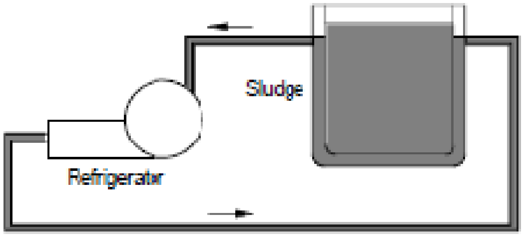

Figure 2.5 A Sludge Frezer (Martel et al., 1996)

2.1.2.1.4 Mixing Ball Mills. The mixing ball mills consist of a vertical or horizontally mounted cylindrical or conical mill with a volume of approximately one m^3, completely filled with grinding balls, and a mixer mounted therein. The balls are generally stone materials with a diameter of 0.2–0.3 mm. The mixer provides rotation in the mill. Microrganism disintegration of shear and pressure stresses that occur when balls effect (Müller, 2000b). The mixing ball mill technology was applied at laboratory and full scale to the WWTP in 2002. The ball speed was generally 6-15 m/s, and the diameter of ball was typically at 0.25-0.35 mm while this method was applied. Enhanced VS degradation of 5%, and 10-21% increased biogas formation were mostly succeed.

2.1.2.1.5 High Pressure Homogenization Unit. The high-pressure homogenization unit comprises of a multi stage high-pressure pump and a homogenization valve. The high-pressure pump applies a force to the sludge with a 300 m/s valve and cavitation bubbles form in the sludge particles. These bubbles cause an increase in temperature and pressure and create conditions for sludge disintegration. Disintegration of microorganisms in the high-pressure homogenization unit by cavitation caused by sudden pressure release (Müller, 2000b). It has been experimentally determined that the amount of methane gas produced during anaerobic degredation increased by 30% and the amount of mineralized sludge can be reduced by 23% (Onyeche, 2003). This method has been used at full scale. When 150-600 bar is used in this unit, caused that biogas production is increased 18-64%.

2.1.2.2 Chemical Tretment Method

The complex organic compounds minimization can also be achieved by means of strong mineral alkali or acids.

Between chemical processes, the using ozonation method is especial influence, because no chemicals are added. The alkali or acids using decomposes the sludge cells at optimal temperatures.

All chemical methods are summarized below.

2.1.2.2.1 Alkaline or Acid Hydrolysis. The alkaline hydrolysis method is more widely used. Alkaline pretreatment method is able to decompose lipids, carbohydrates and proteins into smaller moleculer weight soluble materials, threrefore increasing the sludge solubility. In this process pH of the sludge increases up to 12. This method can be used to hydrolyse and resolve lipids, hydrocarbons and proteins into smaller soluble materials (Chiu et al. 1997; Mukherjee & Levine 1992).

Alkaline pretreatment is more effective for COD solubilisation. Then, if all soluble components formed are biodegradable, the removal efficiency is lower with the anaerobic stabilization.

Enhanced dewaterability of sludge, low investment cost, pathogen inactivation are advantages for alkaline pretreatment. Otherwise, equipment corrosion, high operation cost, negative impact on the following anaerobic digestion unit, only applies at lab scale are disadvantage for alkaline method.

2.1.2.2.2 Pre-treatment Ozone Application. The most effective method of chemical pretreatment processes. No chemical addition is required. The purpose of ozonation is hydrolysis and oxidization of organic material.

Mustranta and Viikai 1993; Scheminski et al. 1999; Liu et al. 2001 have studied that the proposed ozone dose is 0.05- 0.5 g O_3/g TS. The ideal dosage for should be determine according to sludge type and characterization.

Ozone treatment's advantage is better dewaterability final sludge, applied at full, scale; on the other hand high-energy consumption is disadvantage for this process.

2.1.2.2.3 Free Nitrous Acid (FNA) Pretreatment Method. FNA pretreatment is an advanced method to reach sludge minimization (Wnag at al., 2013b; Zahedi et al., 2016). This method is generally aed at 1.0-2.5 mg HNO_2-N/L for 5-24 h with an enhanced 15-56% methane formation. FNA method may increase sludge minimization ratio and sludge minimization occur (Wang et al., 2013b, 2014b). It should be underlined that FNA is a chemical that produced as a wastewater treatment sub-product by nitrification of anaerobic sludge supernatant.

For better sludge minimization FNA method has also been combined with heat (55 ^{0}C) (Wang et al., 2014b). It was informed, in which the sludge minimization enhanced from 35% (without pretreatment) to 41% after FNA method of about 1.0

mg HNO_2-N/L. On the contrary, combined heat pretreatment and FNA reached a sludge minimization of 44% (Wnag et al., 2014b).

The advantages of FNA method that no impact on sludge settleability and discharge quality, low capital and working cost. Only used at lab scale is disadvantage of this method. Schematic diagram of FNA method is given in Figure 2.6 (Wei, Wang, Zhang, Laloo, Duan, Batstone & Yuan, 2018).

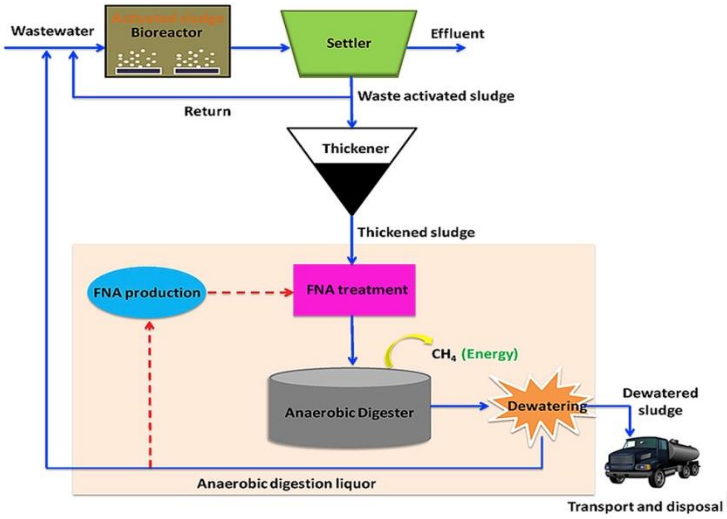

Figure 2.6 Schematic diagram of FNA method (Wei, Wang, Zhang, Laloo, Duan, Batstone & Yuan, 2018)

2.1.2.3 Biological Pretreatments Method

The activated sludge disintegration is depends on enzyme existence. The compounds forming the cell wall are broken down with enzyme addition and thus the production of sludge is reduced. When the enzyme method is applied after the mechanical method, the excess sludge production efficiency increases.

Temperature phased anaerobic stabilization (TPAD) is mostly applied in biological pretreatments method. It has been advanced to enhance the anaerobic stabilization yield, where a low HRT of thermophilic anaerobic stabilization unit.

2.1.3 Sludge Minimization Method According To Operating Conditions

2.1.3.1 Dissolved Oxygen

Excess sludge production decreases when the dissolved oxygen concentration is high. However, the mechanism of reducing excess sludge production with high dissolved oxygen concentration has not yet been explained. Two hypothesis have been presented to reduce excess sludge production with high dissolved oxygen. In the first hypothesis, it is argued that high dissolved oxygen concentration increases active biomass. Thus, the sludge load in the biological treatment is reduced and lower amount of sludge is produced. In the second hypothesis, it is argued that a high concentration of dissolved oxygen results in a deep diffusion event, which causes the growth of aerobic volume in sludge, flocks. The biomass, which is hydrolyzed in the flock, is decomposed aerobically and the amount of sludge amount decreases (Liu & Tay, 2001). Abbasi et al. (2000) increased the dissolved oxygen concentration from 1.8 to 6 mg / L and achieved 25% reduction in sludge production. Jung et al. (2006) to decide the impact of batch aeration on sludge production in their batch tests found that shorter operating cycle time is more effective in reducing sludge production.

High dissolved oxygen; it has many advantages such as inhibiting the growth of filamentous bacteria, biomass supply is high in the aeration basin, good settable sludge, less sludge production, oxygen transfer high capability and more stable system (Liu, 2003). However, more than 50% of the total energy demand of the biological treatment is required to supply oxygen to the aeration tank. Therefore, increasing the dissolved oxygen concentration to reduce sludge production will increase the cost.

2.1.3.2 Sludge Age

Sludge age is explained as the time when microorganisms remain in the activated sludge process. Microorganisms prefer to maintain life functions instead of reproduction. Due to the high sludge age, the nutrients used by the microorganisms decrease and the energy used for the maintenance of the microorganism cells and the microorganisms digest their cells (internal respiration) increases. Because of internal respiration, the nutrient entering the process converted into carbon dioxide and water, and excess sludge production in the system is decreased. Amount of biomass in the process increases due to the increase in sludge age. In a study by Low and Chase (1999a), they increased the biomass concentration from 3 to 6 mg/L by 12% and increased from 1.7 to 10.3 mg/L by 44% reduction in excess sludge production.

2.1.3.3 pH

The ideal pH range 7.0-7.5 for biological treatments used in domestic wastewater treatment. pH is not an effective parameter in decreasing excess sludge producing in the biological treatment. However, the effectiveness of methods such as metabolic uncoupling and thermochemical increases with the selection of appropriate pH. Low and Chase (1998) in their study pH from 7.0 to 6.2 biomass reduction increased from 62% to 77% with 100 mg / L paranitrophenol addition.

2.1.3.4 Temperature

The biological reaction rates in the activated sludge process depend on the temperature. High temperature is an effective factor in reducing sludge production. Tian et al. (1994) have determined that sludge production at 8 °C is 12-20% more than 20 °C. If temperature organic in flock is low, sludge production is higher. It is due to the collecting of cell protoplasm in the form (Lishman et al., 2000).

2.1.3.5 Excess Carbon

Many bacterial species produce excess metabolites under conditions of excess carbon and limited nutrients. At the same time, the carbon uptake rate and carbon dioxide formation of the bacteria increase and biomass production decreases. Under extreme carbon conditions, two possibilities are considered for the reduction of biomass production. The first possibility is that ions such as protons and K^+ weaken the cytoplasmic membrane potential and cause energy separation. The second possibility is that organisms change the metabolic reaction path (Low & Chase, 1999b).

In general, activated sludge is limiting for carbon cell growth in the process. This method can be used for the biological treatment of industrial wastewaters where nutrients are limited. However, additional treatment will be required to reduce the carbon concentration below the required value (Low & Chase, 1999b).

CHAPTER THREE
MATERIAL AND METHODS

3.1 Introduction of Wastewater Treatment Plants

In this study, Adana Seyhan WWTP and Karaduvar WWTP were investigated. 2015 summer and winter seasons' data collected from wastewater treatment plants were used to generate mass balances.

Seyhan WWTP is designed as C removal plant and operating with 3-4 days sludge age. Karaduvar WWTP is designed as C, N & P removal plant and operating with 15-16 days sludge age.

Main purpose of selecting two different plants which are different operation strategy and different process design is compare spesific primary/biological sludge production rates per m^3 ww, sludge production rate per kg COD removed, polymer consumption per ton sludge etc.

Process description and design parameters of treatment plants are given in this section.

3.1.1 Adana Seyhan Wastewater Treatment Plant

Adana Seyhan Wastewater Treatment Plant's the first phase contains mechanical pre-treatment, primary sedimentation and biological treatment according to the high loaded activated sludge process (VL_{BOD5} = 1.5 kg/m^3/d), getting the loads for the target year 2010 as design basis. Within the first phase, a sludge stabilisation (anaerobic mesophilic digestion) and sludge dewatering facilities were constructed. Average dry weather flow of plant is 227,346 m^3/d. The biological stage of the present design phase is designed for the removal of carbonaceous compounds and suspended solids.

Biological treatment stage after implementation of Nitrogen and Phosphorus removal is already designed for the second phase (target year 2025). The plant has a treatment efficiency that provide discharge criteria according to standards and effluent treatment discharge into drainage channel TD8.

Methane gas is generated from mixture of excess sludge, which is produced from biological treatment, and primary sludge from bottom of primary sedimentation tanks and is used for electrical energy that more than 50 % of the plant requirement can be supplied.

Flow diagram of Seyhan WWTP is given in Figure 3.1. The units of the plant are summarized below and design parameters are given in Table 3.1.

1. Screening station (2 pieces coarse screens and 4 pieces fine screens)
2. Aerated grit and grease removal tanks, sand classifier (4 pieces)
3. Primary sedimentation tanks (12 pieces)
4. Intermediate pumping station
5. Distribution structure for aeration tanks
6. Aeration tanks (6 pieces)
7. Distribution upflow of final sedimentation tanks
8. Final sedimentation tanks (8 pieces)
9. Return sludge pumping stations
10. Excess sludge pumping station
11. Raw sludge pumping station
12. Sludge pre-thickeners (gravity type) (3 pieces)
13. Digester feed pumping station
14. Anaerobic Digester Tanks (6 pieces)
15. Sludge post-thickener (gravity tpye) (1 piece)
16. Sludge dewatering (decanter) (3 piece)

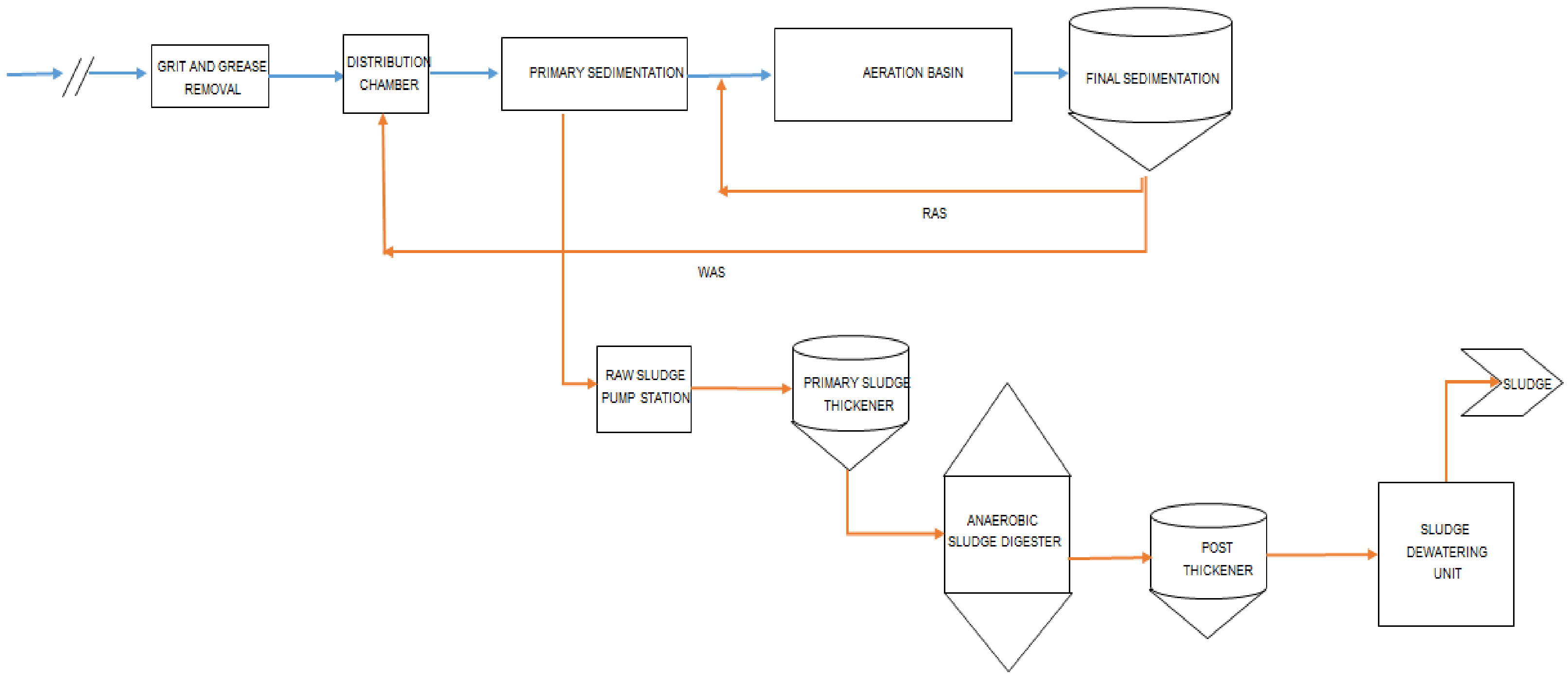

Figure 3.1 Flow diagram of Seyhan WWTP

Table 3.1 Seyhan WWTP design parameters

Parameters	Units	2010		2025	
Total population	48 $mgBOD_5/PE$ 55 $mgBOD_5/PE$	1151066 PE_{48}		1760958 PE_{55}	
Average dry weather flow	m^3/d	227346		311973	
Average flow Q_{ort}	L/h	2631		3611	
Maximum flow Q_{max}	kg/d	4410		5851	
BOD_5 load, raw	kg/d	55251		96853	
BOD_5 concentration, raw	mg/L	243		310	
SS load, raw	kg/d	63308		123267	
SS concentration, raw	mg/L	278		395	
Total N load, raw	(kg/d) (BOD_5/6)	-		16142	
Total N concentration, raw	mg/L	-		51.7	
Total P load, raw	(kg/d) (BOD_5/30)	-		3228	
Total P concentration, raw	mg/L	-		10.35	
Temperature of wastewater	^oC	14	25	14	25
Total sludge age, θ_c	d	2.17	2.35	2.06	2.21

3.1.2 Mersin Karaduvar Wastewater Treatment Plant

Karaduvar Wastewater Treatment Plant is designed for the removal of Carbonaceous, Nitrogen and Phosphorus compounds that for the target year 2020. Maximum plant flow is 189523 m^3/d. The excess sludge that is produced after wastewater treatment is dewatered, dried and removal from the plant. Biogas is produced in mesophilic anaerobic digester tanks with a capacity of 6,000 m^3 each, and produced biogas is used for electrical energy production and a large part of the electrical energy of the plant is supplied by this energy. The plant is already designed for target year 2025 as extension.

Flow diagram of Karaduvar Wastewater Treatment Plant is given in Figure 3.2. The units of the plant are summarized Karaduvar WWTP units are given below and design parameters are given in Table 3.2.

1. Fine screens (6 pieces)
2. Aerated grit and grease chambers (2 pieces)
3. Primary settling tanks (5 pieces)
4. Phosphorus removal tanks (2 pieces)
5. Aeration tanks (8 pieces)
6. Return sludge pumping station
7. Final settling tanks (7 pieces)
8. Excess sludge thickener for biological sludge 3pcs (drum thickener)
9. Gravity thickener for primary sludge (3 pieces)
10. Anaerobic digesters (3 pieces)
11. Secondary thickener (gravity type) (4 pieces)
12. Sludge dewatering (decanter) (3 pieces)
13. Solar drying (pilot plant)

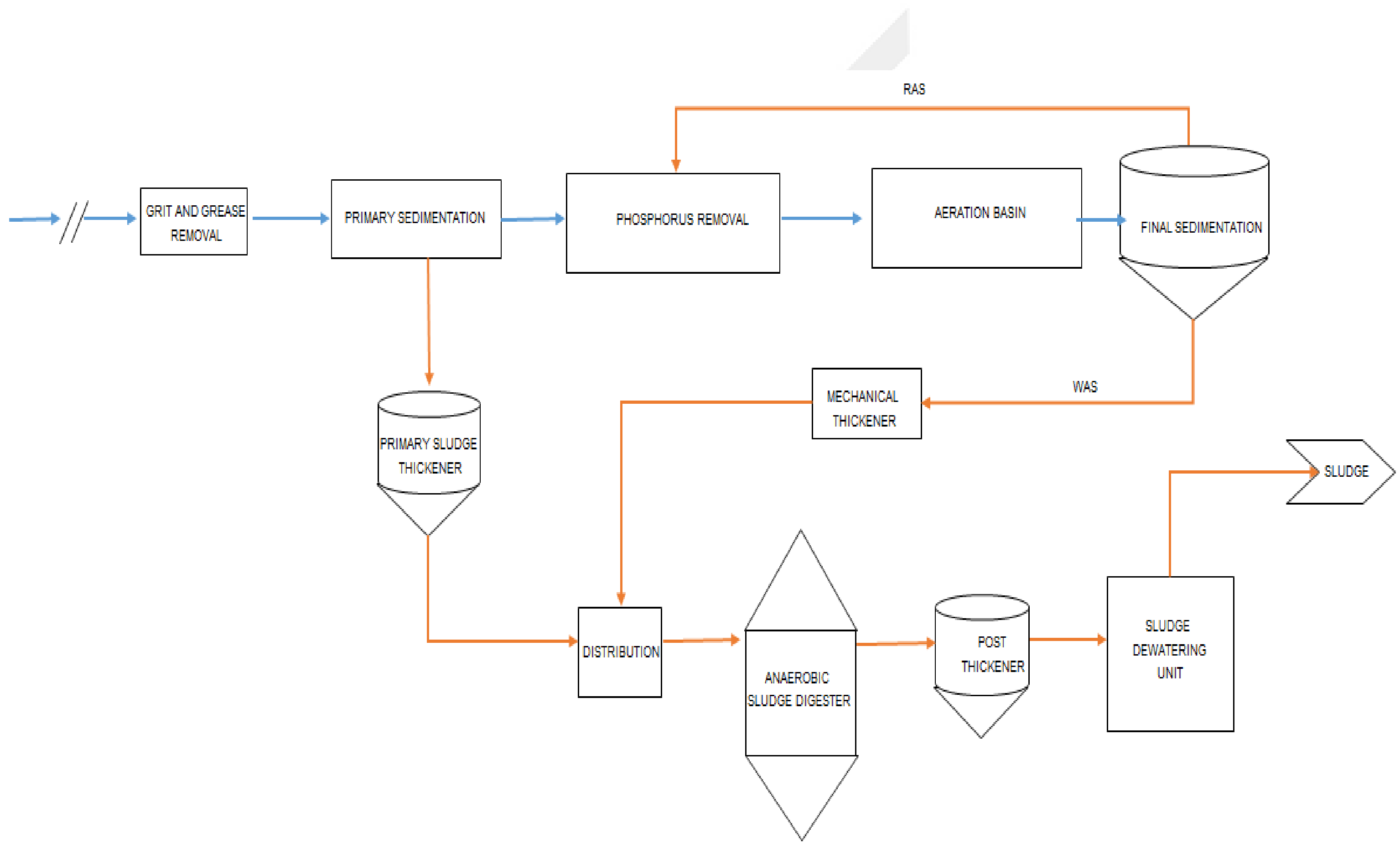

Figure 3.2 Flow diagram of Karaduvar WWTP

Table 3.2 Karaduvar WWTP design parameters

Parameters	**Units**	**2005**		**2020**		**2030**	
Total population	PE	734613		1040398		1258977	
Total ww flow	m^3/d	136934		189523		227843	
Average flow Q_{ort}	m^3/h	7573		10325		12405	
Maximum flow Q_{max}	m^3/h	10602		14455		17367	
BOD_5 load, raw	kg/d	28281		46818		69268	
BOD_5 concentration, raw	mg/L	214		247		304	
COD load, raw	kg/d	51242		83232		125942	
COD concentration, raw	mg/L	374		439		553	
SS load, raw	kg/d	37386		56474		80613	
SS concentration, raw	mg/L	273		298		354	
Total N load, raw	kg/d	5372		8584		12696	
Total N concentration, raw	mg/L	39		45		56	
Total P load, raw	(kg/d) (BOD_5/30)	1.424		2.060		2.553	
Total P concentration, raw	mg/L	10		11		11	
Temperature	^oC	29	15	29	15	29	15
Sludge age, θ_c	d	8.4	8.4	8.4	8.4	8.4	8.4

3.1.3 Mass Balances of Plant Winter and Summer Seasons

Mass balances of plants were generated-according to data, which collected from wastewater treatments plants. Figure 3.3 and Figure 3.4 are about mass balance of Seyhan WWTP Winter and Summer Season in 2015. Figure 3.5 and Figure 3.6 are about mass balance of Karaduvar WWTP Winter and Summer Season in 2015.

Data collected from Seyhan and Karaduvar WWTPs are used for plant flow chart mass balance schema as shown in Figure 3.3, Figure 3.4, Figure 3.5 and Figure 3.6. Inflow wastewater pollution loads and daily sludge production rates have calculated. Then calculated values have compared with existing sludge removal rates which are primary sludge + waste activated sludge (PS+WAS) amount and volume. Plant data were analysed for anaerobic digestion process according to raw sludge calculations. Anaerobic digestion mass balance calculated according to plant biogas production, VSS removal rates, VSS content of sludge. All calculated values are given in detail in Table 3.3.

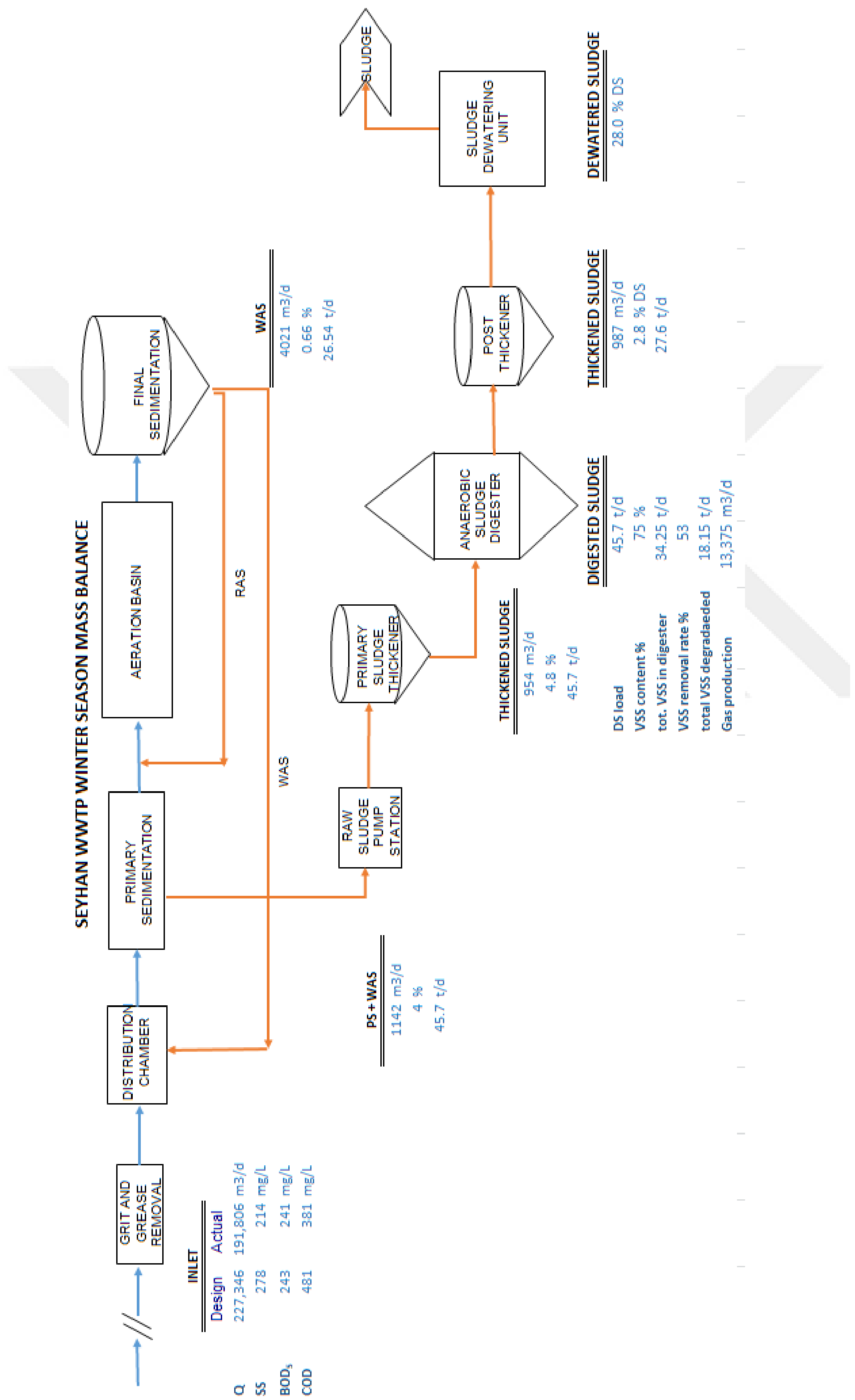

Figure 3.3 Seyhan WWTP winter season mass balance

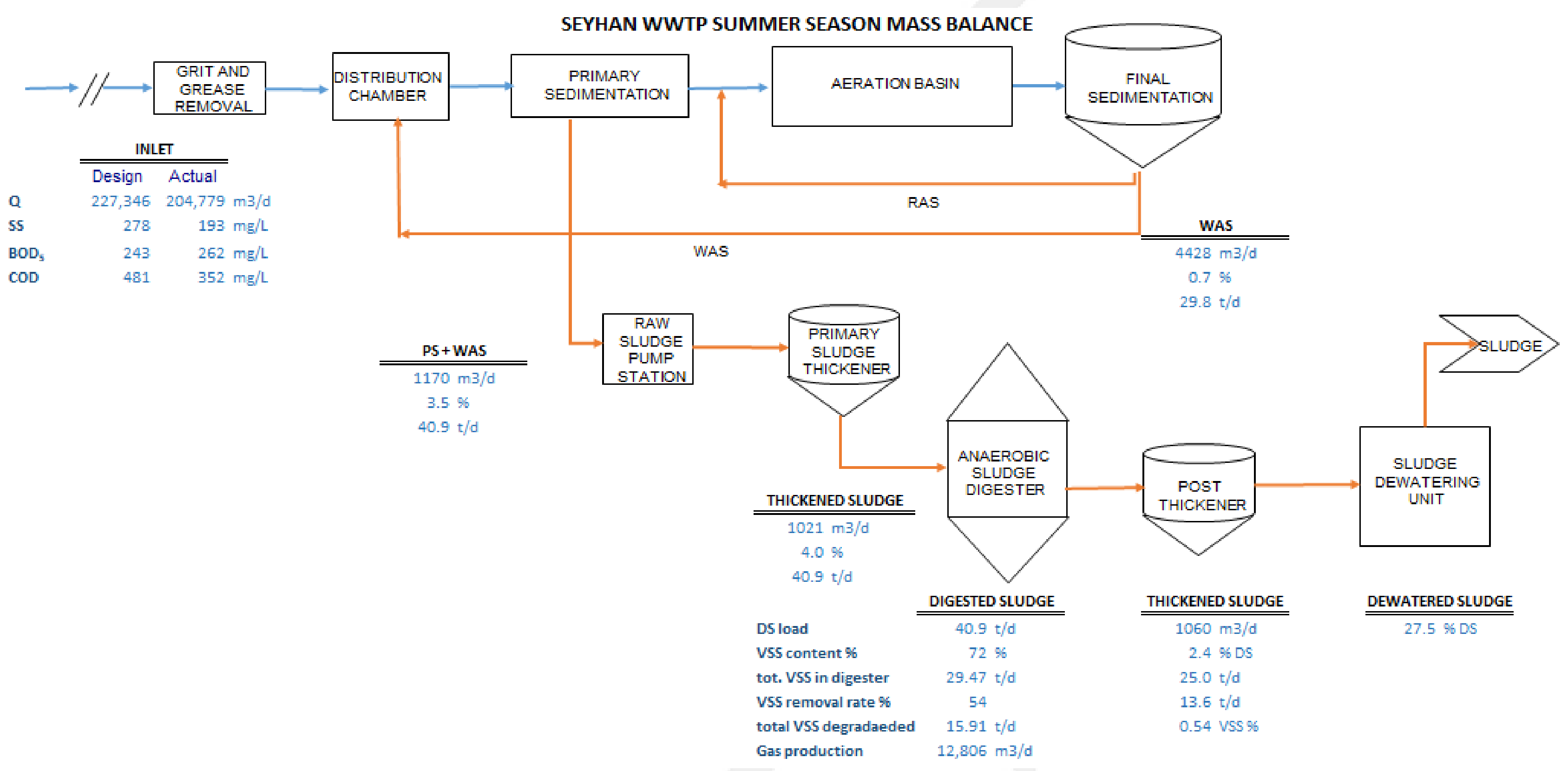

Figure 3.4 Seyhan WWTP summer season mass balance

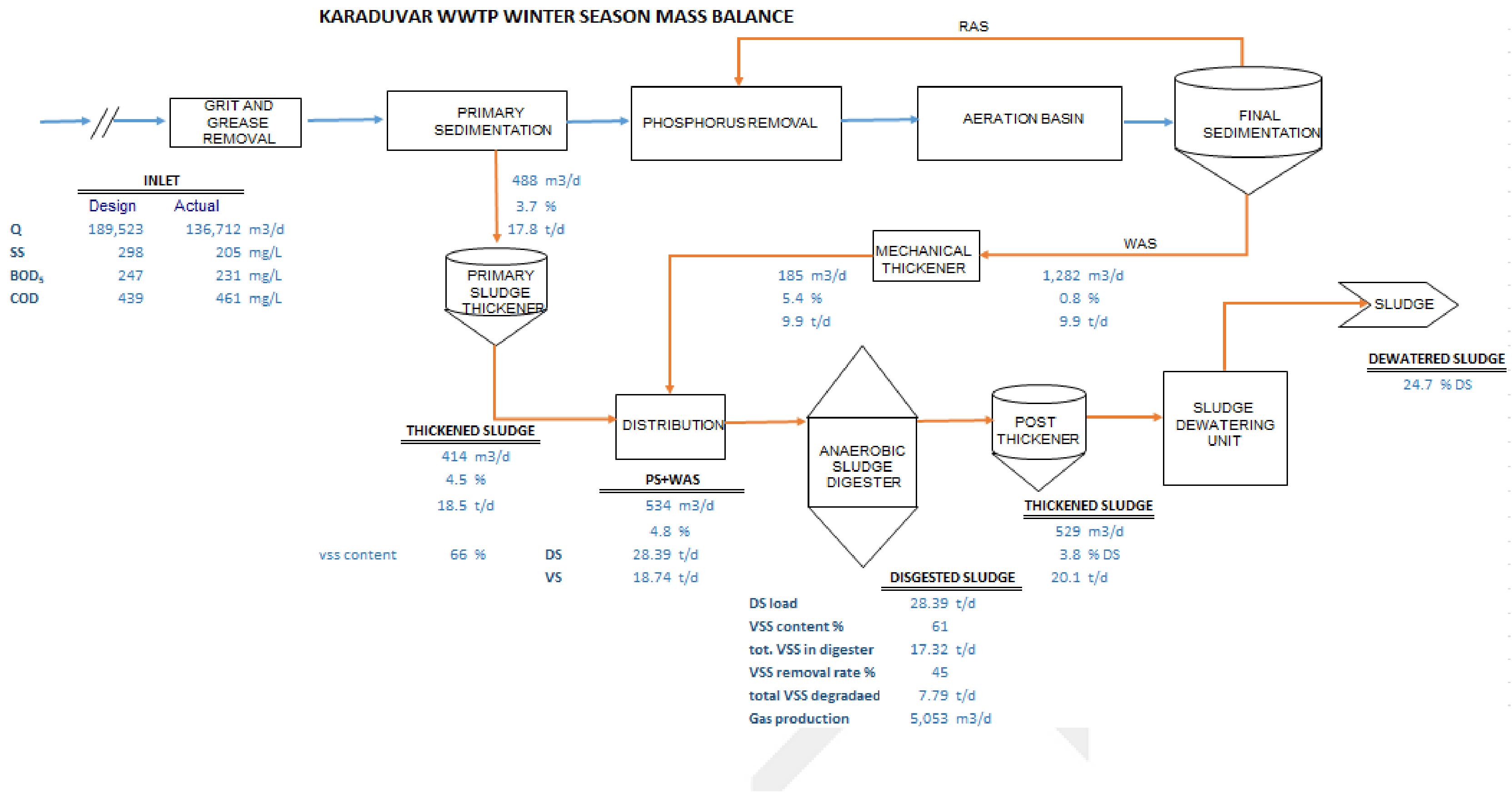

Figure 3.5 Karaduvar WWTP winter season mass balance

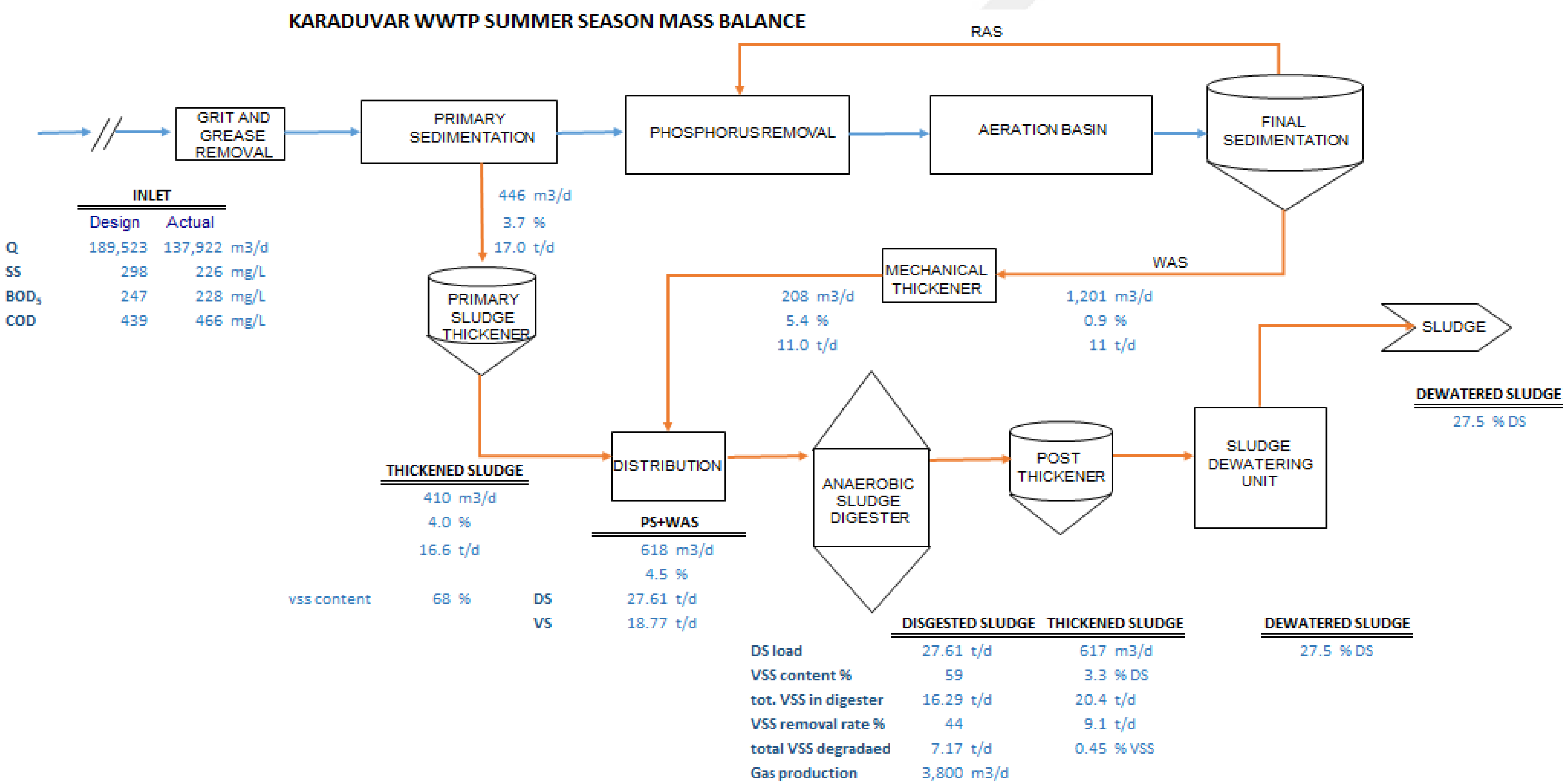

Figure 3.6 Karaduvar WWTP summer season mass balance

3.2 Comparison of Seyhan and Karaduvar WWTP

Winter and Summer Season in 2015 Plant data were analysed and then mass balances and comparison charts of plants were generated.

Table 3.3 Comparison chart of Seyhan and Karaduvar WWTPs

PARAMETERS	UNIT	SUMMER		WINTER	
		SEYHAN	KARADUVAR	SEYHAN	KARADUVAR
Flow, average	m^3/day	204779	137922	191806	136712
Sludge Age (θ_c)	day	3.18	16.90	4.11	16.33
Waste Activated Sludge (WAS)	kg/day	29800	11033	26540	9917
Primary sludge (PS)	kg/day	11133	16577	19127	18470
PS+WAS	kg/day	40933	27610	45667	28387
Spesific energy consumption	kwh/m^3 ww	0.203	0.170	0.214	0.168
Biogas production	m^3/d	12806	3800	13375	5053
Total energy consumption	kWh/month	1273939	735389	1188297	665666
Total polymer consumption	kg/month	4210	3000	4882	3000
WAS Production rate	kgWAS/m^3 ww	0.15	0.08	0.14	0.07
PS Production rate	kgPS/m^3 ww	0.05	0.12	0.10	0.14
SS Load	kg/day	39590.6	31170.4	40982.6	28078.8
COD Load	kg/day	72013.9	64239.6	73078.2	63040.6
BOD Load	kg/day	53583.8	31427.9	46225.3	31567.3
SS Removal Rate in Primary Sed.	%	30%	54%	50%	63%
COD Removal Rate in Primary Sed.	%	30%	54%	50%	63%
WAS Production rate / kgCOD	kgWAS/kg COD degreaded	0.29	0.08	0.18	0.06
WAS Production rate / kgSS	kgWAS/kgS Sdegreaded	0.53	0.16	0.32	0.13
VSS degradation ratio in digester	%	54	44	53	45
Digested sludge	t/day	25.0	20.4	27.6	20.1
Polymer	kg/t sludge	5.61	4.91	5.89	4.97

Evaluation of parameters; as shown in Table 3.3 Seyhan and Karaduvar wastewater treatment plant data are summarized. According to the results given in

Table 3.3. Seyhan WWTP has produced 0.15 kg waste activated sludge per m^3 wastewater in summer season on the contrary Karaduvar WWTP has produced 0.08 kg waste activated sludge per m3 wastewater in summer season. It means Karaduvar WWTP has produced 46 % less sludge than Seyhan WWTP in summer season. In winter season it is also similar Karaduvar WWTP has produced 50 % less sludge than Seyhan WWTP.

But this comparison is not enough for comparison of sludge production rates. Primary sedimentation removal rates also investigated according to laboratory data, which collected from Seyhan and Karaduvar wastewater treatment plants. COD and SS loads are almost similar in both plant. However, COD and SS removal rates are more effective in Karaduvar WWTP. This shows us inflow of aeration tank COD and SS loads are less in Karaduvar WWTP. Therefore, spesific biological sludge production rates examined again and as shown in Table 3.3 as kg WAS production rate per kg COD and SS removed respectively winter and summer season in both treatment plants.

Seyhan WWTP has produced 0.29 kg WAS/kgCOD removed in summer season, 0.18 kg WAS/kgCOD in winter season on the contrary Karaduvar WWTP has produced 0.08 kgWAS/kgCOD removed, 0.06 kgWAS/kgCOD. It means summer and winter season 2015, Seyhan WWTP has produced 72% more biological sludge than Karaduvar WWTP.

It shows us primary sedimentation tank efficiency is crucial for biological sludge production rates. There is also another significant difference with two plants. Sludge age of Karaduvar WWTP five times more than Seyhan WWTP. Sludge age is giving sludge minimization advantage for Karaduvar WWTP. MLSS is directly effecting from sludge age parameter, which is bacteria population in aeration tank. Karaduvar WWTP MLSS concentrations in summer and winter season are average 5800 mg/L, Seyhan WWTP MLSS concentrations in summer and winter season are average 3700 mg/L. Higher MLSS concentration creates more stabil process conditions but on the other hand it creates disadvantage energy consumption in aeration tanks. In Table

3.3, Seyhan WWTP consume more electricity than Karaduvar WWTP for per m^3 treated wastewater. However, Seyhan WWTP has intermediate pumping station, which is consume 360 kWh, 259200 kwh/month electricty. It is design and construction disadvantage of Seyhan WWTP. If we remove this electricty consumption from total consumption Seyhan WWTP, spesific energy consumption rates decrase respectively summer and winter season to 0.165 kWh/m^3 and 0.161 kWh/m^3. It means Seyhan WWTP has consumed respectively summer and winter season 3% - 3.6% less electricty than Karaduvar WWTP.

Polymer consumption comparison as shown in Table 3.3 Karaduvar WWTP has consumed average 4.94 kg poly/t sludge; Seyhan WWTP has consumed average 5.75 kg poly/t sludge. Both plant have anaerobic digesters but thickining units are different from each other.

Waste activated sludge is collecting to inlet of primary sedimentation tank (co-settling for warm climate) in Seyhan WWTP. Then collected sludge bottom of primary sedimentation tank is pumping to primary thickening tanks, which are, designed gravity type. Then thickened sludge is pumping to anaerobic digesters.

In Karaduvar WWTP, primary sludge is collecting from the bottom of primary sedimentation tank and pumping to primary thickeners (gravity type) and waste activated sludge is pumping to mechanical thickener (drum type with polymer addition) to increase WAS dry matter concentration to 5%-6%. Than both sludges are collecting in sludge mixing tank before digester feeding.

As shown in Table 3.3 VSS degradation ratio is higher in Seyhan WWTP than Karaduvar WWTP. It shows that biological sludge in Seyhan WWTP has more VSS content than Karaduvar WWTP. VSS content of biological sludge is directly effecting from sludge age parameter if treatment plant is operating higher sludge age, so biological sludge degredaded more and VSS content of sludge decrase and this value proves it to us. VSS contents of raw sludge are given in mass balance figures, as shown in Figure 3.3, Figure 3.4, Figure 3.5, and Figure 3.6.

It is also effecting to polymer consumption. Because polymer consumption and sludge cake dryness is directly effecting from inorganic content/VSS content of sludge. If sludge has got more inorganic content/less VSS, sludge dewatering unit works more effective and consume less polymer.

According to Table 3.4 and Table 3.5, calculated thickened sludge VSS ratios recpectively Seyhan WWTP and Karaduvar WWTP are 54% VSS content and 45% VSS content. Karaduvar WWTP has got less VSS content/more inorganic content. It gives advantage to sludge dewatering process and it proves to us polymer consumption amounts in sludge dewatering unit. Both plant had reach same DS percentage after dewatering unit and Karaduvar had used 14 % less polymer than Seyhan WWTP for per ton-dewatered sludge.

Table 3.4 Seyhan WWTP digester parameters summer season

Parameter	Unit	Digested Sludge	Thickened Sludge	Dewatered Sludge
DS Load	t/day	40.9	25	25
VSS	%	72	54	
VSS	t/day	29.4	13.6	
VSS removal rate	%	54		
DS	%			27.5

Table 3.5 Karaduvar WWTP digester parameters summer season

Parameter	Unit	Digested Sludge	Thickened Sludge	Dewatered Sludge
DS Load	t/day	27.6	25	25
VSS	%	59	45	
VSS	t/day	16.2	9.1	
VSS removal rate	%	44		
DS	%			27.5

3.3 Results of Seyhan and Karaduvar WWTP Comparison

Seyhan WWTP is consuming 3% less electricty than Karaduvar WWTP beacuse of sludge age and MLSS concentration. In addition, Seyhan WWTP is producing more biogas than Karaduvar WWTP beacuse of more VSS content of PS and WAS. VSS content of waste activated sludge is effecting directly to sludge age.

It makes sludge transportation and disposal easier and decrases costs of sludge removal. In addition, Karaduvar WWTP consume less polymer beacuse of sludge age parameter.

As a result, it shows that sludge minimization techniques is key parameter for wastewater treatment plant operation. It is balance of between energy consumption and sludge production.

CHAPTER FOUR
EXCESS SLUDGE MINIMIZATION PROCESS APPLICATION TO SEYHAN & KARADUVAR WASTEWATER TREATMET PLANTS

This chapter studies one of the sludge minimization application to Seyhan and Karaduvar WWTPs. Thermal hdyrolysis process (THP) is selected as an excess sludge minimization techniqeu on sludge line because sludge digestion capacity can be increased with THP process. As a result of THP process biogas production can be increased with better hydrolysis process, sludge dewatering process can work better with less VSS content and sludge disposal cost can also be reduced with better dewatering process.

Sludge is heated up to 180 ^{0}C in determined contact time with vapour pressure. THP is a process for increase solubility of sludge and prepares it for better anaerobic digestion process as a result more biogas production and odourless sludge. So sludge with about 12% DS can be used in the same way as raw sludge with 5-6% DS. Sludge concentration is higher in the digester feed, buffer capacity is higher and a stabil digestion process (Kepp & Solheim, 2001). Expected increase in methane production will be 25-72% with 30-41% solubilization increase for both wastewater treatment plants (Sapkaite et al., 2017). The mass reducing is even higher, over 50% due to a better dewaterability (Kepp & Solheim, 2001). According to CAMBI dewatered sludge cake dry solid percentage could achieve >30% DS.

According to this values THP flow chart shown in Figure 4.1 and THP effect on both plant is given below in Table 4.1.

Pre-dewatering unit, pre-heating tank, steam tank, flush tank have to add to exiting WWTPs as a THP units. There is no need extra heat source for steam production. Existing co-generation systems are producing excess heats and this heat can be used for steam production.

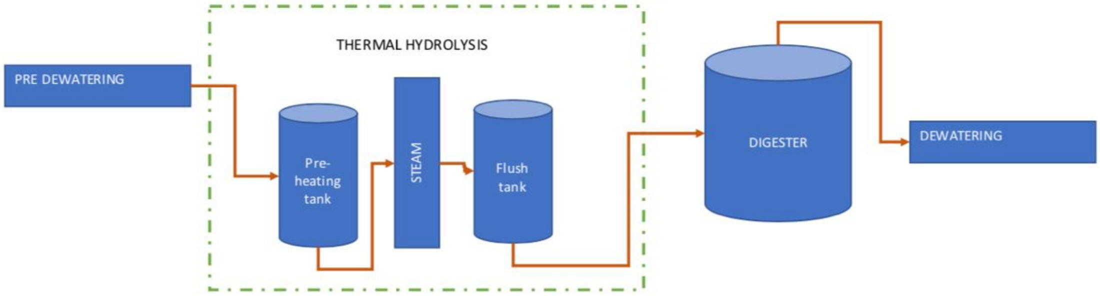

Figure 4.1 Flow diagram of thermal hydrolysis process

Table 4.1 Thermal hydrolysis process effects on Seyhan and Karaduvar Wastewater Ttreatment Plants

Parameter	Unit	Seyhan WWTP without THP	Seyhan WWTP with THP	Karaduvar WWTP without THP	Karaduvar WWTP with THP
Raw Sludge	t/day	40.9	40.9	27.6	27.6
DS feed %	%	4.0 %	12%	4.5%	12%
Mass reduction	%	38%	50%	25%	50%
DS after digestion t/day	t/day	25	20.4	20.4	13.8
DS in sludge cake	%	27.5 %	35 %	27.5 %	35 %
Amount of sludge cake	t/day	90	58	74	39
Biogas production [a]	m^3/day	12806	19209	3800	5700
Energy value [b]	kWh	30724	46101	9120	13680
Daily energy consumption [c]	kWh/day	42464	42464	24512	24512
Energy recovery	%	72 %	108 %	37%	55%

Table 4.1 continues

[a] 50% increase in biogas production assumed.
[b] 1 m^3 biogas is converting to 2,4 kWh electricity with biogas engine in both plant (average values from operation parameters).
[c] THP energy consumption assumed 0.

This study showed that theoretically if THP integrated to both plant sludge cake amount will deacrease respectively Seyhan and Karaduvar WWTPs, 35% - 47% because of mass reduction increase in digestion process. At the same time, transportation and disposal costs can decrase for both plant. As shown in Figure 4.2 flow diagram of Seyhan and Karaduvar WWTPs when THP added to existing treatment plants.

On the other hand, energy recovery rate can achieve 100% for Seyhan WWTP and it creates opportunities for electricity selling as a renewable energy production. Sales cost is regulated by EPDK (Energy Market Regulatory Authority) as a 0.13 $/kWh renewable energy. Decreasing in sludge cake amount and increasing in biogas production will deacrease operation costs in both plant.

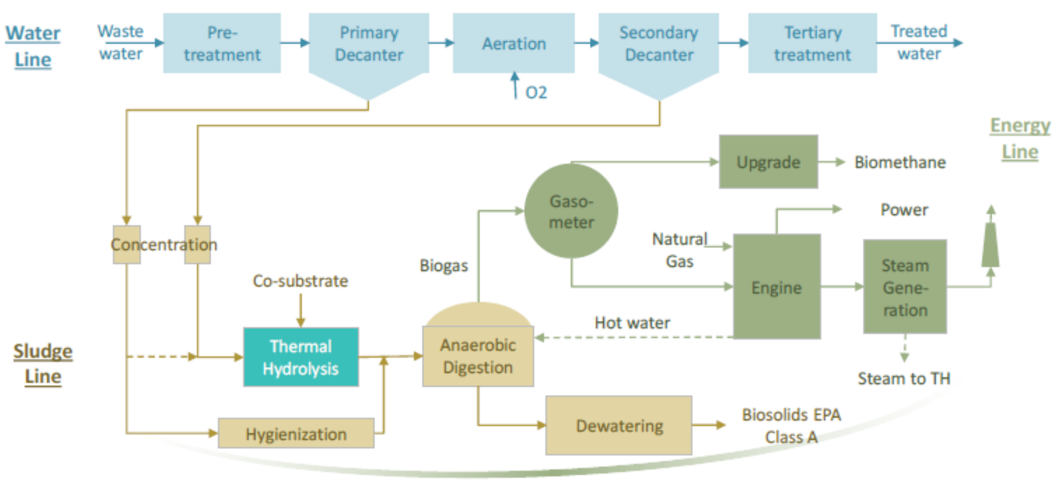

Figure 4.2 Flow diagram of Seyhan and Karaduvar WWTPs when THP added

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

Excess sludge production is the main problem in the biological wastewater treatment. The excess sludge treatment cost constitutes a large part of the operational cost of the biological treatment. Therefore, it is important to sludge minimization in the biological wastewater treatment plants.

The most important issues in the applicability of the excess sludge production process are the investment cost, operating cost due to energy consumption and chemical substance consumption and the efficiency of the system.

Chemical, bacterial or enzymatic methods used to reduce excess sludge production cause many environmental problems such as color problems, nutrient release, and toxicity of metabolic separators. In addition, these methods require high investment and operating costs.

In this study compared plants showed that there is a critical balance between reduction of sludge amount and energy consumption in operated plants. Both can be achieved with optimum operational conditions.

In addition to comparision of existing WWTPs, this study showed that theoretically if thermal hydrolysis process integrated to wastewater treatment plant sludge cake amount will deacrease in Seyhan and Karaduvar WWTP, 35% - 47% respectively, beacause of mass reduction increase in digestion process. At the same time, transportation and disposal costs can decrase for both plant. It showed that thermal hydrolysis process can be beneficial for sludge minimization and operation cost optimization. Advantages of THP execution to existing plants are capacity extension, biogas enhancing, sludge minimization and energy recovery rate enhancing.

This study also showed that THP could be benefical especially in design step of wastewater treatment plant. The main benefits for design step are smaller digester volume and small capacities of sludge removal units. It decreases the construction costs directly.

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