DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PREPARATION OF SOLIDS BALANCES FOR MUNICIPAL WASTEWATER TREATMENT FACILITIES

by

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İZMİR

PREPARATION OF SOLIDS BALANCES FOR MUNICIPAL WASTEWATER TREATMENT FACILITIES

A Thesis Submitted to the Graduate School of Natural and Applied Sciences of Dokuz Eylül University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering, Environmental Engineering Program

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“PREPARATION OF SOLIDS BALANCES FOR MUNICIPAL WASTEWATER TREATMENT FACILITIES”** completed by **SELİN ÇANKAYA** under supervision of **PROF.DR. AZİZE AYOL** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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PREPARATION OF SOLIDS BALANCES FOR MUNICIPAL WASTEWATER TREATMENT FACILITIES

ABSTRACT

Mass balance is a well-known method in many engineering applications including reactor design, process evaluation, and benchmarking. This method assumes and calculates the remaining stable the outputs and inputs of substances in a mass flow system. In environmental engineering field, preparation of mass balances is considered as a very important tool to compute the fluxes of substances compare operational conditions and check the general validity in wastewater treatment facilities (WWTFs). It is a very current way to compute the influent and effluent flows and their characteristics at wastewater treatment plants. However, application of mass balances on WWTP data is mainly difficult since the treatment processes are dynamic systems and the variability of the influent loading is unknown (Puig et al., 2008).

Although mass balance calculations have been preferred to improve the quality of WWTF information (Meijer et al. 2002), getting reliable information from raw WWTF data is mainly not possible. For example, to establish a mass balance in the biological WWTFs having activated sludge units for process integrity, all in- and outgoing flows including the activated sludge composition and sludge production should be known (Puig et al., 2008). For process design including mass balances, the use of mathematical modeling of wastewater treatment processes has taken great attention based on engineering scale applications since 1990s and early 2000s. To evaluate and refine process configurations not only in the design of a particular unit process, but also in terms of plant-wide effects, some companies have developed simulation software programs such as BioWin (EnviroSim Associates Ltd., Flam borough, Ontario, Canada); GPS-X (Hydromantis Inc., Hamilton, Ontario, Canada); ATV-131 E (DWA, Germany) (WERF, 2010). The models are very useful to develop the steady-state mass balances of the integrated plant processes regarding the influent and effluent characteristics, kinetic and stoichiometric parameters, and the effects of sidestream loads.

In this MSc. Thesis, a spread-sheet was developed by using Microsoft Excel to calculate the mass balance in biological WWTFs. It is capable to present how different wastewater treatment processes and their recycled flows affect the mass balance results. This research has been studied with three kinds of biological wastewater treatment processes -conventional activated sludge process, extended aeration activated sludge process, and A^2/O process (BNR)- and flows. It has been computed with three iterations for each processes since there is no need for further iteration. The flows are 1000 cubic meter, 10,000 cubic meter, and 100,000 cubic meter. The constants and coefficients were chosen the same for all processes so it was suitable to comparison. It computed flow, BOD, TSS loads and recycle streams for conventional and extended aeration active sludge systems while flow, BOD, TSS, Org-N, NH_4^+-N, NO_3^--N, TN and TP loads were taken into account for biological nutrient removal system (BNR). In the calculations, medium strength domestic/municipal wastewater characteristics were used. The results showed that the conventional active sludge system is less stable than the other processes since its iteration differences exceeding 5 percent are higher than those in the other processes. The computing steps and the results are given in details and compared them for the treatment processes and flows examined in the thesis.

Keywords: Mass balance, solids balance, wastewater treatment, nutrient removal, N and P cycles.

KENTSEL ATIKSU ARITMA TESİSLERİ İÇİN KATI MADDE DENGELERİNİN HAZIRLANMASI

ÖZ

Kütle dengesi; reaktör tasarımı, proses değerlendirilmesi gibi pek çok mühendislik uygulamalarında kullanılan ve iyi bilinen bir yöntemdir. Bu metot, kütle akışının olduğu bir sistemde giriş ve çıkış maddelerinin korunduğunu varsayan bir hesaplama yönetimidir. Çevre Mühendisliği'nde, atıksu arıtma tesislerinde (AAT), giriş, çıkış atıksu debileri ve atıksu özelliklerine göre bileşen akılarının hesaplanması, farklı işletim koşullarının karşılaştırılması ve tesisinin genel durumunun değerlendirilmesinde, katı kütle dengelerinin hazırlanması önemli bir araç olarak göz önünde bulundurulmaktadır. AAT'lerde bu hesaplamanın yapılmasında uygulanan işlem adımları doğrudan uygulanan adımlar olmakla birlikte, AAT işletim verilerine bu dengenin uygulanması, arıtım proseslerinin çok dinamik sistemler olması ve tesise giriş yüklerindeki salınımlar nedeniyle çok kolay değildir (Puig vd., 2008).

Her ne kadar kütle dengesi hesaplamaları AAT işletim kalitesini arttırmak üzere tercih edilse de (Meijer vd. 2002), AAT'ye ait ham veriden güvenli bir bilginin elde edilmesi genellikle mümkün olmamaktadır. Örneğin, aktif çamur sistemine sahip bir biyolojik atıksu arıtma tesisinde proses entegrasyonuna yönelik olarak tüm giren ve çıkan atıksu debileri, aktif çamurun özellikleri ve çamur üretiminin bilinmesi gerekmektedir (Puig vd., 2008). Kütle dengesini içeren proses tasarımlarında, atıksu arıtım proseslerinin matematiksel modellemesinin mühendislik ölçeğinde uygulanması, 1990'lı yıllar ve 2000'li yılların başlarından beri oldukça dikkat çekmektedir. Proses konfigürasyonlarına karar verilmesi ve değerlendirilmesinde sadece özel ünitelerin tasarımında değil aynı zamanda tesis genelinde etkilerin değerlendirilmesinde, bazı firma ve kuruluşlar tarafından BioWin (EnviroSim Associates Ltd., Flamborough, Ontario, Kanada), GPS-X (Hydromantis Inc., Hamilton, Ontario, Kanada); ATV-131 E (DWA, Almanya) simülasyon programları geliştirilmiştir (WERF, 2010). Bu modeller, giriş-çıkış atıksu debileri ve atıksu özellikleri, kinetik ve stokiyometrik parametreler ve tesis içi yan akımlar göz önünde bulundurularak tüm tesis için entegre bir kütle dengesinin geliştirilmesinde oldukça yararlıdır.

Bu tez çalışmasında Microsoft Excel program kullanılarak biyolojik atıksu arıtma tesislerinde kütle denkliğinin çıkarılmasına yönelik olarak bir hesaplama programı oluşturulmuştur. Bu hesaplama yöntemi, farklı atıksu arıtma akım şemalarında uygulanan proseslerin ve onların oluşturduğu yan akımların kütle dengesi sonuçlarını nasıl etkilediğini ortaya koymaktadır. Bu araştırmada üç farklı proses türü (klasik aktif çamur, uzun havalandırmalı aktif çamur ve A^2/O prosesi) ve üç farklı debi (1000 metreküp/gün, 10000 metreküp/gün, 100000 metreküp/gün) ile çalışılmıştır. Her bir proses için üç iterasyon yapılmış olup, dördüncü bir iterasyona gerek kalmamıştır. Hesaplamalarda kullanılan sabitler, katsayılar ve kabul edilen yaklaşımlar, kıyaslama yapılabilmesi açısından her bir proses için aynı seçilmiştir. Klasik ve uzun havalandırmalı aktif çamur sistemlerinde yan akımlarda debi, BOİ, TKM; biyolojik nütrient giderimini yapan A^2/O prosesinde, yan akımlarda debi, BOİ, TKM, organik azot, amonyak azotu, nitrat azotu, toplam azot ve toplam fosfor hesaplamalarda dikkate alınmıştır. Tüm hesaplamalar, orta derecede kirliliğe sahip evsel atıksu karakterizasyonu dikkate alınarak yapılmıştır. Sonuçlarda, klasik aktif çamur sisteminin diğer sistemlere oranla, iterasyon farklarının bazı hesaplarda yüzde 5’i aşmasından dolayı daha az kararlı olduğunu göstermiştir. Bu yüksek lisans tezinde, tüm hesaplama adımları, yapılan kabuller ve elde edilen sonuçlar proses ve debi farklılıklarına göre detaylı olarak verilmektedir.

Anahtar Kelimeler: Kütle dengesi, katı dengesi, atıksu arıtımı, N ve P döngüleri.

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Wastewater treatment facilities (WWTFs) have well-designed unit operations and unit processes in order to prevent water pollution. The unit operations and processes are located as successive individual units either as single unit or as multiple units in parallel. However, all of them are connected each other and affect the treatment performance of the successive units. Therefore, integrity of the units is very important (Ekama, 2009, WERF, 2010). To implement this integrity in WWTPs, preparation of mass balances is a very important tool to compute the fluxes of substances from incoming wastewater and although the facility's units, to compare operational conditions and to check the general validity in WWTFs depending on the set discharging limits for receiving media. However, application of mass balances on WWTP data is mainly difficult since the treatment processes are dynamic systems and the variability of the influent loading is unknown (Puig et al., 2008). The preparation of mass balances is also important for design and operation of sludge treatment units.

Mass balance is based on a basic principle that any matter cannot disappear or be created without any cause. Mass balancing is a well-known technique and widely used in engineering (Puig et al., 2008). In WWTFs, the loading to any particular unit operation or process during wastewater treatment, and thus the design sizing, is strictly dependent on the raw wastewater characteristics, performance of all preceding operations and processes (WERF, 2010). Therefore, the balance should include each of the major pollutants regarding the discharging limits set by legislation. For the mass balance preparation, flow, biodegradable oxygen demand (BOD), and total suspended solids (TSS) parameters should be known as a minimum requirement. Depending on the flow diagram of WWTF, chemical oxygen demand (COD), nitrogen (N) and its fractions, phosphorus (P), and also inert solids should be considered (Metcalf & Eddy, 2003). Mass balances are commonly prepared as individual balances around each unit process regarding the parameter given above and follows the computation method by determining the rate of accumulation for a given parameter, which should be equal to the difference between inflow and outflow plus or minus generation or destruction (WERF, 2010). The balanced effluent from upstream processes is used as the influent value for the following downstream process. Iterative calculations by using computer programs like BioWin or GPS-X are done until all recycle and conversion conditions balance come to the reasonable iteration limits. The models used for mass balance preparation for a WWTF can be categorized into two classes: steady-state models and dynamic models. Dynamic models require all the influent characteristics, reactor sizes, initial reactor concentrations to be quantitatively defined before simulation while the steady-state models require the explicit equations linking influent characteristics to unit operation performance (Ekama, 2009).

The scientific research study conducted in Department of Environmental Engineering at Dokuz Eylül University aimed to emphasize the importance of the mass balance technique to predict the fluxes of substances, compare operational conditions and check the general validity under different in WWTFs different operational conditions.

1.2 Scope and Research Objectives of Thesis

The mass balancing is very important tool for wastewater treatment operations regarding the recycle flows streamed to head of the plant causing the shock loading following process facilities. The beneficial and purposive technique can be used at the designing stage or operation stage in the wastewater treatment field. The research objectives of this thesis are:

- to establish the mass balances for different wastewater treatment flow diagrams,
- to evaluate the wastewater flow rate effects on the mass balance results,
- to develop a spread-sheet capable to calculate the mass balance in biological WWTFs and to present how different wastewater treatment processes and their recycled flows affect the mass balance results and overall treatment performance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the wastewater treatment technology particularly biological process applied to the wastewaters coming from either domestic/municipal or industrial sources. It focuses the activated sludge processes for the preparation of mass balances in these plants.

2.2 Activated Sludge Systems

The activated sludge process (AS) includes a number of modifications and variations: conventional activated sludge, extended aeration system, biological nutrient removal systems, etc. As a result of improvement in practice, these systems can be used for domestic, municipal and industrial wastewater treatment purpose regarding the bulking control technologies and/or nutrient removal from wastewater.

Conventional activated sludge process is commonly used for domestic wastewater treatment, or as a secondary treatment of industrial wastewater treatment facilities. The main target of the conventional active sludge systems is the removal of carbonaceous organic matter. If nitrogen removal is also aimed; anoxic denitrification is continued in a separate zone. The conventional system is usually managed under a stable dissolved oxygen concentration (DO) (Balku, 2007). The flow diagram belonging a conventional activated sludge (CAS) process is given in Figure 2.1.

Extended aeration is one of the modified AS process, which has been mostly used for sanitary wastewater treatment plants. It has many advantageous to treat wastewaters due to its high retention time (HRT) ranged 18-36 hours, low active biomass and low organic loading rate, low ammonia effluent, low sludge production, and low BOD effluent (W.W Eckenfelder, 1998; F.R Spellman, 2000). The flow diagram of an extended aeration activated sludge process is given in Figure 2.2.

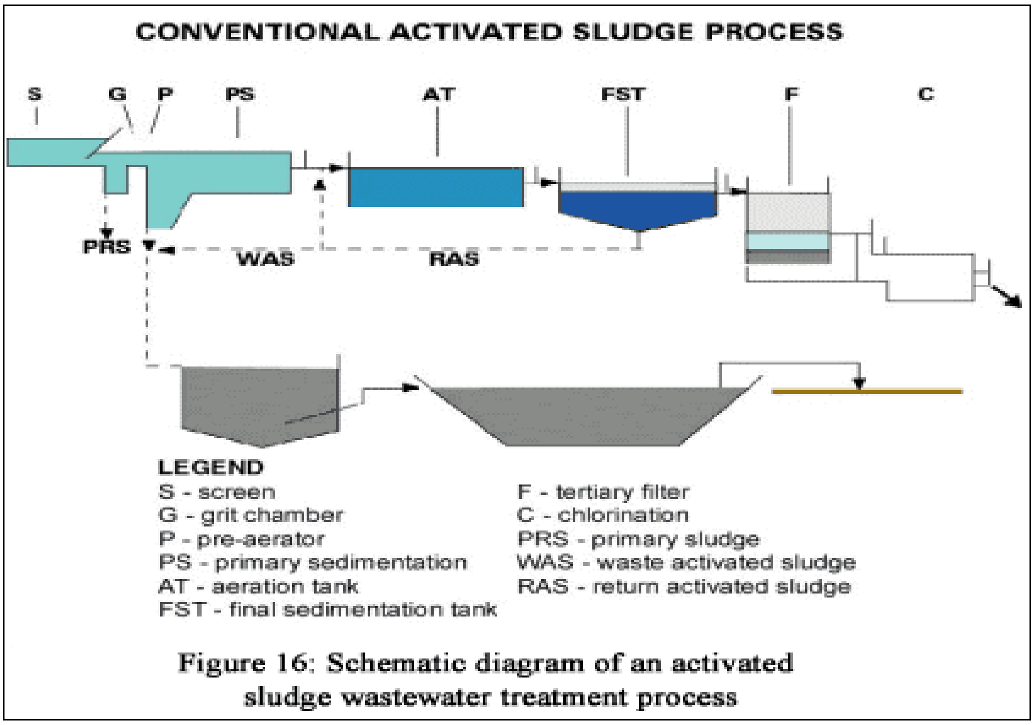

Figure 2.1 CAS process diagram. (Source: United Nations Environment Programme, www.unep.or.jp, 2012)

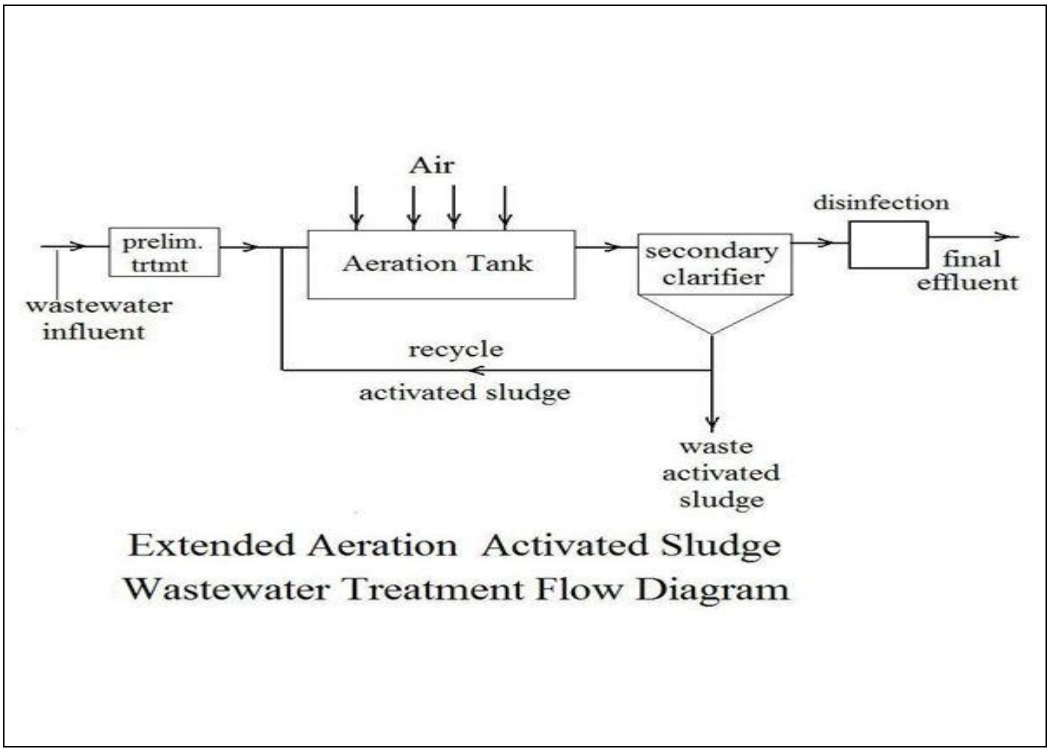

Figure 2.2 EAAS wastewater treatment flow scheme (Source: www.brighthub.com, 2012)

2.3 Biological Nutrient Removal (BNR) Systems

BNR processes generally include anaerobic, anoxic, and aerobic zones with a secondary settling tank, one after another with multiple recycle streams. The tanks are commonly partitioned such that back mixing is minimized to secure the plug withdrawal conditions in the influence of bioreactors. Fermentable organic substances from the influent are mixed with the RAS and converted to volatile fatty acids (VFA) by heterotrophic organisms in anaerobic zone. The subsequent is used up by phosphorus accumulating organisms (PAO) and stocked as poly-β hydroxyl alkanets (PHA). Also poly-phosphate and hence energy are internally released for VFA accumulation.

In the anoxic zone, nitrate coming from the aerobic zone is transformed to dinitrogen by facultative heterotrophic organisms. After Heterotrophic organisms consumed all the biodegradable organics in the previous zones. Two main processes happen in aerobic zone with dissolved oxygen: first is the releasing of phosphate obtained by PAO growing on the stocked PHA. The phosphorus is internally stocked as poly-phosphate. Therefore, it occurs a net reduction of phosphate in wastewater. The second process is nitrification of ammonia by the autotrophic organisms. Generally the last part is not aerated to minimize the amount of DO which goes to anoxic zone (T.T Lee et al., 2000). Figure 2.3 shows the flow diagram for a BNR process.

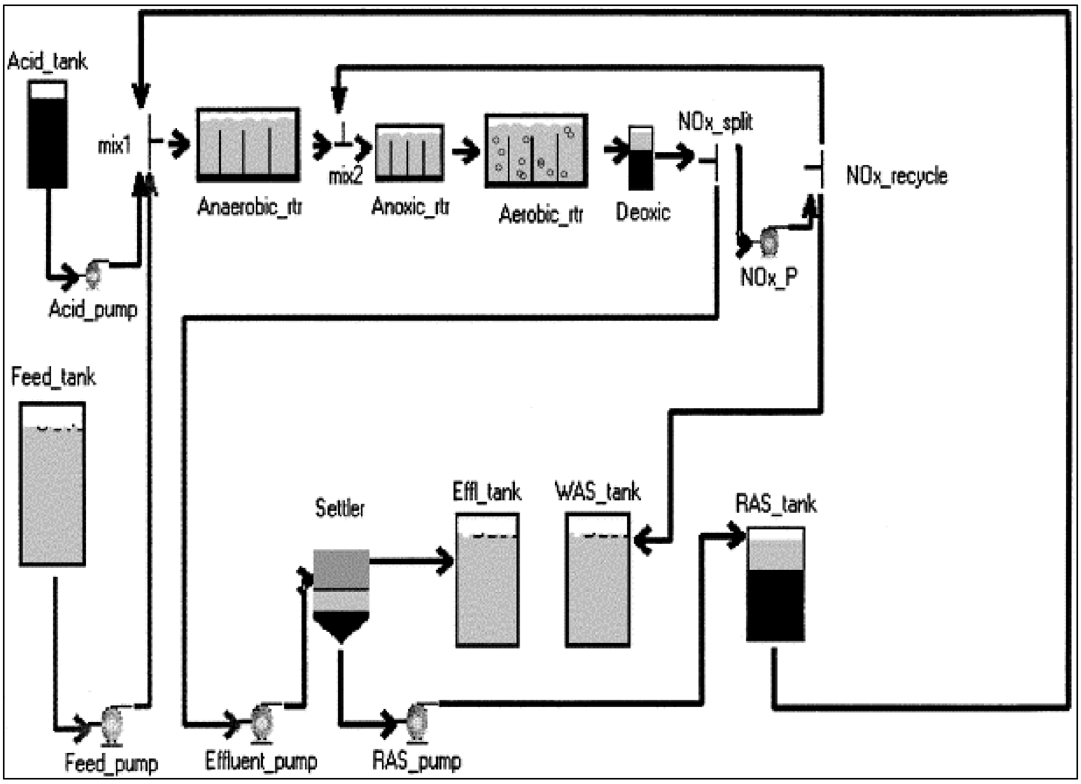

Figure 2.3 Typical BNR activated sludge process scheme. (T.T Lee et al., 2000)

2.4 Sludge Processing and Disposal

In WWTFs, sludge processing units are the important tanks where the mass balance should be regarded. The design engineers should consider the solids production in wastewater treatment plant design. Because of the wide variation of quality and quantity of solids produced at plants, it is difficult to predict solids quantities accurately. However, the information for estimating solids production by using plant-specific data representing the wastewater characteristics and the treatment processes used is important, the obtaining a reliable data is sometimes impossible. In this case, default approaches or sophisticated mathematical models can be used (WERF, 2010). It is reported that a domestic WWTF typically produces about 0.23 kg/m^3 (1 dry ton/ mil gal) of solids. Treatment plants having solids destruction processes like digestion or heat treatment can produce generate less, and those using chemical addition will produce more. That said, 0.25 kg/m^3 is a convenient benchmark for cursory comparisons (WERF, 2010).

The mass balance as an important tool should show key constituents including flow, total suspended solids (TSS), and biochemical oxygen demand (BOD) for conventional activated sludge processes and also including the solids produced by nitrogen- and phosphorus-removal processes and the process assumptions used in the calculations (WERF, 2010). Figure 2.4 shows the treatment processes and disposal methods applicable to sludge produced during wastewater treatment processes.

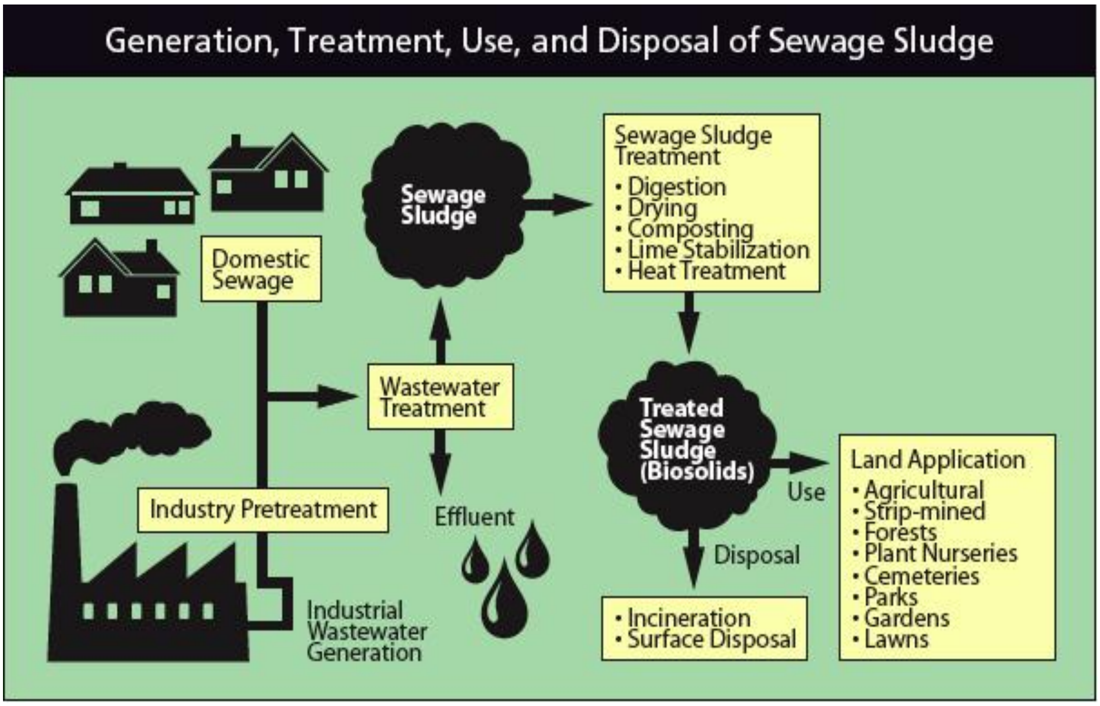

Figure 2.4 Generation, treatment, use and disposal of sewage sludge (Source: EPA, 2012)

2.5 Mass Balance

A mass balance is the way, which uses the law of the conservation of mass in the area of the physical inquiry regarding the inputs and outputs of the substances. The precise conservation law applied in the method strictly depends on the problem all about the mass conservation stating that no matter can disappear or be created without any cause (Himmelblau, David M. 1967). For this reason, the mass balance principle has widely been used in environmental engineering applications. For instance, this theory has been used for designing of reactors, understanding the alternative processes. These include the integral analysis methods like energy balance and somehow more complicated entropy balance. In practice, the budget calculation (inputs-outputs) can be defined via mass balance equations which are employed to analyze the recording data in environmental measurements. For instance in biology, the dynamic energy budget for metabolic organization can be given as a good example of using time, mass and energy balances together. As mentioned above, the basic mass balance principle covers that the mass entering to the system or units as an input should be consider either the system exit as an output or are accumulated in the system. The mass balance can be formulized as follows:

INPUT = OUTPUT + ACCUMULATION

The mass balance equation will generate or consume of each chemical substance in the treatment process. One term in this equation is responsible for bio-chemical reactions meaning the depletion in case of a negative and generation for positive. The term is responsible for the total balance. The modified version of the equation can be applied to both reactive systems and population balances as shown below that it can be tuned into the previous equation if the generation term is zero:

INPUT + GENERATION = OUTPUT + ACCUMULATION + CONSUMPTION

-To create a balance the boundary conditions of the system must be well determined.
-A steady state condition, which makes the accumulation term zero, simplifies mass balances (Himmelblau, David M. 1967).

2.5.1 Mass Balance in Environmental Engineering

Strict effluent demands for wastewater treatment plants (WWTPs) may outcome with the use of more energy. Therefore, WWTP designs are getting more complex and difficult to operate because of providing these demands (Olsson, 2006). Reliable process information is a must for managing the increasing costs for wastewater treatment and it needs optimized operation as well as design. In this sense, WWTP performance criteria has demonstrated to be efficient management way to compare WWTPs and draw conclusions of general validity by helping of mass balance methods (Benedettietal,2006; Nyserda,2008; Unie van Waterschappen, 2003). The data accumulated on wastewater treatment is focalized on the discharge legislation. Effluent discharge and overall removal efficiency must be reported to provide the legislation. For this reason, in WWTP practice, mostly influent and effluent wastewater characteristics are measured. The information, compounded with financial information from WWTP operation, is the major source of current benchmarks for comparison of operational efficiency. These benchmarks have procured water boards that mean to reduce cost, mostly by negotiating adventitious agreements for energy and chemical delivery. But, actual benchmarks don’t procure the convenient operational information for (cost) optimization of individual WWTPs. These data is often existing (e.g. the solids retention time (SRT), sludge loading and the oxygen demand). Nevertheless, the qualification of this information is often inadequate for WWTPs management (S.Puig, M.C.M van Loosdrecht, J. Colprim, S.C.F Meijer, 2008).

Ekama (2009) focused on the steady-state models to design wastewater treatment plants and remarked the importance of mass balances. Because the steady-state models permit reactor measurements and interdependent flows are established from clear equations in the way of unit performance criteria. First, the overall WWTP scheme has to be drawn and every parameters of main system have to be determined. For example, to model anaerobic digestion with a plant-wide WWTP models; COD, nitrogen and carbon fluxes have to be calculated because they enter the anaerobic digestion influent (AD). Ekama (2009) has pointed out that the COD and N mass balance using steady-state models for activated sludge (AS) organics degradation, nitrification and denitrification (ND), and anaerobic (AD) and aerobic (AerD) digestion of wastewater sludge are correlated with bioprocess transformation stoichiometry to form C, H, O, N, COD, and charge mass balance based models so that also C (also H and O) can be tracked through the whole WWTP (Ekama, 2009).

2.5.2 COD Balance

For appropriate design of biological WWTFs, COD based mass balances are very important. There are different design and modeling approaches for activated sludge processes including ASM1, ASM2 models developed by IWA Task Group on Good Modeling Practice (Gillot et al., 2008). The German Standard ATV-DVWK-A 131E namely "Dimensioning of Single-Stage Activated Sludge Plants" is one of the design approach including BNR processes and single stage activated sludge process. It also includes dynamic simulation for plant operation. ATV 131 E Standard use a COD based balance for predicting the sludge production in the plants. Herein, a summary of COD balance taken from the standard is given.

Calculation of the Sludge Production

The sludge generated, quantified as COD, ($X_{COD,SP}$) is composed from the inert particulate influent COD, the biomass formed ($X_{COD,BM}$) and the inert solid matter ($X_{COD,inert,BM}$) remaining from the endogenous decay of the biomass.

$$X_{COD,SP} = X_{COD,inert,IAT} + X_{COD,BM} + X_{COD,inert,BM} \qquad \text{(mg/l)}$$

For the formation and the endogenous decay of biomass the following correlation applies:

$$X_{COD,BM} = C_{COD,inert,IAT} * Y - X_{COD,BM} * tss * b * F_T \qquad \text{(mg/l)}$$

$$X_{COD,BM} = C_{COD,inert,IAT} * Y * 1/(1+b * tss * F_T) \qquad \text{(mg/l)}$$

$$F_T = 1.072^{(T-15)}$$

The yield factor Y = 0.67 g COD/g COD_{deg} and the decay coefficient b = $0.17d^{-1}$ at 15° C are both assumed analogous to those in Activated Sludge Model No. 1 (Henze et al., 1987).

The inert solid matter remaining from the endogenous decay can be set as 20 % of the decayed biomass:

$X_{COD,inert,BM} = 0.2 * X_{COD,BM} * tss * b * F_T$ (mg/l)

The mass of solid matter, which is recorded as COD (XCOD,SP) is 80 % organic. If one reckons with 1.45 g COD/g SS and taking into account the inorganic filterable substances of the influent, one the obtains:

$SP_{d,c} = Q_d * [(X_{COD,SP}/0.8*1.45)+(X_{inorgSS,IAT})]/100$ (kg SS/d) or

$SP_{d,c} = Q_d * [(X_{COD,SP}/0.8*1.45)+(B * X_{SS,IAT})] /100$ (kg SS/d)

2.5.3 Purpose of Solids Mass Balance

Facilities of sludge-processing like digestion, thickening, and dewatering generate waste streams that have to be recycled to the treatment process or to treatment facilities planned especially for the objective. When the flows are recycled to the treatment process, they should be steered into the top of the plant flow for subsequent treatment. The loads of recycled flows on incremental solids, hydraulic, and organic charge on the wastewater treatment facilities that must be taken into consideration in the plant design. It is required to make a solids balance to estimate these incremental values for the treatment system (Metcalf &Eddy, WETR, 2004).

Apart from the solid balances, the most common mass balances types in WWTF are Nitrogen and Phosphorus mass balances. Two important reasons of using these elements are:

- Important cycles for life
- Easier calculation.

A mass flow diagram of a full-scale WWTP studied by Puig et al. (2008) is given in Figure 2.5.

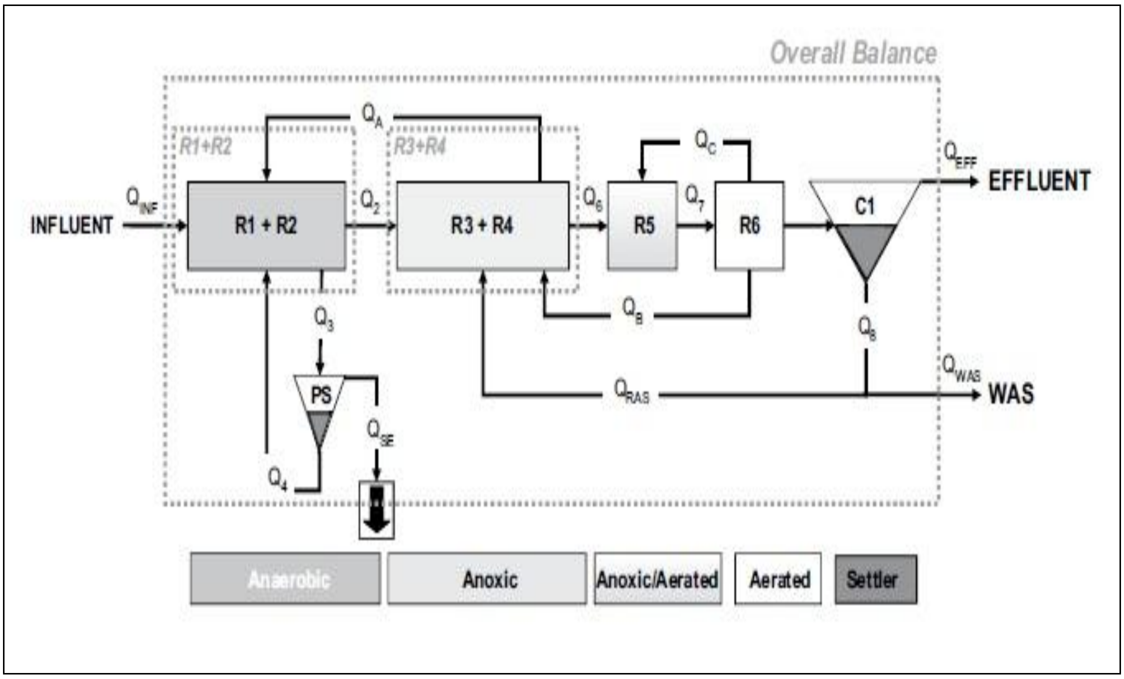

Figure 2.5 Mass flow diagram of the full-scale WWTP (Source: S.Puig et al 2008)

2.5.4 Activated Sludge Models

The International Association on Water Pollution Research and Control- IWA (formerly IAWPRC) published a Task Group on Mathematical Modeling for Design and Operation of Activated Sludge Processes. So it has been a discipline more than 15 years and Professor G.V.R Marais from University of Cape Town, South Africa improved it to the most sophisticated level. Although various models were developed, the little part of them was usable because of the computer capacity limits and the way of the models' written form as very complex at that time. The task group's intent was to create a common platform which could be used for carbon and nitrogen removal via activated sludge processes with a low complication. They first developed the Activated Sludge Model No1. (ASM1). After discussions at the IAWPRC seminar at Denmark in 1985, the final design was published as STR No1 in 1987. Researchers studied five years to improve the model including a guideline for wastewater characterization and advancement of computer notations and also with realistic model results. The ASM1 has been used very much as a matrix for the other advanced models. At the middle of the 1990s, the biological phosphorus removal was included the model as ASM2, which has nitrogen removal and biological phosphorus removal. Before it was published in 1994, due to the act of denitrification in biological phosphorus removal was still unclear; the researchers did not first add this part to the model. Denitrifying PAOs (phosphorus accumulating organisms) were needed improvements. They included these developments to ASM2 in 1999. ASM3 established by Task Group in 1998 was a new designing stage. They aimed to make a tool for use in next generation of activated sludge models and built on recent developments (M. Henze, W. Gujer, T. Mino, M. Loosdrecht, 2000). ASM3 can predict oxygen consumption, sludge production, nitrification and denitrification of activated sludge systems. In addition to ASM1, ASM3 includes storage of organic substrates as a new process. The lysis (decay) process is exchanged for an endogenous respiration process. Typical kinetic and stoichiometric parameters are calculated for 10°C and 20°C together with the composition of a typical primary effluent in terms of the model components (Gujer et al., 1999).

All activated sludge models (ASM1, ASM2, ASM2d, and ASM3) proposed by the International Water Association (IWA) task group on mathematical modeling for design and operation of biological wastewater treatment are the most commonly used mathematical description for modeling biological wastewater treatment processes (Liwarska-Bizukojc and Biernacki, 2010). The ASMs or ASM-based models can be applied by helping of the simulation software programs such as ASIM, BioWin, GPS-X, WEST, DESASS (Gernaey et al., 2004; Ferrer et al., 2008). To do this successfully, the model calibration is very important. However, the modeling activated sludge systems has become an accepted practice in Wastewater Treatment Plant (WWTP) design, teaching and research, the model applications include process alternatives in design phase and process optimization (Keskitalo and Leiviskä, 2012). ‘‘Biomath-Calibration” protocol for ASMs offered by Vanrolleghem et al. (2003) included four steps: ‘’(1) definition of the target(s), (2) the collection of the detailed information on the activated sludge plant, (3) steady-state and dynamic calibration, and (4) decision-making’’. Langergraber et al. (2004) proposed another model calibration protocol including seven steps: ‘’(1) definition of objectives, (2) data collection and model selection, (3) data quality control, (4) evaluation of model structure and experimental design, (5) data collection for simulation study, (6) calibration/validation, and (7) study and evaluation of success (Langergraber et al., 2004)''. Beyond this, two more calibration protocols -the Dutch Foundation of Applied Water Research (STOWA) and Water Environment Research Foundation (WERF) protocols- are available (Liwarska-Bizukojc and Biernacki, 2010).

The identifying of ASM parameters is very complicated because of the nature of the ASMs and ASM-based models, and the numerous parameters incorporated in them (Henze et al., 2000). The changes of the number of parameters within ASMs developments are given in Figure 2.6.

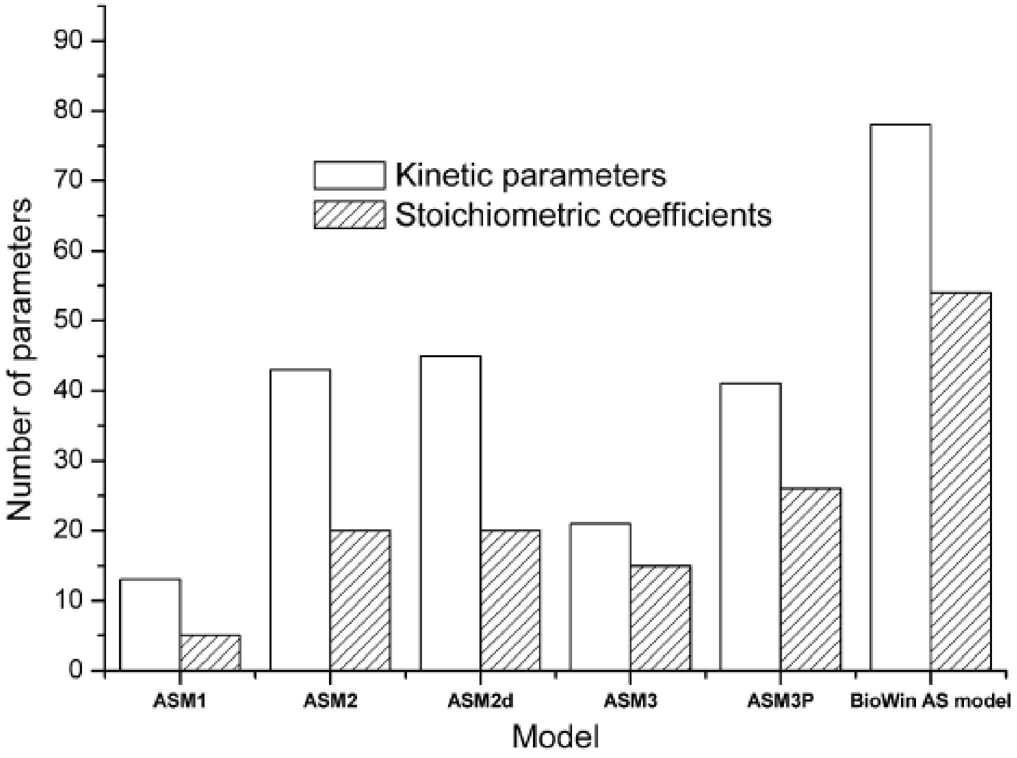

Figure 2.6 The changes of the number of parameters within ASMs development (Source: Liwarska-Bizukojc and Biernacki, 2010)

The selection of parameter subsets for ASM model calibration protocols is very important. In addition, the determination of all model parameters is very expensive and time consuming process and needs a sensitivity analysis. The sensitivity analysis for ASMs is applied for selection of the parameters having influence on the model outputs significantly (Liwarska-Bizukojc and Biernacki, 2010). Sin et al. (2009) have stated that the sensitivity analysis would be a very valuable tool for the supplementation of the uncertainty analysis of WWTP models.

Liwarska-Bizukojc and Biernacki (2010) have pointed out that the sensitivity analysis for the complex ASM based models as the BioWin activated sludge (AS) model has hardly ever been performed. In their work, they applied the standard sensitivity measures in order to fill this gap and worked to verify the predictability of the BioWin AS model, which is implemented in BioWin software, and select its most influential kinetic and stoichiometric parameters. The model used in their work includes the seven functional categories as ‘’(1) growth and decay of Ordinary Heterotrophic Organisms (OHOs), (2) growth and decay of methylotrophs, (3) hydrolysis, adsorption, ammonification and assimilative denitrification, (4) growth and decay of Ammonia Oxidising Biomass (AOB), (5) growth and decay of Nitrite Oxidising Biomass (NOB), (6) growth and decay of ANaerobic AMMonia OXidisers (ANAMMOX) and (7) growth and decay of phosphorus accumulating organisms (PAOs)’’. To describe these processes, the BioWin AS model used 78 kinetic parameters and 54 stoichiometric coefficients.

2.5.4.1 WERF Protocol and BioWin Model

WERF protocol indicates the North American (United States and Canada) practice of ASM calibration and is based on a large number of experiences of consultants and researchers with modeling of full-scale activated sludge treatment plants for a wide range of purposes (Sin et al., 2005). WERF protocol includes four steps. In the first step, the plant configuration is set-up in the simulator (collection of physical plant data, influent loading data and plant performance data), while additional data including collection of historical data, new measurements (full-scale and lab-scale) and clearly stating underlying assumptions is collected about the WWTP under study in the second step. The third one is the calibration step, and the last one is the model validation. Following the successful validation, the model is ready for full-scale application.

BioWin is the model including a combination of the international models ASM1, ASM2d and ASM3 proposed by the IWA and, in addition, anaerobic digestion model (ADM). The software integrated activated sludge/anaerobic digestion (AS/AD) model was established by EnviroSimAssociates Ltd., Canada. The BioWin integrated AS/AD model includes 50 state variables and 60 process expressions describing the biological processes occurring in activated sludge and anaerobic digestion systems, several chemical precipitation reactions, and gas–liquid mass transfer for six gases.

2.5.4.2 ATV-DVWK-A 131E

German ATV-DVWK rules and standards are developed by German Water Associations and include the issues on the wastewater, water and waste facilities for planning, construction and operation. ATV models have different alternatives of the most practical way for designing of AS and BNR processes. They use many empiric formula, which are very close to actual situations. The German Standard ATV-DVWK-A 131E namely “Dimensioning of Single-Stage Activated Sludge Plants” is one of the design approach including BNR processes and single stage activated sludge process. It also includes dynamic simulation for plant operation. ATV 131 E Standard use a COD based balance for predicting the sludge production in the plants. In Section 2.5.2, COD balance taken from the standard is summarized.

Beyond the ATV-DVWK-A 131E standard, there are various models about different topics like ATV-A 128E Standards for the Dimensioning and Design of Storm-water Structures in Combined Wastewater Sewers; ATV-A 148E Service and Operating Instructions for Personnel of wastewater Pumping Stations, Wastewater Pressure Pipelines and Storm water Tanks; ATV-DVWK-A 157E Sewer System Structures; ATV A 126 Principles for Wastewater Treatment in Sewage Treatment Plants; ATV-A 106 E Design and Construction Planning of Wastewater Treatment

Facilities; and ATV-A 123E Treatment and Disposal of Sludge from Small Sewage Treatment Plants.

2.6 About Nitrogen

Nitrogen pollution has serious results in environment. For example, groundwater in many parts of the country, and even some surface waters, frequently has nitrate concentrations in excess of US drinking water standards (10 mg NO_3±N/l) (Baker, 1992). Elevated concentrations of ammonia (>0.1 mgNH_3±N/l) are toxic to fish. Nitrogen is frequently a restrictive nutrient in aquatic ecosystems, especially in estuaries, but excessive inputs of N can occur in an surplus of algae with insanitary impacts (anoxia of bottom waters; red tides, etc.) (extension.missouri.edu, 2012).

‘’Living organisms need nitrogen (in the form of protein) to survive. Nitrogen fertilizer applied to agricultural fields or urban lawns in excess of crop needs becomes a pollutant; additional losses of N occur when animals are nourished with crop, which excrete N. In modern cities, N penetrates sewers as human excretion (generally urine), ground food from garbage disposals and N including chemicals (detergents, etc.) Nitrogen removal by conventional wastewater treatment is peculiarly 50%. Modern nitrification and denitrification (NDN) processes eliminate more nitrogen, but treatment effectiveness in well-run NDN facilities are still only 85%. Nitrogen pollution comes from different sources and is hard to control. However, it is essential to progress a comprehensive view of N cycling in the entire ecosystem to improve useful management tactics to control it (Vitousek et al.,1997)’’.

2.6.1 Nitrogen Cycle

The nitrogen cycle is the procedure by which nitrogen is converted between its different chemical forms. This transformation can be make to both biological and non-biological procedures. Important procedures in the nitrogen cycle involve fixation, mineralization, nitrification, and denitrification (en.wikipedia.org, 2012).

The nitrogen cycle is of particular interest to ecologists procedures, including primary production and decomposition. Activities that human do like fossil fuel combustion, use of unnatural nitrogen fertilizers, and sending of nitrogen in effluent water have dramatically altered the global nitrogen cycle (Steven B. Carroll, Steven D. Salt, 2004). Figure 2.7 shows nitrogen cycle in nature, scratched by EPA, (2012).

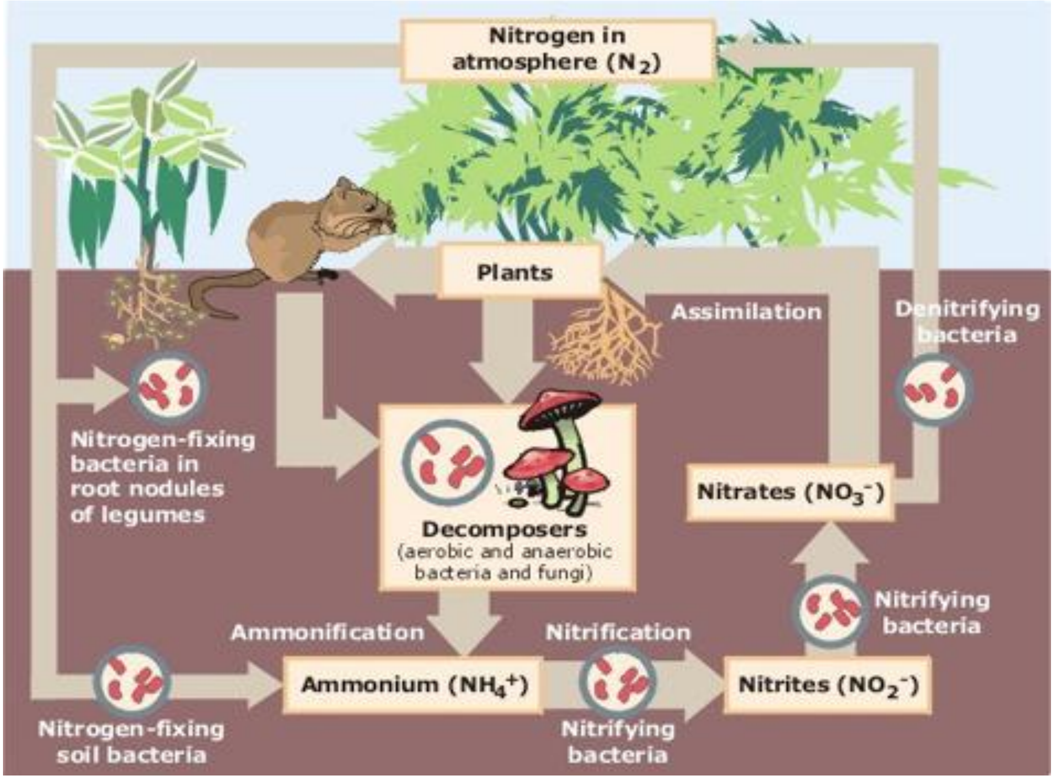

Figure 2.7 Nitrogen cycle (Source: EPA, 2012)

2.6.2 N Cycle in Wastewater Treatment

Large amounts of nitrogen are released into the atmosphere by discharging through a drain field into the ground by onsite sewage facilities like septic tanks and holding tanks. The soil in some unsuitable areas or the wastewater itself with some pollutants leaks into the aquifer. These pollutants can be accumulated or mixed with drinking water resources. One of the most dangerous pollutants is nitrogen in the form of nitrates. The accepted EPA limit for drinking water is less than 10 ppm (parts per million) or 10 milligrams per liter, and a typical household sewage produces a range of 20-85 ppm. Many American states have started to have advanced treatment systems as a part of the traditional onsite sewage systems. All these systems decrease the amount of nitrogen along with the other pollutants in the wastewater (en.wikipedia.org, 2012). Figure 2.8 shows cultivation, irrigation and drainage, and natural system loads for N mass balance.

In Europe and Turkey, new WWTF have been built with nutrient removal units as advanced treatment processes. Figure 2.9 shows Nitrogen mass balance for wastewater in the Central Arizona-Phoenix (CAP) ecosystem (Lauver and Baker, 2000).

Additional risks posed by increased availability of inorganic nitrogen in aquatic ecosystems contain water acidification; eutrophication of fresh and saltwater systems; and toxicity issues for animals, containing humans (Camargo, J.A. & Alonso,A., 2006)

‘’Eutrophication frequently causes lower dissolved oxygen levels in the water column, containing hypoxic and anoxic conditions, which can cause death of aquatic fauna. Comparatively sessile benthos, or bottom-dwelling creatures, is especially vulnerable by reason of their lack of mobility, though large fish kills are common. Oceanic dead zones near the mouth of the Mississippi in the Gulf of Mexico are a well-known examples of algal bloom-induced hypoxia (Rabalais, Nancy N., R. Eugene Turner, and William J. Wiseman, Jr., 2002)’’.

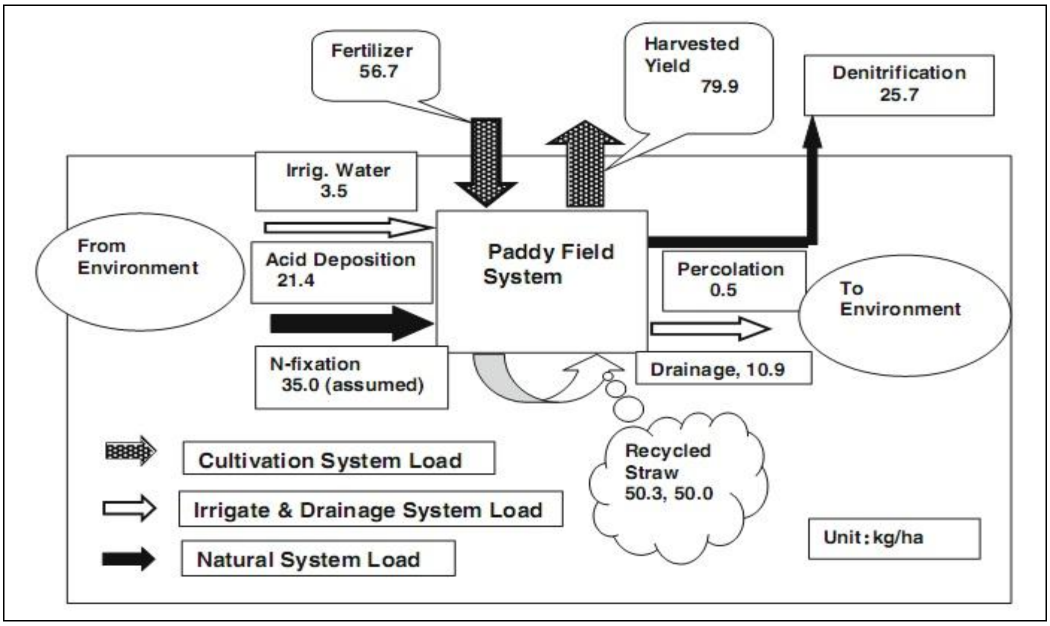

Figure 2.8 Cultivation, irrigation and drainage, and natural system loads for N mass balance (Source: Maruyama et al 2008)

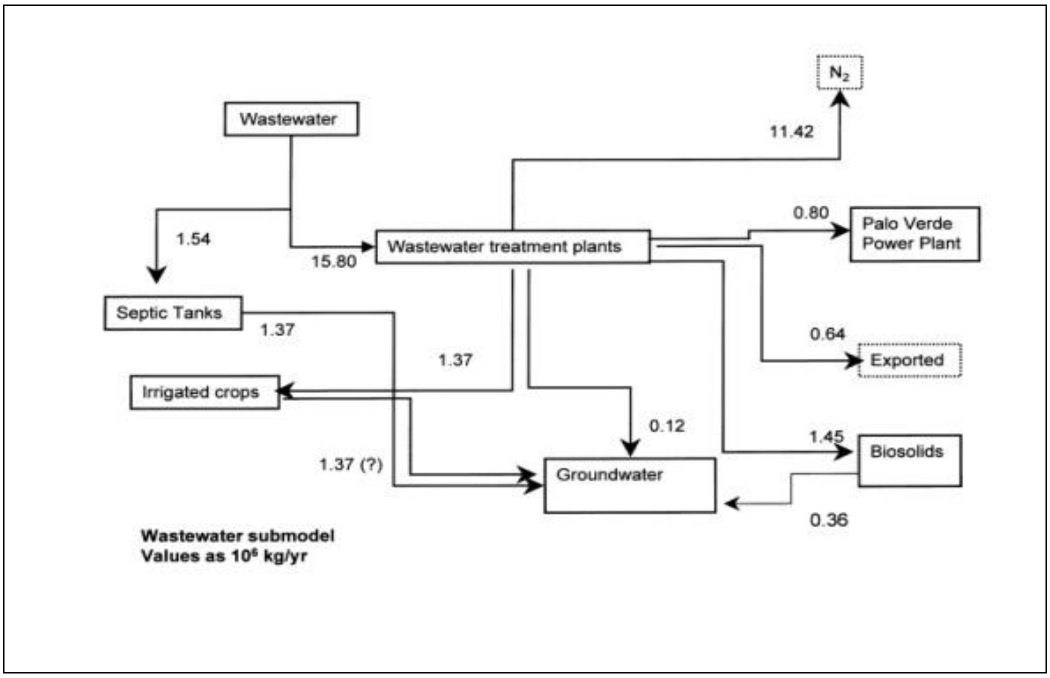

Figure 2.9 Nitrogen mass balance for wastewater in the CAP ecosystem (Source: Lauver&Baker, 2000)

2.7 Phosphorus Cycle

The phosphorus cycle is a biogeochemical cycle that the motion of phosphorus through the lithosphere, hydrosphere and biosphere. The atmosphere does not play very important role in the motion of phosphorus, in that phosphorus and phosphorus-based compounds are generally solids at the typical ranges of temperature and pressure existed on Earth (en.wikipedia.org, 2012). The phosphorus cycle is schematized in Figure 2.10.

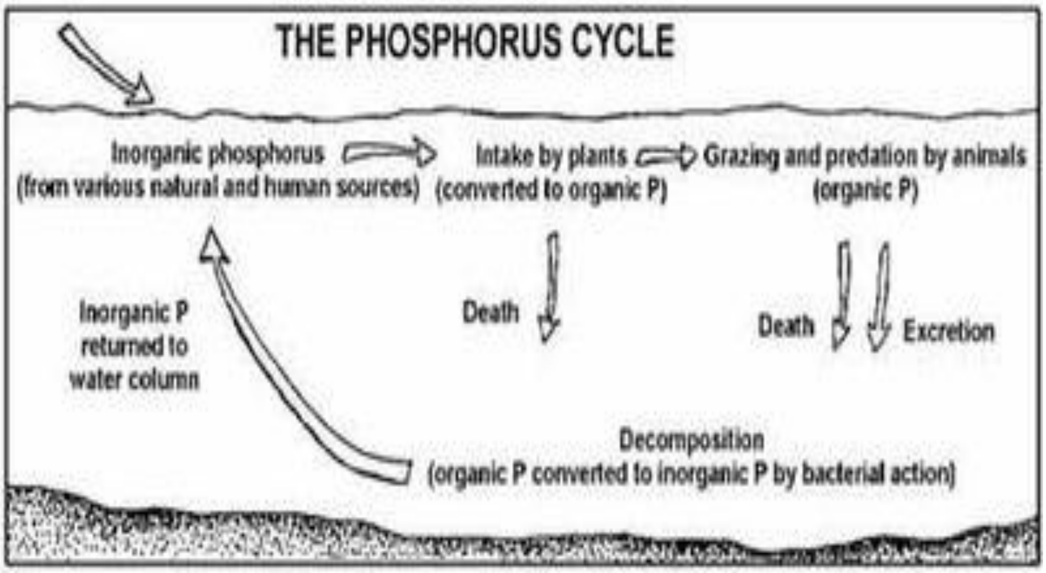

Figure 2.10 The phosphorus cycle (Source: EPA)

2.7.1 Phosphorus in Environment

Phosphorus in the form of ions is a vital element for the plants and animal in nature. Phosphorus as a nutrient puts a limit to aquatic organisms. It is found in the most important life-sustaining molecules in the biosphere in a very large scale. It is mainly found in rock formations and soil minerals. It causes pollution in lakes and rivers. Enriching phosphate causes eutrophication of fresh and inshore marine waters, which leads to the generation of algae due to the excess nutrients. Algae are consumed by bacteria and a bacterial bloom occurs. Bacteria perform cellular respiration and all of the oxygen in the water is used by decomposers, which causes colossal fish death (en.wikipedia.org, 2012).

Living organisms cannot sustain their lives without nutrients and survive their ecosystems. But large amounts of nutrients like phosphorus and nitrogen have some negative effects on the aquatic ecosystems Fresh water eutrophication might be accelerated by surface and subsurface runoff and erosion from high-P soils. A complicated interaction between the type of P input, soil type and management, and transport processes depending on hydrological conditions forms the processes controlling soil P release to surface runoff and to subsurface flow (Branom J.R and Sarkar D, 2004).

2.8 Applications of Mass Balance for Wastewater Treatment Facilities

Mass balance is a recognized technique and largely used in engineering (Adgate et al., 1998; Baker and Hites, 2000). In chemical/petrochemical industries, the standard of process information importantly affects the performance and increase (Narasimhan and Jordache, 2000). But, the technology infrequently is implemented in WWTPs practice. The measured data possibly involves large errors without a convenient control of WWTP information. In design and operation, process engineers usually calculate the data by using large safety factors (Bixio et al., 2002). But, the importance of these errors and its efficiencies on the computed operational situations has not been investigate before, in the field of wastewater treatment (S.Puig, M.C.M van Loosdrecht, J. Colprim, S.C.F Meijer, 2008).

Mass balances over WWTPs are perfect ways to determine the fluxes of substances, analogize operational conditions and draw conclusions of general validity (Nowak et al.1999). Because of the process' dynamic and the instability of the influent loading, practice of mass balance on WWTP data is difficult. A WWTP mass balance management has to be made a practice to procure reliable information from raw WWTP data. This needs an alternative measurement strategy. In addition to influent and effluent, all in- and outgoing flows containing the activated sludge composition and sludge production should be measured for mass balance calculations (S.Puig, M.C.M van Loosdrecht, J. Colprim, S.C.F Meijer, 2008).

Wentzel et al. (2006) worked on the mass balance-based plant-wide wastewater treatment plant models regarding the biodegradability of wastewater organics under anaerobic conditions. To assess and quantify the interdependencies of the various unit operations making up the WWTP, models that track materials of importance through the WWTP on a mass balance basis are required. They stated that the materials mass balance based models of the entire WWTP would be a valuable tool to aid optimization of WWTP design and performance with the advantages including:

- *‘’Tracking compounds through the WWTP to ensure continuity,*
- *Identifying characteristics of streams from one unit operation (e.g. primary settling) to a downstream one (e.g. aerobic/anaerobic digestion); this will assist in design and performance assessment and optimization of the various unit operations in the WWTP,*
- *Assessing the impact of recycling sludge thickening and dewatering liquors from downstream operations on upstream operations,*
- *Identifying bottlenecks and overloaded unit operations which limit the capacity of the WWTP,*
- *Optimizing unit operations for maximum throughput and minimum impact on effluent quality and upstream units,*
- *Identifying from the influent wastewater characteristics, and the type, design and operation of the specific unit operations making up the WWTP, the extent to which mineral precipitation problems will arise in the sludge treatment operations,*
- *Assessing the impact of interventions, such as including additional unit operations in the WWTP sequence like phosphorus precipitation or nitrification of recycling liquors,*
- *Identifying WWTP operational and analytical data that do not conform to mass balance and continuity principles’’.*

In the mass balance preparation of WWTP using mathematical models like ASM1, ADM1, a requirement of plant-wide WWTP mass balances models is that all materials of importance in all of the individual unit operations are included, so that materials are common at the links between unit operations (Wild and Siegrist, 1999). It means that the modeling parameters in an individual unit operation that may not be of significance to that unit operation, but may be crucial to a unit operation that receives the output. For example, in AS models C is not usually included as a compound, but C is important in the AD of sewage sludges since it directly effects the gas production and composition, and influences the pH established through the weak acid/base chemistry. The overall objective is to develop materials mass balance models for the entire WWTP including all materials of importance such as COD (electron), C, N, P, alkalinity (proton), Ca and Mg. In most WWTPs, unit operations in which transformations of the materials take place that need to be modeled are primary sedimentation, biological wastewater treatment in AS systems, including or excluding biological N and P removal, sludge thickening and aerobic and anaerobic stabilization of primary and secondary sludges (Wentzel et al., 2006).

Puig et al. (2008) have pointed out that the measured data of WWTPs often contains errors, which can prohibit the use of WWTP data for process evaluation, process design, benchmarking or modeling purposes. They proposed a practical stepwise methodology to check WWTP data using mass balances. In their work, they found that the poor WWTP data quality leads to large errors when calculating key operational conditions such as the solids retention time (SRT), oxygen consumption (OC) and the different internal conversions rates. They concluded that by improving WWTP data quality using mass balance calculations useful new information becomes available for process evaluation, WWTPs design and benchmarking.

Katsoyiannis and Samara (2005) used ‘’the mass balance technique for investigating the fate and the mass balance of persistent organic pollutants (POPs) during the conventional activated sludge treatment process in WWTP of the city of Thessaloniki, Greece. The POPs of interest were 7 polychlorinated biphenyls and 19 organochlorine pesticides. Target compounds were determined at six different points across the treatment system: the influent, the effluent of the primary sedimentation tank, the effluent of the secondary sedimentation tank, the primary sludge, the activated sludge from the recirculation stream, and the digested/dewatered sludge. The distribution of POPs between the dissolved and the adsorbed phases of wastewater and sludge was investigated. This approach can be used not only for C, N, P balances; but also applicable for other pollutants available in municipal wastewaters like POPs’’.

Ekama (2009) provided ‘’a basis demonstrating the benefits of including steady-state mass balances based kinetic and stoichiometric models in plant-wide WWTP dynamic simulation software for design and operation. It is recommended that WWTP simulation software be extended to include steady-state mass balance kinetic and stoichiometric models as pre-processors to assist with WWTP layout design, reactor sizing, option exploration and comparisons, wastewater characteristic estimation, recycle ratio determination, initial concentration calculation and simulation software output evaluation’’.

Lauver and Baker (2000) calculated a complete nitrogen mass balance for all wastewater generated in the Central Arizona Phoenix ecosystem was developed using data from the 18 largest wastewater treatment plants (99% of flow). Components included total N in raw wastewater, denitrification in wastewater treatment plants, biosolids production, and effluent (reuse, recharge, and discharge). Denitrification and biosolids production remove 81% of wastewater N. Nearly all biosolids are recycled to cotton fields within the ecosystem. Most effluent is recycled within the ecosystem. As the result of wastewater management practices developed to reuse wastewater, wastewater N is either deliberately volatilized or accumulates within the system; only 4% of the original wastewater N is exported via the Gila River.

Hao et al. (2012) used extended Activated Sludge Model No. 2d (ASM2d) to incorporate the processes of both predation and viral infection for sludge minimization in a sequencing batch reactor (SBR) system enriching polyphosphate-accumulating organisms (PAOs). They firstly calibrated and validated the model by different experimental results. It was formulated with three individual processes for decay; and it was effectively calibrated with a set of experimental results and 6 kinetic parameters needing adjustment. It was validated against another set of experimental results.

Argaman (1995) have indicated that the proposed model was most applicable in the preliminary phases of a system design, when various process alternatives were evaluated. In that work, it was stated that the steady-state analyses were often adequate and the absolute accuracy of all process parameters was less critical. Use of the model for design purposes is achieved by simultaneous solution of a set of equations and can be solved by commercially available software. That work presented a solution procedure which was specifically developed for designing.

Some examples of mass balance schemes from different studies are given in the Figures 2.11 and 2.14.

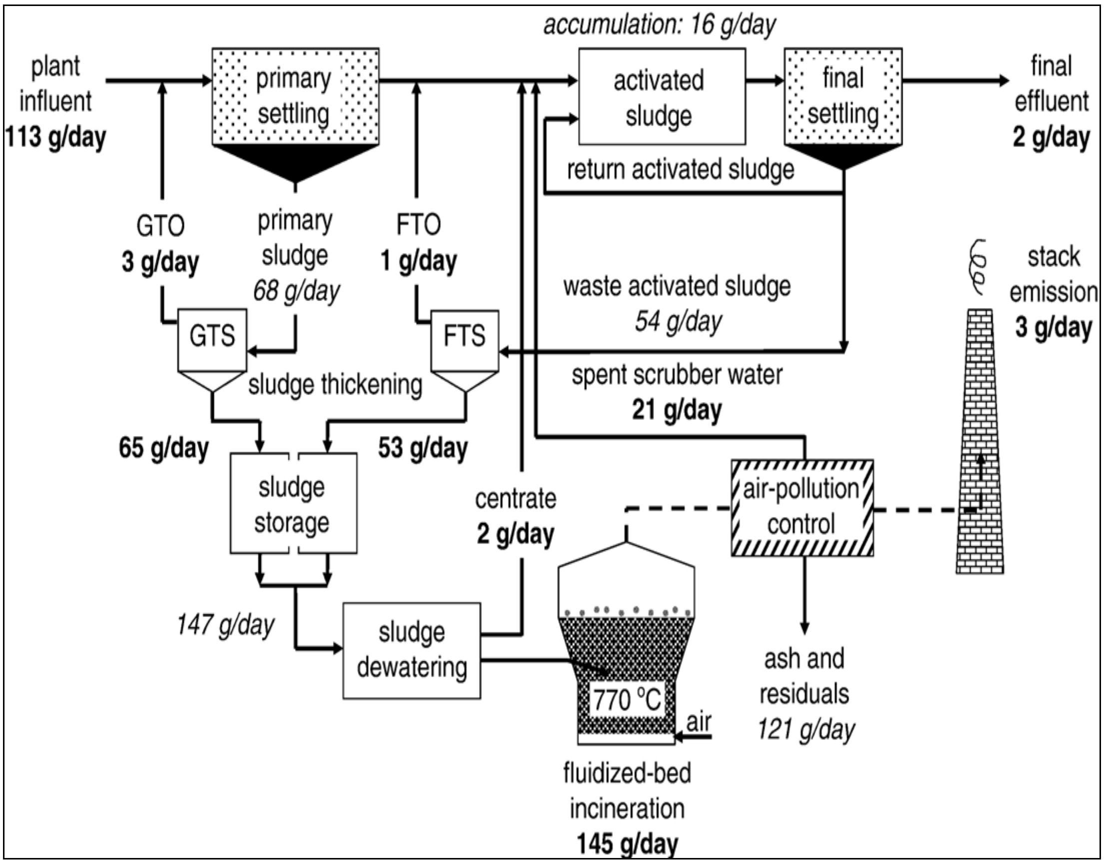

Figure 2.11 Schematic diagram showing mass flow rates of Hg in various process streams. Measured values are shown in bold, and calculated values are shown in italics.(Source: Balogh&Nollet, 2007)

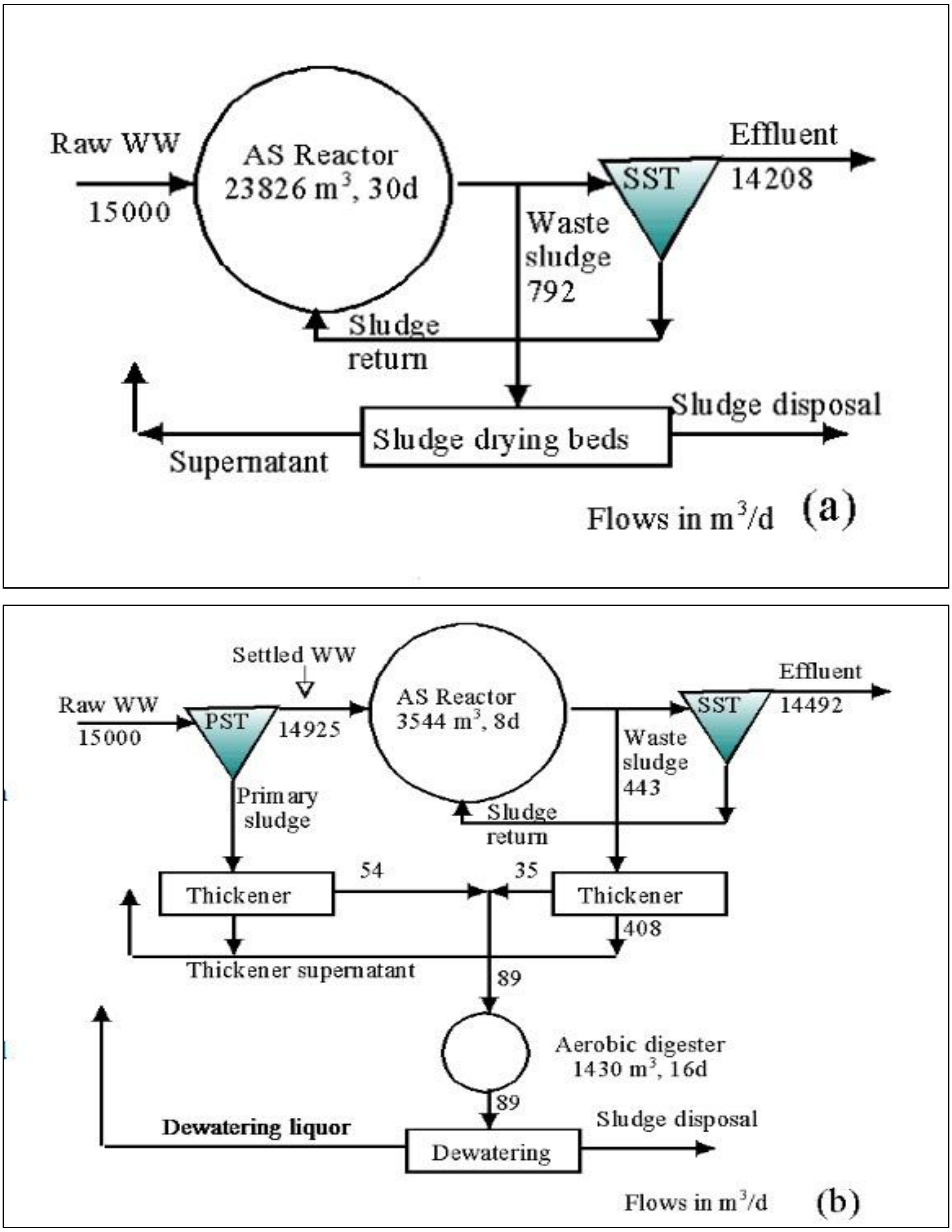

Figure 2.12 Wastewater treatment plant schemes treating (1) raw wastewater at a long sludge age (extended aeration) (a) and (2) including primary settling tank, short sludge age activated sludge system and aerobic digestion of primary and waste activated sludges (b) analyzed with the steady state activated sludge and aerobic digestion models and simulated with ASM1 (Thickener supernatant and dewatering liquor recycling not simulated).(Sötemann et al, 2006)

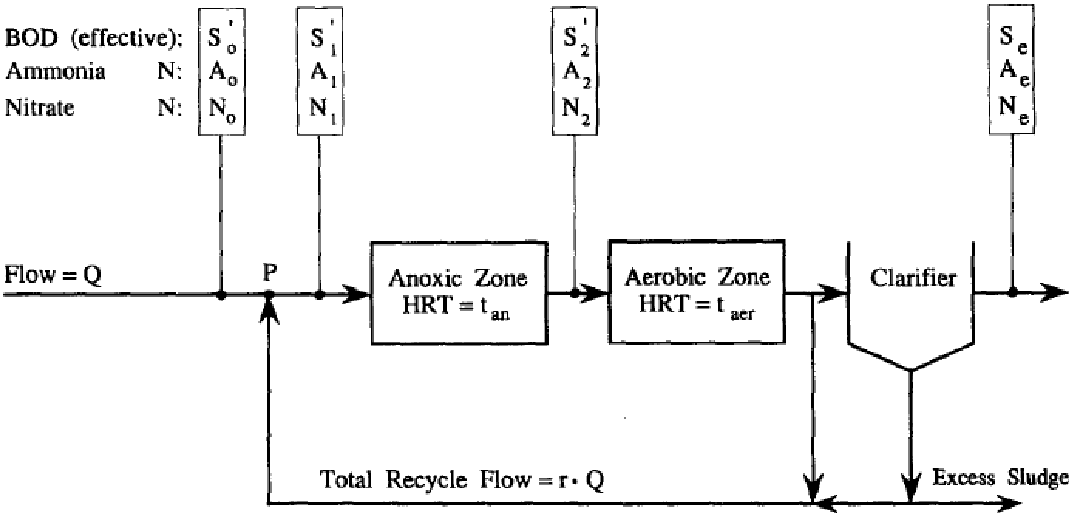

Figure 2.13 Flow scheme and symbols definitions for nitrogen--removing activated sludge- Steady-state model of activated sludge-I (Source: Argaman, 1995).

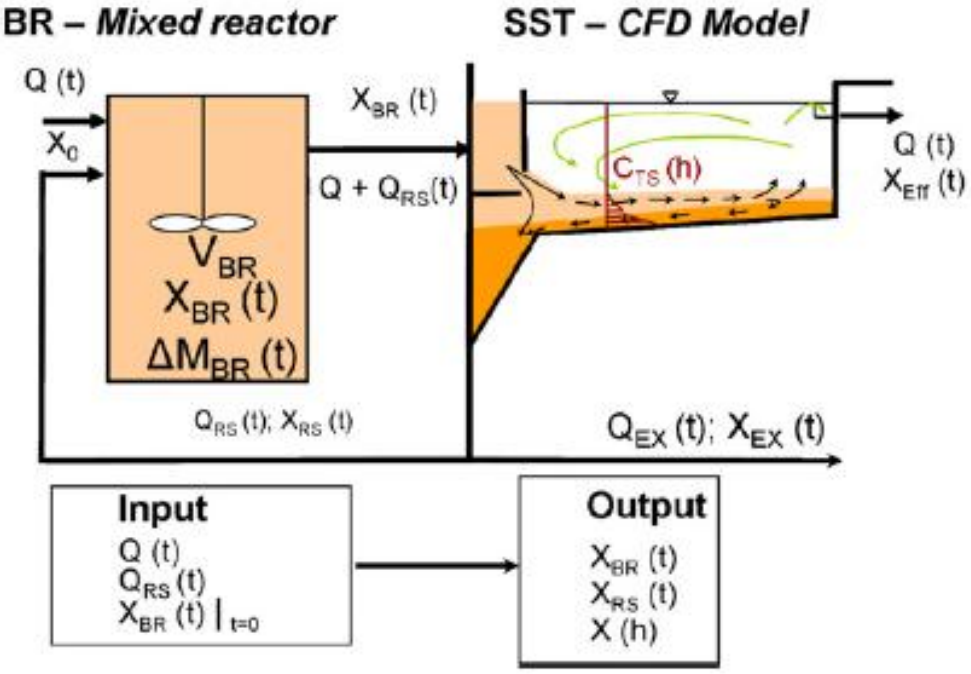

Figure 2.14 Mass transport model for Biological reactor (BR) and Secondary settling tank (SST) (Source: Patziger et al., 2012).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of The Municipal Wastewater Treatment Plants

In this thesis, three different wastewater treatment processes, which are widely used in wastewater treatment field were selected. The treatment processes are Conventional Active Sludge System (CAS), Extended Active Sludge System (EAS), and Biological Nutrient Removal System (BNR, A^2/O). The flow schemes of the WWTPs are presented between Figures 3.1 and 3.3.

3.2 Mass Balance Preparation Approach

A method to calculate the quantities of solid production is used to prepare the mass balance for the treatment processes linking between the designs parameters for each process and the solid production. The mass balance must consist of the important elements like flow, total suspended solids (TSS), and biochemical oxygen demand (BOD) and the assumptions that the design engineers use in the processes. Solids produced by nitrogen- and phosphorus-removal processes should also be taken into the mass balance including the recycle streams in the plants. In the first method, the engineer accepts that a certain fixed ratio of the solids or BOD is recycled from downstream processes to the head of the plant. Then the solid balance is iterated until the recycled quantities found at the head of the plant equals to the sum of recycled quantities calculated for each process. On the other hand, the second method estimates the treatment plant’s net solids production according to historical data, estimated influent strength, or experience at similar facilities. After this operation, this information is used to estimate the quantities of solid exiting the treatment plant and generally applied to the output end of the dewatering process. And then solids loading to a specific process via the mass balance are back-calculated with the help of mass balance. In this thesis, the first approach was used to calculate the mass balance of the selected wastewater treatment flow diagrams.

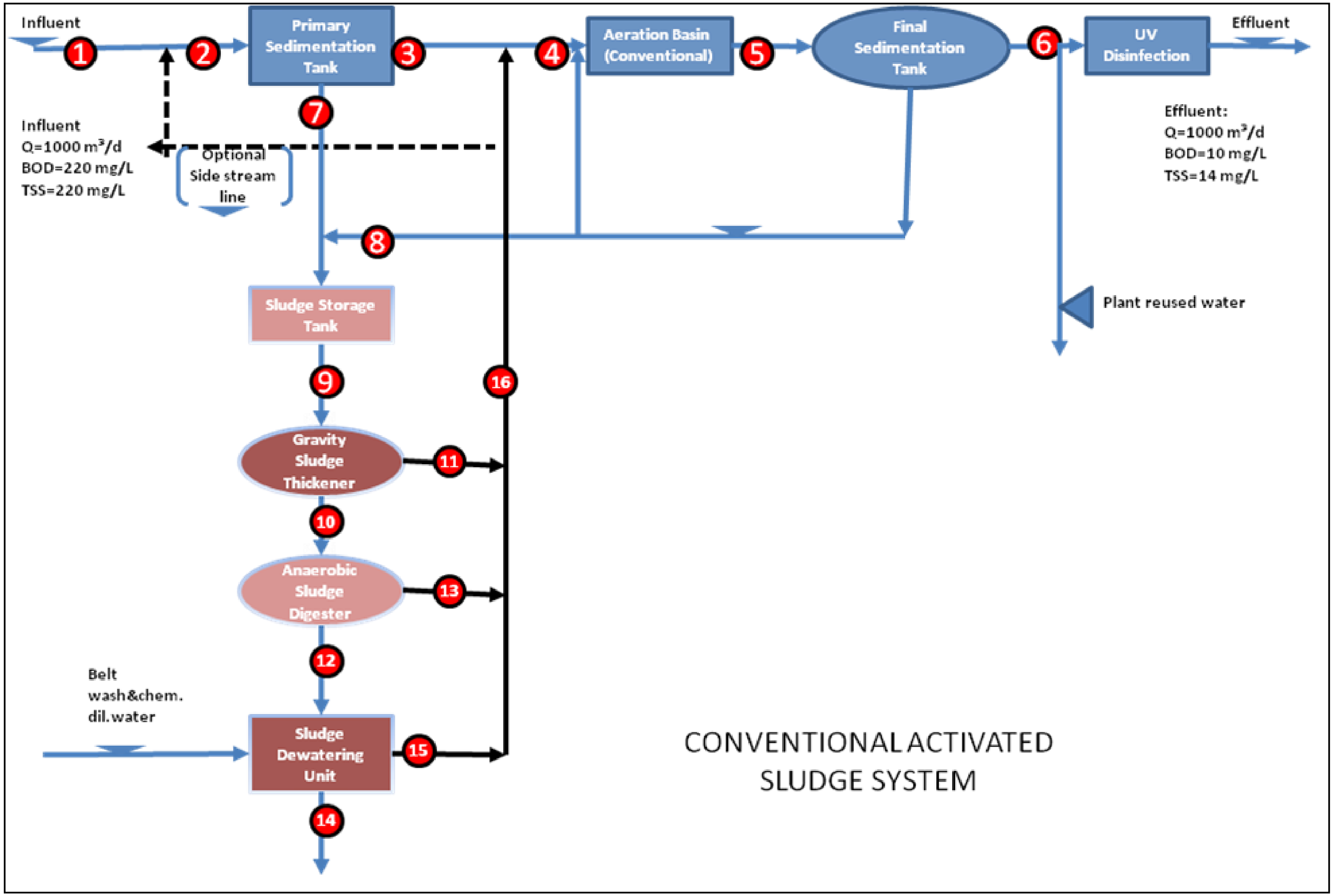

Figure 3.1 Conventional activated sludge system process scheme

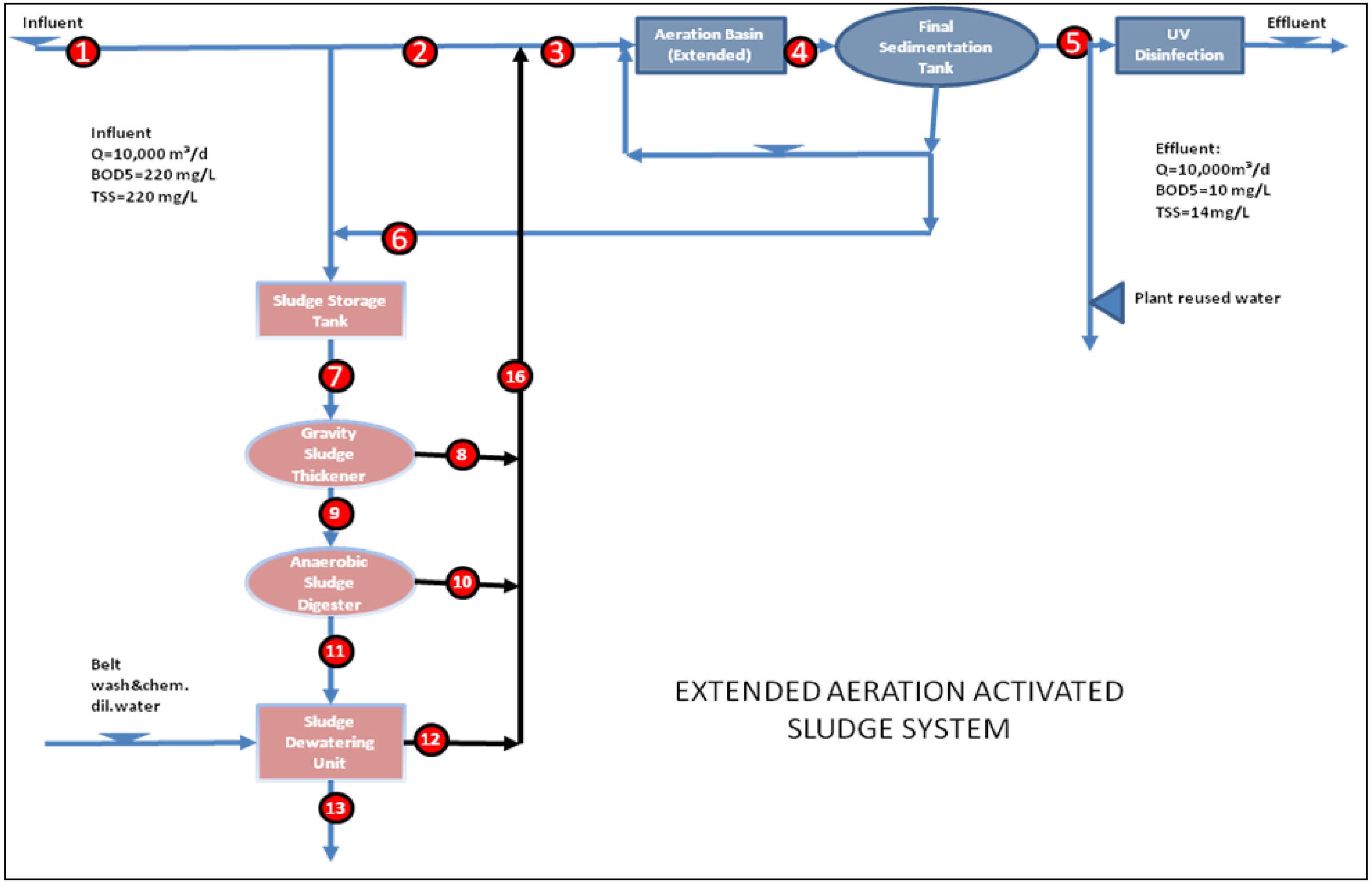

Figure 3.2 Extended aeration activated sludge system process scheme

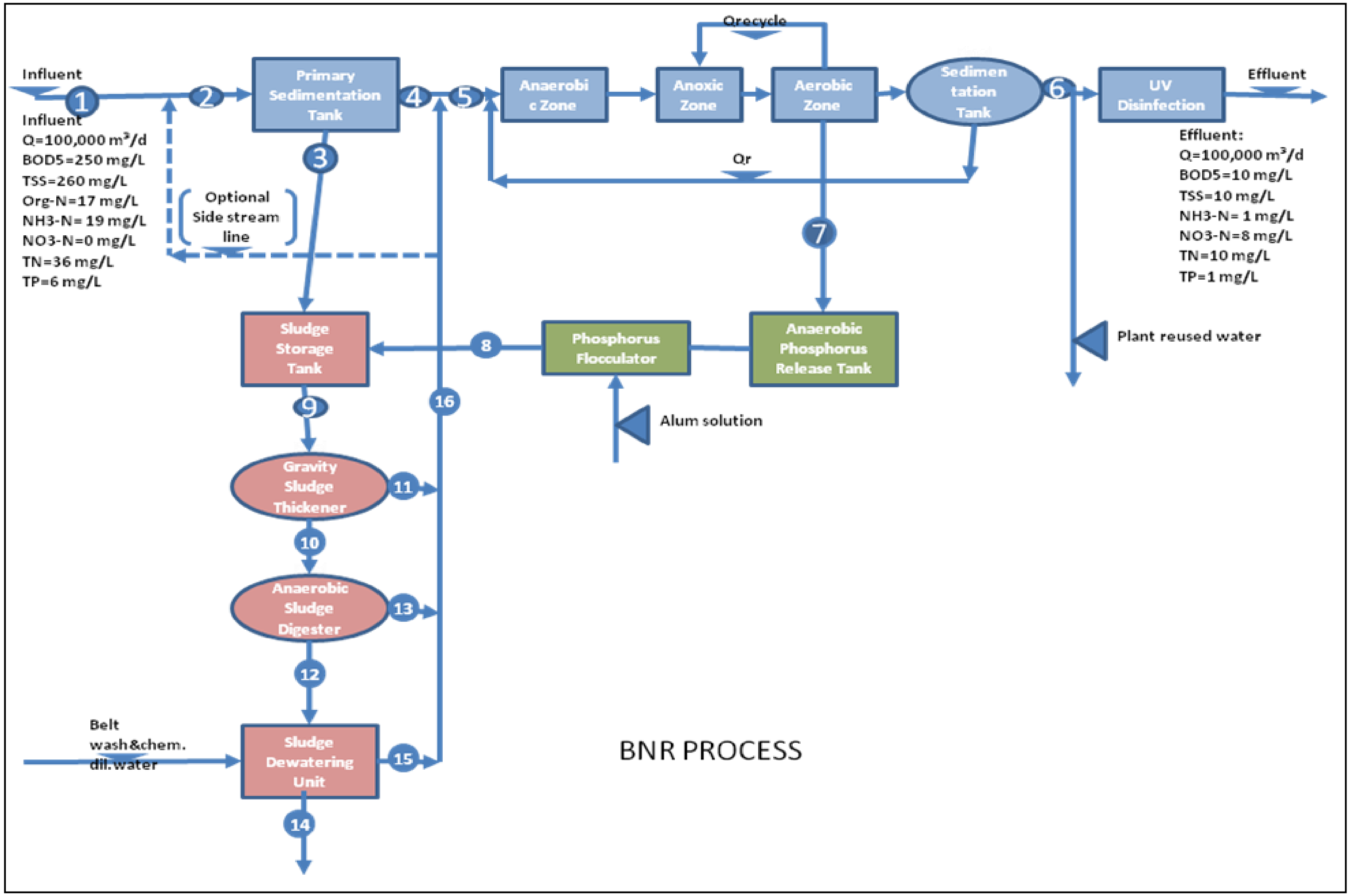

Figure 3.3 Biological nutrient removal process scheme

Expected fluctuations in wastewater characteristics that result from changes in industrial contribution, storm water flows, seasonal weather conditions, and an expanded collection area must be considered by engineers. Peak solids production and daily changes must be studied seriously by the engineers to comprehend the solid handling processes (Water Environment Federation and the American Society of Civil Engineers / Environmental and Water Resources Institute, 2010).

A mass balance can be roughly defined as a computation depending on the average flow and average BOD and suspended solids concentrations. If it is desired to size some facilities like sludge storage tanks and plant piping correctly, a mass balance for the maximum expected concentration of BOD and suspended solids in the untreated wastewater should also be performed. That the storage capacity in the wastewater and sludge-handling facilities shows a tendency to leave peak solids to the plant is one of the main reasons for that. For instance, the resulting peak solids loading to a dewatering unit may be only 1.5 times the average loading. Furthermore, it’s been seen that periods of maximum hydraulic loading cannot show a correlation with periods of maximum BOD and suspended solids. As a result, it is not possible to use coincident maximum hydraulic loadings while preparing a mass balance for maximum organic loadings (Metcalf&Eddy, 2004, Fourth Edition).

In this thesis, the iterative method is used to find the best results of mass balances. A spread-sheet by using Microsoft Excel was first established for conventional activated sludge system and then improved for extended aeration activated sludge system and also BNR system. All calculations were automatically done when the inputs are set up. It is important to have a reliable information of unit operations. The calculations were done for three different flow rates: 1000 m^3/day, 10,000 m^3/day, and 100,000 m^3/day. All constants and coefficients are taken from the Metcalf & Eddy (2004). Typical medium strength domestic wastewater characteristics were used for the computations as reported in Table 3.1.

Table 3.1 Typical Composition of Raw Domestic Wastewater (*Source:* Metcalf and Eddy, Inc., 1991, *Wastewater engineering*, 3d ed. (New York: McGraw-Hill).

	Weak	**Medium**	Strong
Solids, total (TS), mg/L	350	**720**	1200
Total dissolved (TDS), mg/L	250	**500**	850
Total suspended (TSS), mg/L	100	**220**	350
Settleable solids, mg/L	5	**10**	20
BOD_5, mg/L	110	**220**	400
TOC, mg/L	80	**160**	290
COD, mg/L	250	**500**	1000
Nitrogen (total as N), mg/L	20	**40**	85
Organic, mg/L	8	**14**	35
Free ammonia, mg/L	12	**25**	50
Nitrites + nitrates, mg/L	0	**0**	0
Phosphorus (total as P), mg/L	4	**8**	15
Organic, mg/L	1	**3**	5
Inorganic, mg/L	3	**5**	10
Chlorides, mg/L	30	**50**	100
Sulfate, mg/L	20	**30**	50
Alkalinity, mg/L as $CaCO_3$	50	**100**	200
Grease, mg/L	50	**100**	150
Total coliform, no/100 mL	10^6~10^7	**10^7~10^8**	10^7~10^9

3.3 Basis of Solids Balance Evaluations

When the wastewater characteristics and flow rates were first introduced the Excel spread-sheet, iteration calculations were repeated until the interval of iteration is less than 10%. Three flows were determined and computed for each processes that 1000 m^3 / d, 10,000 m^3 / d, 100,000 m^3 / d. The calculation results are given in Chapter 4 of this thesis. However, one example showing the calculation steps and assumptions is presented in the subsection 3.3.1.

3.3.1 Mass Balance Example

This example shows the iterations of CAS mass balance step by step. The more details about calculation approach can be found elsewhere in the WERF Manuel, Chapter 20 by Water Environment Federation and the American Society of Civil Engineers/Environmental and Water Resources Institute (2010).

Step 1:Mass of BOD and TSS in Influent

- Mass (kg/d) = Concentration (mg/l) * Q (m^3/d)/1000

Table 3.2 Solids characteristics for mass balance

	In SI units
Q [m^3/d]	1000
Influent BOD [mg/L]	220
TSS [mg/L]	220
TSS after grit removal [mg/L]	180
Solids characteristics, % Primary	4.8
Thickened WAS	5.5
TSS digested	5.3
Specific Gravity	1
Biodegradable fraction of WAS	65
Effluent characteristics BOD [mg/L]	10
TSS [mg/L]	14
U_{BOD}[mg/L]	1.42

Table 3.3 Influent Mass Loads

BOD (kg/d)	220
TSS (kg/d)	220
TSS after grit removal (kg/d)	180

Step 2: Soluble BOD in Effluent

- Biodegradable portion = Effluent TSS * 65%
- UBOD = Biodegradable portion * 1.42
- BOD of effluent TSS = 0.68 (obtained using $k = 0.23\ d^{-1}$) * UBOD
- Effluent soluble BOD escaping treatment = Effluent BOD–BOD of Effluent TSS

Table 3.4 Soluble BOD in effluent

BOD of Effluent TSS (Biodegradable portion is 65%) (mg/L)	9.1
UBOD (mg/L)	12.9
BOD of effluent TSS (mg/L)	8.8
Effluent soluble BOD escaping treatment (mg/L)	1.2

Step 3: First Iteration

Step 3.1: Primary Settling

- Assume 33% removal of BOD and 70% removal of TSS
- Estimate mass of BOD and TSS removed and mass of BOD and TSS that will go to bioreactors.
- Mass (kg/d) = Concentration (mg/L) * Q (m^3/d)/1 000g/kg
- Estimate concentration of BOD in primary effluent and volatile fraction of primary solids.

Table 3.5 Primary Settling

BOD removed (kg/d)	72.6
BOD to secondary (kg/d)	147.4
TSS removed (kg/d)	126
TSS to secondary (kg/d)	54
Primary effluent BOD (kg/d)	147.4

Table 3.6 Volatile fraction of primary solids

Volatile fraction of influent TSS	0.67
Volatile fraction of grit	0.1
Volatile fraction of incoming TSS discharge to secondary process	0.85
VSS in influent before grit (kg/d)	147.4
VSS removed in grit (kg/d)	4
VSS in secondary influent (kg/d)	45.9
VSS in primary solids (kg/d)	97.5
Volatile fraction in primary solids	0.77

Step 3.2: Secondary Process

-Compute mass quantities of BOD and TSS in effluent

Table 3.7 Operating parameters

MLSS [mg/L]	3500
Volatile fraction	0.8
Y_{obs}	0.3125
Mixed-liquor volatile suspended solids (MLVSS) [mg/L]	2800

Table 3.8 Effluent mass quantities

BOD (kg/d)	10
TSS (kg/d)	14

- Calculate the amount of TSS produced in the biological process (assume primary solids flow is small relative to plant flow)
- TSS produced =[Y_{obs} * Q * (So- S)]/10 00 g/kg where So= concentration of BOD in primary effluent and S = concentration of soluble BOD in the final effluent.
- Calculate total amount to be wasted assuming a volatile solids concentration of 80%, and calculate mass of waste solids and flow rate of waste solids.

TSS produced in the biological process

(kg/d) : 42.9

VSS wasted at 80% volatile (kg/d) : 53.6

Fixed solids (by difference) (kg/d) : 10.7

Mass of waste activated sludge (WAS)

(kg/d) : 39.6

Flow rate of WAS (m^3/d): 11.3

Step 3.3: Gravity Belt Thickening

a. Operating parameters

Table 3.9 Gravity Belt Thickeners

Thickened solids (%)	4.8
Solids recovery (%)	92
Specific gravity	1

- [Flow rate = (mass of WAS * 0.92)/(1 000 * 0.048)]

Flow rate(m^3/d) : 0.76

- Determine recycle flow rate = (Flow rate of WAS - Flow rate of thickened sludge)
- Mass of TSS to digester mass = (Mass of WAS * 0.92)
- Mass of TSS to head works mass = (Mass of WAS - Mass to digester)
- Concentration of TSS in recycle TSS = (Mass TSS * 1 000 g/kg)/Recycle flow rate
- BOD concentration of TSS (BOD = TSS * 0.65 * 1.42 * 0.68)

-. Mass of BOD in recycle [BOD = (Concentration * Flow rate)/1 000 g/kg]

Recycle flow rate (m^3/d) :	10.5
TSS to digester (kg/d) :	36.5
TSS to headwork (kg/d):	3
TSS concentration in recycle (mg/L):	300
Determine BOD concentration of TSS (mg/L) :	138
Total BOD in recycle (kg/d):	1.5

Step 3.4: Anaerobic Digestion

Table 3.10 Set operating parameters

VSS destruction (%)	47
Gas production (m^3/kg)	0.9
BOD in digester supernatant (mg/L)	1000
TSS in digester supernatant (mg/L)	5000
TSS concentration in digested solids (%)	5

- Calculate total solids fed to the digester and flow rate
- TSS mass = Mass primary solids + mass thickened WAS (TWAS)
- Estimate VSS mass fed to digester (assume 80% volatile)
- Estimate VSS in mixture fed to digester and calculate VSS destroyed (assuming 50% destruction)
- Estimate mass flow of primary solids to digester (4.8% solids)
- Estimate mass flow of TWAS to digester
- Estimate total mass flow and fixed solids by difference
- Estimate mass of TSS in digested solids and gas production

TSS mass, from primary solids and TWAS [kg/d]: 162.5
Total flow rate [m^3/d] : 3288.6
VSS mass fed to the digester (kg/d) : 126.7
Percent VSS mass fed to digester : 0.78
VSS destroyed [kg/d] : 59.5
Mass flow to digester-primary solids [kg/d] : 2625
TWAS mass flow [kg/d] : 663.6
Total mass flow [kg/d] : 3288.6
Fixed solids [kg/d] : 35.8
TSS mass in digested solids [kg/d] : 99
Gas [kg/d] : 58.8

Table 3.11 Mass balance around digester

Mass input (kg/d)	3288.6
Less gas (kg/d)	58.8
Mass output (kg/d)	3229.7

Step 3.5: Flowrate Distribution of Supernatant and Digested Solids

- (S/concentration supernatant) + (Total mass in digested sludge - *S*)/solids in sludge = Mass output
- Mass of digested solids (mass = TSS mass in digested sludge - *S*)
- Supernatant flow {flow = *S*/(concentration of solids in supernatant(%)]*1 000 kg/m^3}
- Sludge flow [flow = mass digested solids/(% solids * 1000 kg/m^3)]

Supernatant (%) : 0.5
Solids (%) : 5
S : 7
Digested solids (kg/d): 92.1
Supernatant flow (m^3/d): 1.4
Digested solids flow (m^3/d): 1.8

- BOD = (Supernatant flow * 1000 g/ m^3)/1 000 g/kg
- TSS = (Supernatant flow * 1000 g/ m^3)/1 000 g/kg

BOD (kg/d): 1.4
TSS (kg/d): 7

Step 3.6: Sludge Dewatering

Table 3.12 Establish characteristics

Solids of sludge cake (%)	22
Sp	1.06
Solids capture (%)	96
Filtrate BOD concentration(mg/L)	2000

- Recycle solids = digested solids * capture rate
- Volume = recycle solids/(sp gr * cake solids * 1 000)

Solids [kg/d] : 88.5

Volume (m^3/d) : 0.38

- Flow = (Digested sludge flow – Volume of sludge cake)

-BOD mass = (Filtrate BOD concentration * flow)/1 000

- TSS mass = Digested solids * Percent not captured

Flow (m^3/d) : 1.5

BOD mass (kg/d): 2.9

TSS mass (kg/d): 3.7

Table 3.13 Summary of Recycle Flows

Recycle flow (m^3/d)	13.5
Recycle TSS (kg/d)	13.9
Recycle BOD (kg/d)	5.8

Step 4: Conduct Second Iteration

Step 4.1: New Influent Concentration and Mass of BOD and TSS to Primary Sedimentation

- Estimate new mass of TSS entering primary sedimentation (mass = Influent TSS + Recycle TSS)
- New mass of BOD entering primary sedimentation (mass = Influent BOD +Recycle BOD)
- Estimate BOD removal (assuming 33%) and TSS removal (assuming 70%)

Influent TSS to primary tanks=Influent+Recycle (kg/d) :	193.8
Influent BOD to primary tanks =Influent +Recycle (kg/d) :	225.8
BOD removed [kg/d] :	74.5
BOD to bioreactors [kg/d] :	151.3
TSS removed [kg/d] :	135.7
TSS to bioreactors [kg/d] :	58.2

Step 4.2: Secondary Process

- Using the target F:M ratio and original MLVSS concentration, calculate bioreactor volume and -Set target SRT
- Compute new flow rate (influent flow + recycle flow)

-New bioreactor influent BOD concentration {BOD = [BOD mass to bioreactors (kg/d) * 1 000 g/kg]/Flow rate (m^3/d)}

-New concentration of MLVSS {MLVSS = [(SRT * Q)/V] *[Y *(So S)]/ [1 + (kd * SRT)]}

- Compute MLSS (assuming 80% volatile solids)

-New cell growth {New cells = [$Q * Y_{obs} * (So- S)$]/1000}

-Compute mass of TSS MLSS + new cells

- WAS to thickening WAS = Mass of TSS - Mass of effluent TSS

-Flow rate [Flow rate = (WAS * 1 000)/MLSS]

Target F:M ratio :	0.35
Bioreactor volume [m^3] :	157.5
SRT (days) :	10
Y :	0.5
k_d :	0.06
Flow rate [m^3/d] :	1013.4
BOD concentration (mg/L) :	149.3
New concentration of MLVSS (mg/L):	2800
MLSS (mg/L) :	3500
Mass of new cells (kg/d):	44.1
TSS mass [kg/d] :	55.1
WAS to thickening (kg/d) :	41.1
Flow rate (m^3/d):	11.7

Step 4.3: Gravity Belt Thickening

-Flow rate = (mass of WAS * 0.92)/(1 000 * 0.048)

-Recycle flow rate = Flow rate of WAS – Flow rate of thickened sludge

-Mass of TSS to digester Mass = Mass of WAS * 0.92

-Mass of TSS to influent Mass = Mass of WAS-Mass to digester)

- Concentration of TSS in recycle TSS = Mass TSS * 1000 g/kg)/Recycle flow rate

-BOD concentration of TSS; BOD = TSS * 0.65 * 1.42 * 0.68

-The mass of BOD in recycle; BOD = (Concentration * Flow rate)/1000 g/kg

Flow rate (m^3/d):	0.79
Recycle flow rate (m^3/d):	11
TSS to digester [kg/d] :	38
TSS recycle to headwork [kg/d] :	3.3
TSS [mg/L] :	300
BOD concentration in TSS [g/m3 (mg/L)]:	188.4
BOD mass [kg/d] :	2

Step 4.4: Anaerobic Digestion

Table 3.14 Operating parameters

SRT (days)	10
VSS destruction (%)	47
Gas production [m^3/ kg] VSS destroyed	0.9
BOD in digester supernatant (mg/L)	1000
TSS in digester supernatant (mg/L)	5000
TSS concentration in digested solids (%)	5

-Estimate total solids fed to the digester and flow rate

- TSS Mass = Mass primary solids + Mass TWAS
- Compute VSS mass fed to digester, assume 80% volatile
- Compute VSS in mixture fed to digester and calculate VSS destroyed, assuming 50% destruction
- Compute mass flow of primary solids to digester (4.8% solids)
- Compute mass flow of TWAS to digester
- Compute total mass flow and fixed solids by difference
- Compute mass of TSS in digested solids and gas production

TSS mass, from primary solids and TWAS :	173.5
Total flow rate [m^3/d] :	3515.2
VSS mass fed to the digester (kg/d):	122.5
Percent VSS mass fed to digester :	0.7
VSS destroyed [kg/d] :	57.6
Mass flow to digester-primary solids [kg/d] :	2827.1
TWAS mass flow [kg/d] :	688.1
Total mass flow [kg/d] :	3515.2
Fixed solids [kg/d] :	51
TSS mass in digested solids [kg/d] :	112.3
Gas [kg/d] :	57

Table 3.15 Mass balance around digester

Mass input [kg/d]	3515.2
Less gas [kg/d]	57
Mass output [kg/d]	3458.3

Step 4.5: Flow rate Distribution of Supernatant and Digested Solids

-(S/concentration supernatant) +(Total mass in digested sludge - S)/solids in sludge = Mass output

-Mass of digested solids (mass) = TSS mass in digested solids - S

-Calculate supernatant flow, flow = S/concentration of solids in supernatant (%) * 1 000 kg/ m^3

- Solids flow (flow) = mass digested solids/(% solids * 1 000 kg/m^3)

Supernatant (%) :	0.5
Solids (%) :	5
S	8.1
Digested solids (kg/d) :	104.1
Supernatant flow [m^3/d]:	1.6
Digested solids flow[m^3/d]:	2

- BOD = (Supernatant flow * 1000 g/ m^3)/1 000 g/kg
- TSS = (Supernatant flow * 1000 g/ m^3)/1 000 g/kg

BOD (kg/d):	1.6
TSS (kg/d):	8.1

Step 4.6: Sludge Dewatering

Table 3.16 Establish characteristics

Solids cake (%)	22
Sp	1.06
Solids capture (%)	96
Filtrate BOD concentration (mg/L)	2000

- Recycle solids = digested solids * capture rate
- Volume = recycle solids/(sp gr * cake solids * 1 000)

Solids [kg/d] :	100
Volume(m^3/d):	0.4

Calculate filtrate characteristics:

- Flow = (Digested sludge flow – Volume of sludge cake)
- BOD mass = (Filtrate BOD concentration * flow)/1 000
- TSS mass = Digested solids * Percent not captured

Flow (m^3/d) :	1.6
BOD mass (kg/d):	3.3
TSS mass (kg/d):	4.2

Table 3.17 Summary of Recycle Flows

Recycle flow [m^3/d]	14.2
Recycle TSS (kg/d)	15.6
Recycle BOD (kg/d)	7

Third iteration has been computed with the same estimations.

Table 3.18 Iteration Results

	1.iteration	2.iteration	3.iteration	Difference (%)
Flow [m^3/d]	103.74	27.16	27.50	1.2
BOD (kg/d)	186.41	10.18	10.76	5.4
TSS (kg/d)	13.86	20.38	21.63	5.8

CHAPTER FOUR
RESULTS AND DISCUSIONS

This chapter presents the results of the solid mass balances computed by MS Excel spreadsheet for three different biological wastewater treatment processes at three different flow-rates as explained in Chapter 3. In all computations, the same assumptions and model constants have taken into consideration to compare the results of processes. Only SRT values varied depending on the process type applied.

4.1 Conventional Activated Sludge (CAS) Process Results

For CAS process, SRT value was taken as 10 days. Figure 4.1 shows third iteration results of CAS process with a capacity of 1000 m^3/d. For this process; flow, BOD and TSS parameters have been calculated. Influent and effluent wastewater characteristics, BOD and TSS values after sedimentation as stream number 3, WAS (25.25 m^3/d) as stream number 8, sludge production (0.58 m^3/d) as stream number 14, and finally recycle stream values as number 16 stream are given in Figure 4.1.

The Figure 4.2 shows the second iteration of CAS having a treatment capacity of 10,000 m^3/d. The calculations for recycled streams were stopped at the second iteration since the difference between first and second iteration was less than that between second and third iteration results. As can be seen from Figure 4.2, influent and effluent characteristics, BOD and TSS values after sedimentation as stream number 3, WAS (117.5 m^3/d) as stream number 8, sludge production (4.34 m^3/d) as stream number 14, and finally recycle flow-rate results as stream number 16 are depicted in the flow diagram.

For CAS with a treatment capacity of 100,000 m^3/d, third iteration results are given in Figure 4.3. Similarly, influent and effluent characteristics, BOD and TSS values after sedimentation as stream number 3, WAS (4165 m^3/d) as stream number 8, sludge production (77 m^3/d) as stream number 14, and finally recycle flow-rate results as stream number 16 are shown in the flow diagram.

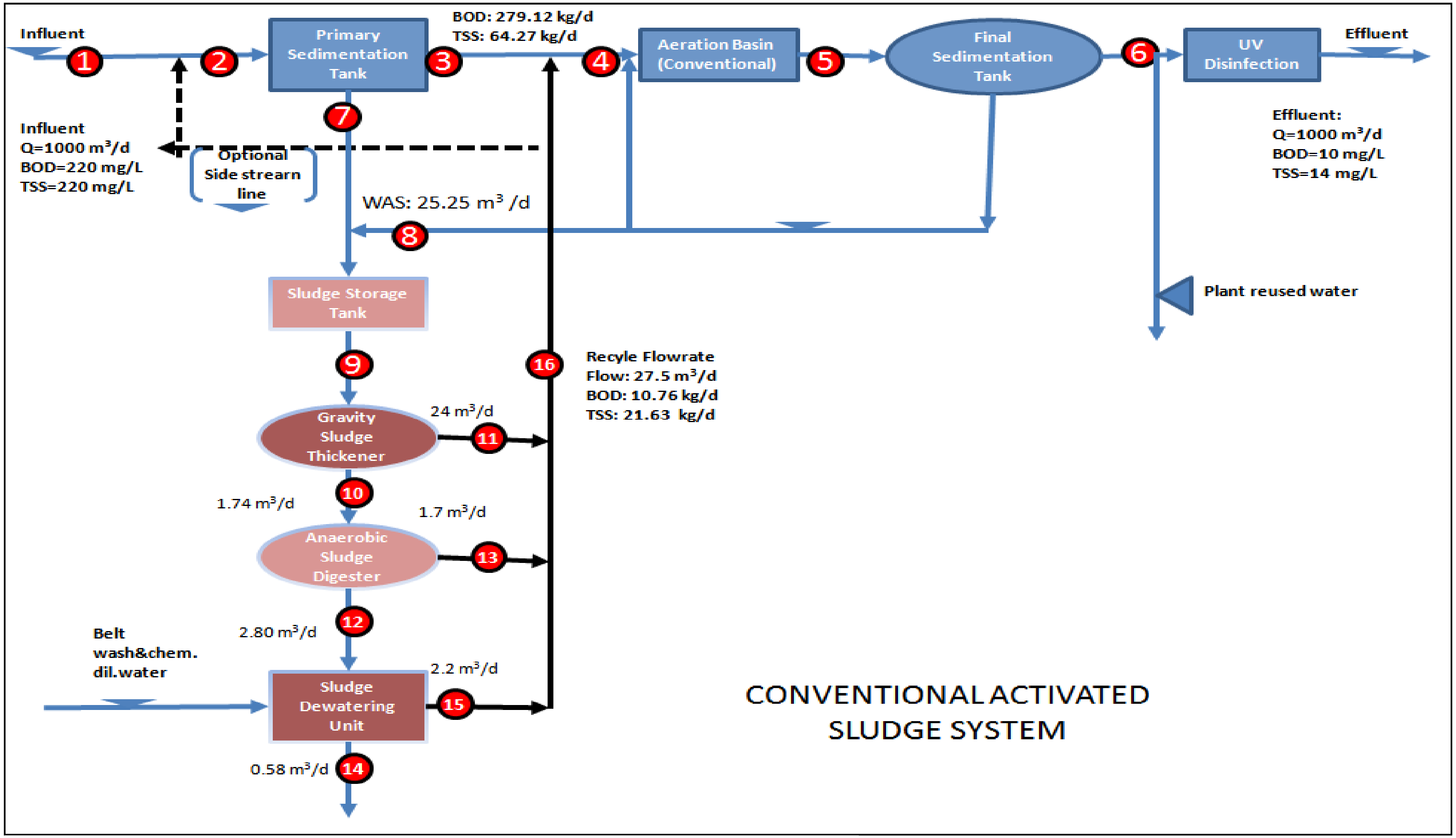

Figure 4.1 Third iteration results for CAS process with a treating capacity of 1000 m^3/d

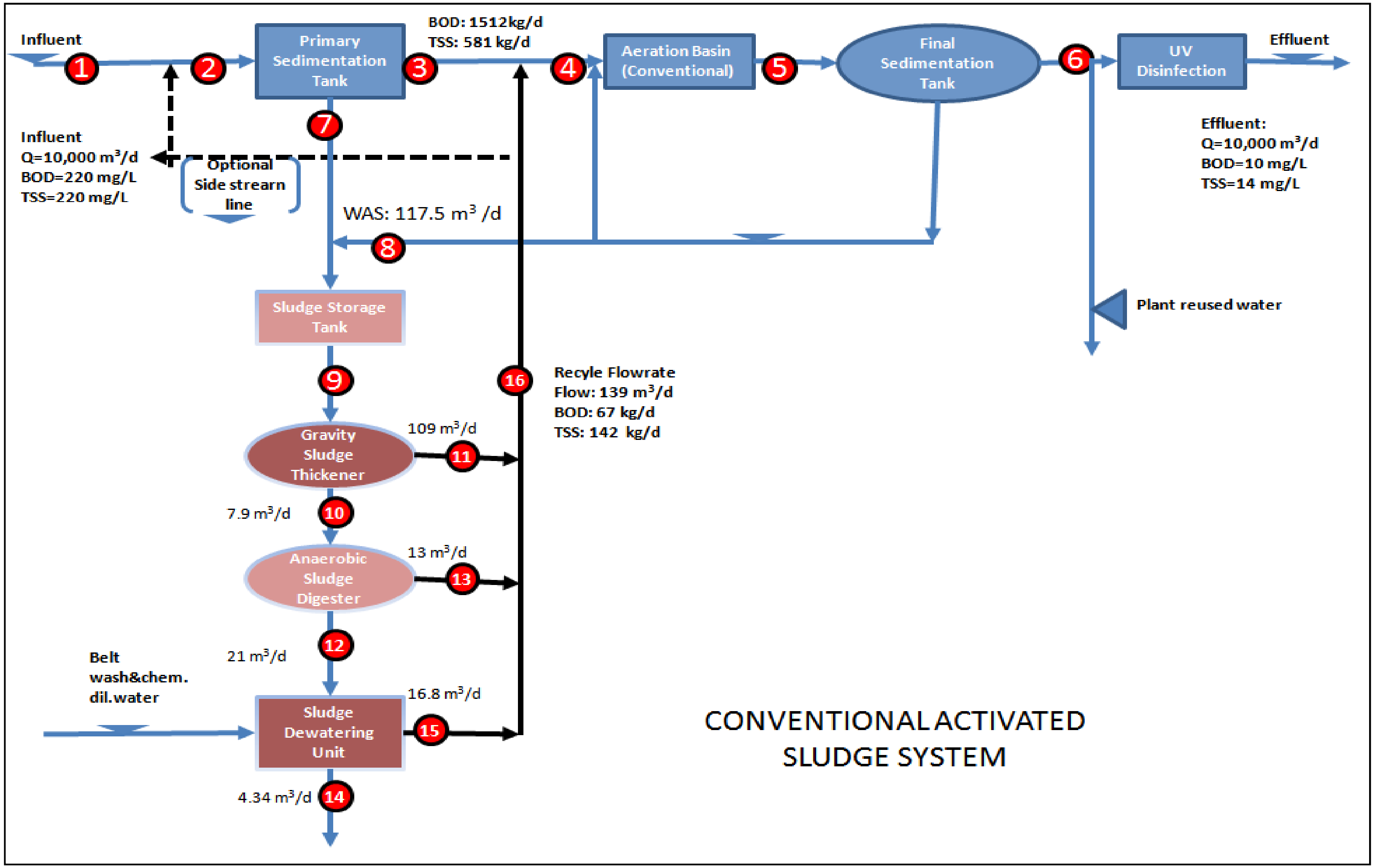

Figure 4.2 Second iteration results for CAS process with a treating capacity of 10,000 m^3/d

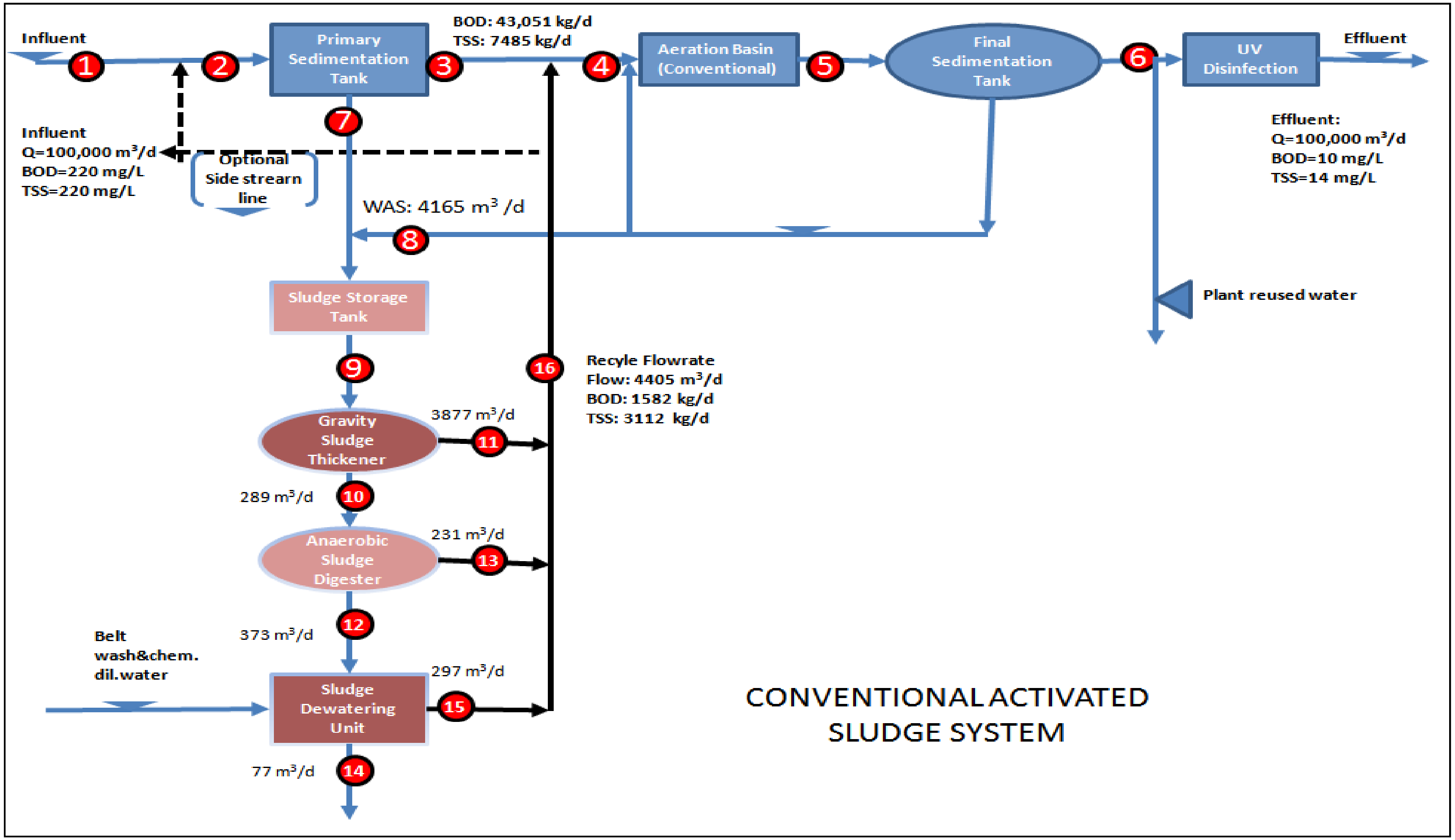

Figure 4.3 Third iteration results for CAS process with a treating capacity of 100,000 m^3/d

The iteration results of the recycled stream (stream number 16) for 1000 m^3/d, 10,000 m^3/d, and 100,000 m^3/d flow-rates are presented in Table 4.1, Table 4.2, and Table 4.3, respectively.

Table 4.1 Iterations of 1000 m^3/d Flow-rate for CAS

Recycled stream	**1.iteration**	**2.iteration**	**3.iteration**	**Difference (%)**
Flow [m^3/d]	103.74	27.16	27.50	1.2
BOD (kg/d)	186.41	10.18	10.76	5.4
TSS (kg/d)	13.86	20.38	21.63	5.8

Table 4.2 Iterations of 10.000 m^3/d Flow-rate for CAS

Recycled stream	**1.iteration**	**2.iteration**	**Difference(%)**
Flow [m^3/d]	134.24	139.87	4.0
BOD (kg/d)	57.88	67.64	14.4
TSS (kg/d)	137.89	142.47	3.2

Table 4.3 Iterations of 100.000 m^3/d Flow-rate for CAS

Recycled stream	**1.iteration**	**2.iteration**	**3.iteration**	**Difference(%)**
Flow [m^3/d]	26561.16	4358.11	4405.29	1.1
BOD (kg/d)	40770.22	1486.31	1582.80	6.1
TSS (kg/d)	4044.88	2907.64	3112.42	6.6

4.2 Biological Nutrient Removal (BNR) System Results

A Microsoft Excel spreadsheet was prepared to solve the mass balances for Biological Nutrient Removal (BNR) processes. The flow diagram includes anaerobic zone, anoxic zone, and aerobic zone (A^2/O). In this BNR system, iterations was calculated based on the flow-rate, BOD, TSS, Org-N, NH_4-N, NO_3-N, TN and TP parameters for recycle streams.

Due to the much components are included in this process, the iteration results are presented in Table forms. Iteration calculations were repeated three times and the third iteration results of BNR process at 1000 m^3/d, 10,000 m^3/d, and 100,000 m^3/d flow-rates are summarized in Table 4.4, Table 4.5, and Table 4.6, respectively. The applied BNR flow diagram for three different treatment capacities as 1000 m^3/d, 10,000 m^3/d, 100,000 m^3/d and the third iteration results including influent and effluent streams as well as the recycled streams are reported between Figures 4.4 and 4.6. Sludge productions are also given in these Figures. Recycled flow (stream number 16) is combined from three streams: the thickener’s supernatant (stream number 11), the digester’s supernatant (stream number 13), and filtrate from dewatering unit (stream number 14).

Table 4.4 Third Iteration Results of BNR Process for 1000 m^3/d Flow-rate

Stream	Flow (m3/d)	BOD5 (kg/d)	TSS (kg/d)	Org-N (kg/d)	NH4-N (kg/d)	NO3-N (kg/d)	TN (kg/d)	TP (kg/d)
1	1000	250	260	17	19	0	36	6
2	1000	250	260	17	19	0	36	6
3	3.5	85.0	163.8	5.1	0.1	0	5.2	1
4	996.5	165	96.2	11.9	18.9	0	30.8	5
5	1135.6	423.2	331.3	27.9	56.3	0	50	40
6	1000	10	10	1	1	8	10	1
7	18.1	42.6	67.9	6.6	0	0.1	6.8	9
8	18.1	42.6	67.9	6.6	0	0	6.6	9
9	48.4	127.9	232	12.7	1.1	0	12.1	11.5
10	3.2	108.7	197.2	10	0.1	0	10	10.8
11	45.2	19.2	34.8	2.8	1	0	2.1	0.7
12	2.3	40.5	120	8	1.2	0	9.1	9.4
13	1	2.6	4	0.5	0.4	0	0.9	0.7
14	0.4	38.5	114.5	7,6	0.2	0	7.8	6
15	6.1	213	147	9.6	18.9	0	29.7	0.1
16	52.3	234.8	185.8	12.8	20.4	0	32.6	1.6

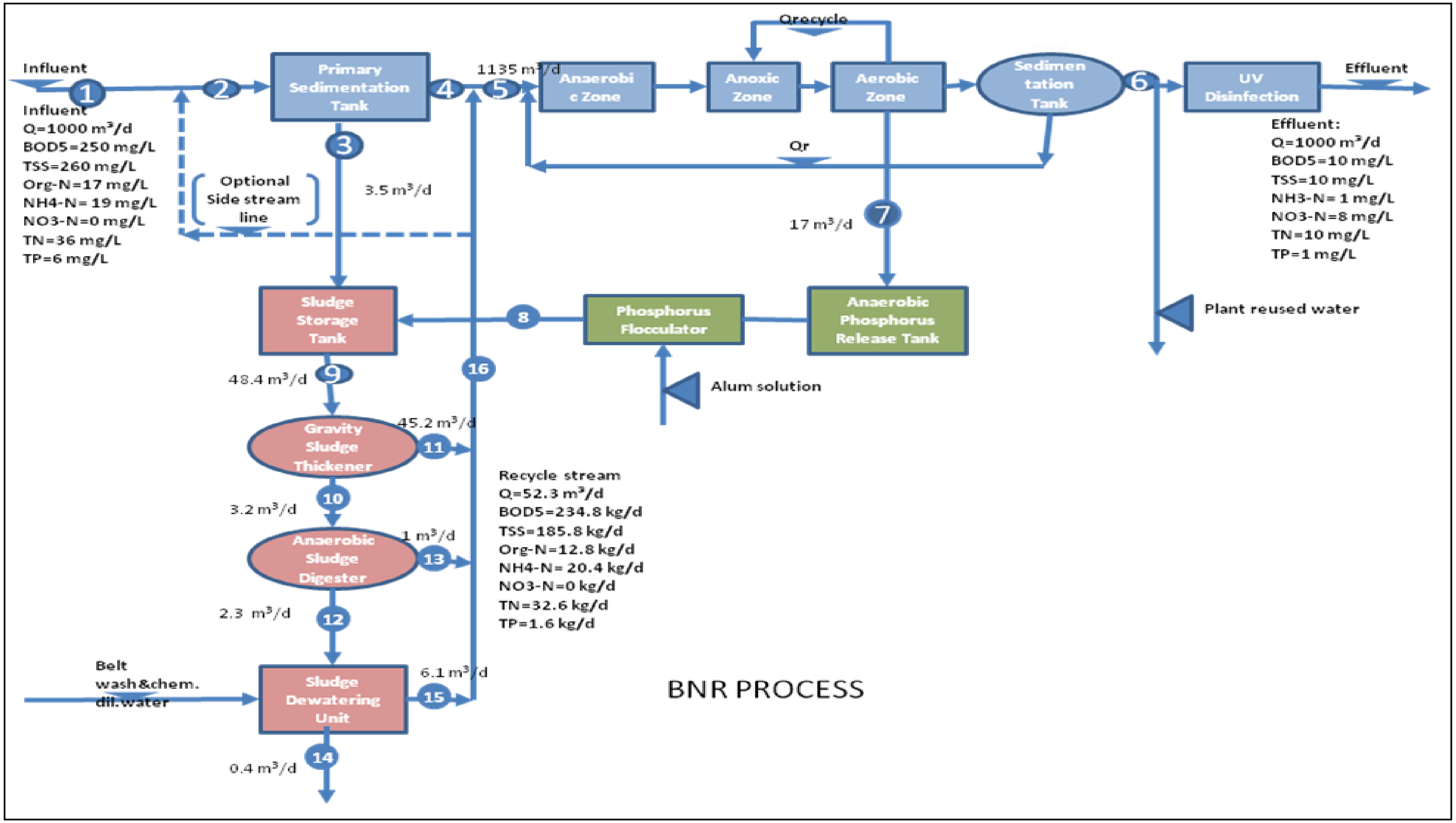

Figure 4.4 Third iteration results for BNR process with a treating capacity of 1000 m^3/d

Table 4.5 Third Iteration Results of BNR Process for 10.000 m^3/d Flow-rate

Stream	Flow (m^3/d)	BOD (kg/d)	TSS (kg/d)	Org-N (kg/d)	NH_4-N (kg/d)	NO_3-N (kg/d)	TN (kg/d)	TP (kg/d)
1	10,000.0	2,500.0	2,600.0	170.0	190.0	0.0	360.0	60.0
2	10,000.0	2,500.0	2,600.0	170.0	190.0	0.0	360.0	60.0
3	35.3	850.0	1,638.0	51.0	0.7	0.0	51.8	9.6
4	9,964.7	1,650.0	962.0	119.0	189.3	0.0	308.2	50.4
5	11,017.2	4,223.3	3,317.0	265.3	397.9	0.0	349.8	372.7
6	1,000.0	10.0	10.0	1.0	1.0	8.0	10.0	1.0
7	175.6	413.3	658.6	64.3	0.2	1.4	65.9	61.7
8	175.6	413.3	658.6	64.3	0.2	0.0	64.5	61.7
9	479.9	1.266.0	2,299.3	116.3	1.9	0.0	119.0	72.3
10	31.6	1.076.1	1,954.4	98.0	0.1	0.0	98.1	67.5
11	448.3	189.9	344.9	18.3	1.8	0.0	20.9	4.8
12	23.1	405.0	1,191.0	78.6	10.8	0.0	89.4	59.1
13	8.5	27.8	34.0	5.1	4.3	0.0	9.4	0.7
14	4.3	384.7	1,136.2	74.7	2.0	0.0	76.7	50.0
15	60.5	2,116.8	1,465.3	95.5	188.1	0.0	284.8	10.1
16	517.3	2,334.5	1,844.2	118.9	194.2	0.0	315.1	15.7

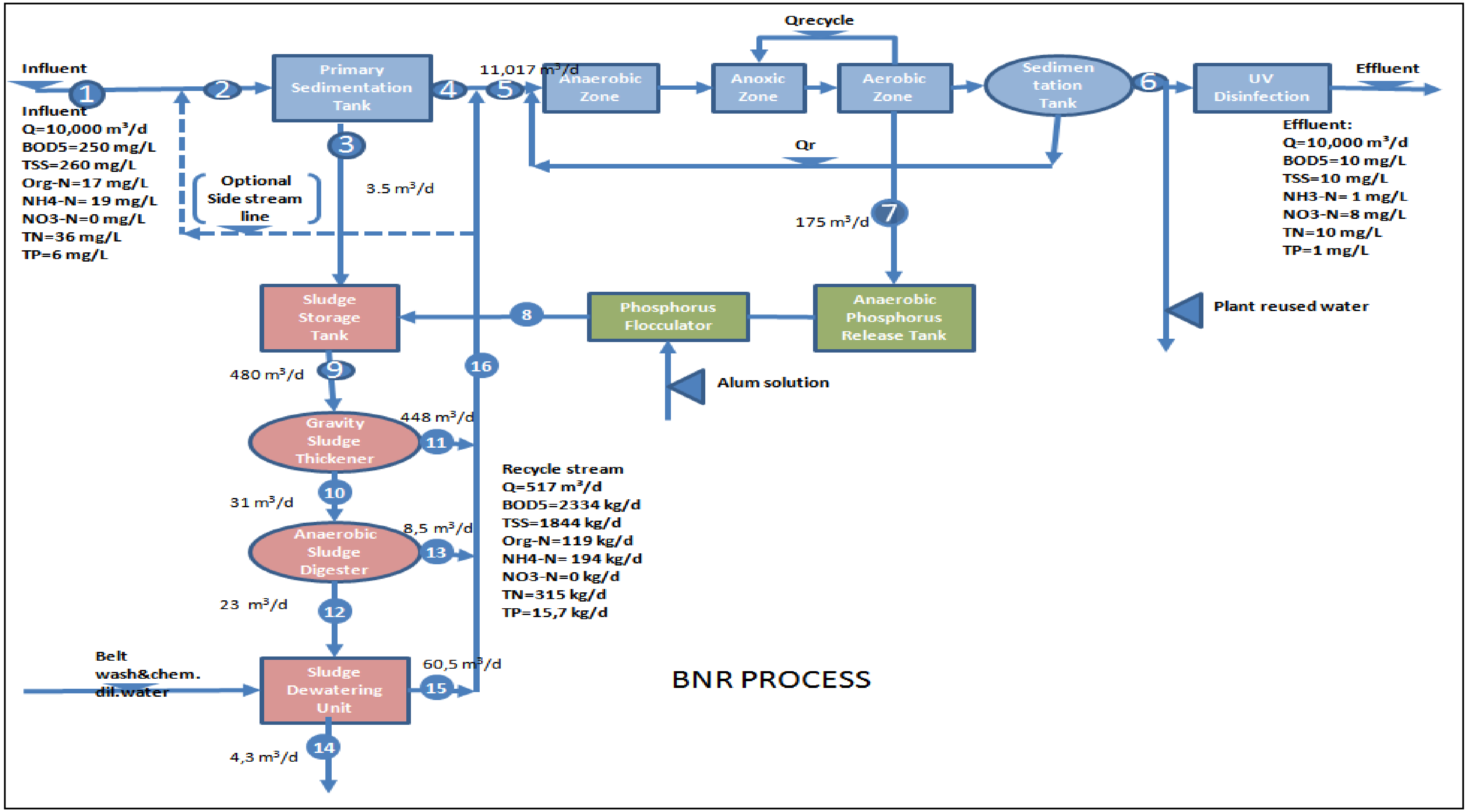

Figure 4.5 Third iteration results for BNR process with a treating capacity of 10,000 m^3/d

Table 4.6 Third Iteration Results of BNR Process for 100.000 m^3/d Flow-rate

Stream	Flow (m^3/d)	BOD (kg/d)	TSS (kg/d)	Org-N (kg/d)	NH_4-N (kg/d)	NO_3-N (kg/d)	TN (kg/d)	TP (kg/d)
1	100,000.0	25,000.0	26,000.0	1,700.0	1,900.0	0.0	3,600.0	600.0
2	100,000.0	25,000.0	26,000.0	1,700.0	1,900.0	0.0	3,600.0	600.0
3	353.4	8,500.0	16,380.0	510.0	6.8	0.0	518.4	96.0
4	99,646.6	16,500.0	9,620.0	1,190.0	1,893.2	0.0	3.081.6	504.0
5	110,171.9	42,223.9	33,165.2	2,643.4	3,959.8	0.0	3.498.3	3,700.1
6	1,000.0	10.0	10.0	1.0	1.0	8.0	10.0	1.0
7	1,756.2	4,133.4	6,585.7	642.8	1.8	14.0	658.6	606.2
8	1,756.2	4,133.4	6,585.7	642.8	1.8	0.0	644.5	606.2
9	4,798.8	12,660.3	22,992.6	1.153.8	9.6	0.0	1,189.8	703.2
10	316.2	10,761.3	19,543.7	979.8	0.6	0.0	980.5	658.0
11	4,482.6	1,899.0	3,448.9	173.9	9.0	0.0	209.3	45.2
12	231.3	4,051.0	11,917.0	786.3	108.0	0.0	894.2	520.5
13	84.5	278.3	338.0	51.2	42.8	0.0	94.0	0.7
14	42.9	3,848.5	11,368.8	746.9	20.0	0.0	767.0	475.0
15	605.5	21,153.1	14,632.7	953.2	1,880.1	0.0	2.834.5	125.1
16	5,172.5	23,330.4	18,419.6	1,178.3	1,931.9	0.0	3.137.8	171.1

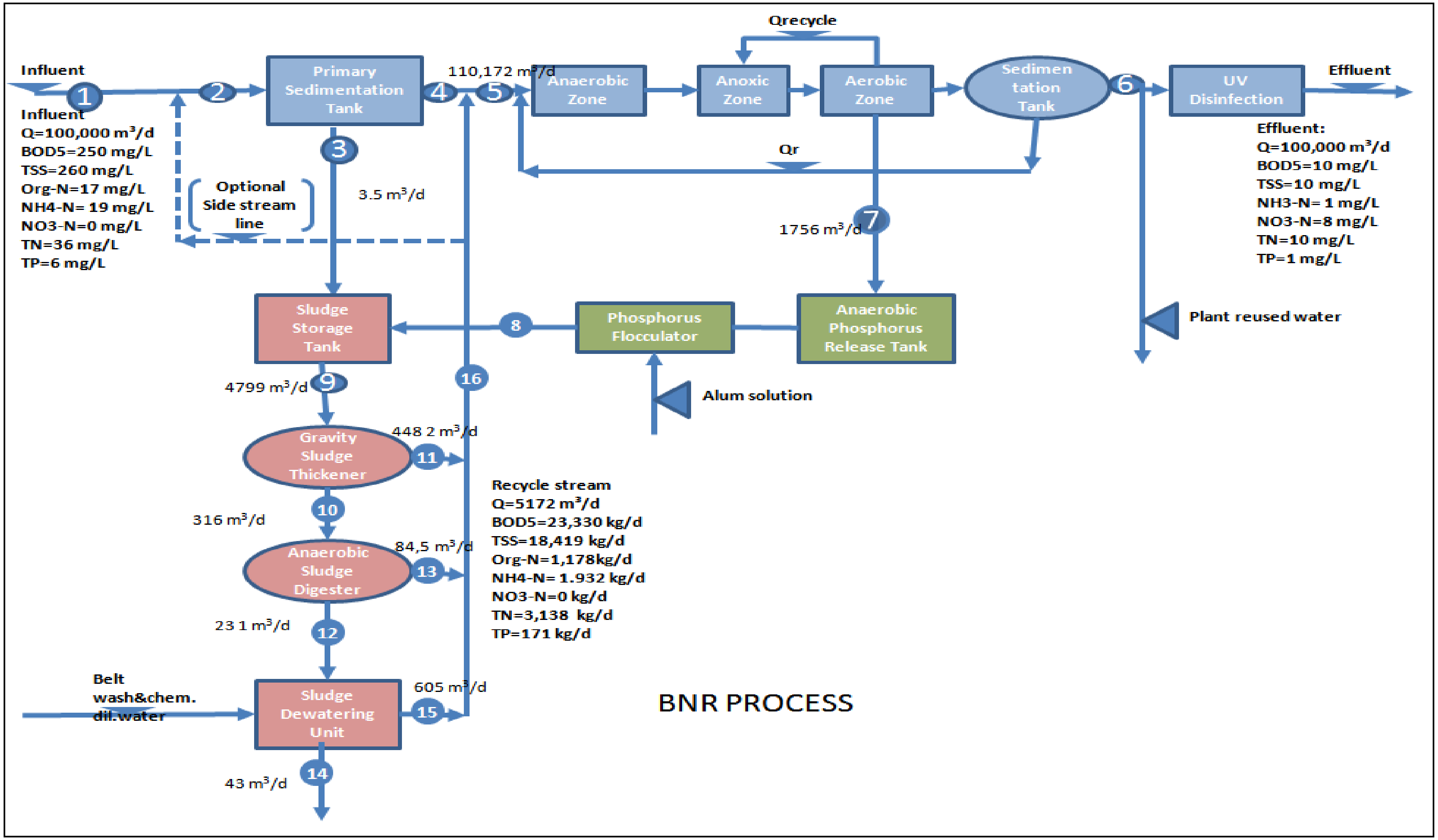

Figure 4.6 Third iteration results for BNR process with a treating capacity of 100,000 m^3/d

The differences between the calculated iterations of the BNR process for 1000 m^3/d, 10,000 m^3/d, and 100,000 m^3/d treatment capacities are reported in the Table 4.7, Table 4.8, and Table 4.9, respectively.

Table 4.7 Iterations of 1.000 m^3/d Flowrate for BNR

Stream16	**1.iteration**	**2.iteration**	**Difference(%)**	**3.iteration**	**Difference (%)**
Flow (m^3/d)	87.8	51.4	-70.87	52.3	1.8
BOD (kg/d)	23.4	234.8	90.04	234.8	0.0
TSS (kg/d)	45.5	189.6	76.00	185.8	-2.1
Org-N (kg/d)	3.0	13.0	76.64	12.8	-1.2
NH_4-N (kg/d)	17.0	20.4	16.78	20.4	-0.1
NO_3-N (kg/d)	0.0	0.0	-	0.0	0
TN (kg/d)	19.2	32.8	41.52	32.6	-0.5
TP (kg/d)	2.2	1.4	-52.68	1.6	8.2

Table 4.8 Iterations of 10.000 m^3/d Flowrate for BNR

Stream16	**1.iteration**	**2.iteration**	**Difference(%)**	**3.iteration**	**Difference (%)**
Flow (m^3/d)	543.1	509.4	-6.62	517.3	1.5
BOD (kg/d)	233.6	2,339.7	90.01	2.334.5	-0.2
TSS (kg/d)	454.9	1,900.1	76.06	1,844.2	-3.0
Org-N (kg/d)	25.5	120.8	78.87	118.9	-1.6
NH_4-N (kg/d)	14.3	194.3	92.62	194.2	-0.1
NO_3-N (kg/d)	0.0	0.0	-	0.0	-
TN (kg/d)	41.6	317.1	86.88	315.1	-0.6
TP (kg/d)	5.2	16.3	68.13	15.7	-3.9

Table 4.9 Iterations of 100.000 m^3/d Flowrate for BNR

Stream16	**1.iteration**	**2.iteration**	**Difference(%)**	**3.iteration**	**Difference (%)**
Flow (m^3/d)	5431.7	5093.6	-6.64	5172.5	1.53
BOD (kg/d)	2338.9	23,385.1	90.00	23,330.4	-0.23
TSS (kg/d)	4.551.9	18,993.3	76.03	18,419.6	-3.11
Org-N (kg/d)	255.6	1197.7	78.66	1178.3	-1.65
NH_4-N (kg/d)	133.6	1933.1	93.09	1931.9	-0.06
NO_3-N (kg/d)	0.0	0.0	-	0.0	-
TN (kg/d)	416.7	3158.6	86.81	3137.8	-0.66
TP (kg/d)	37.5	185.4	79.75	171.1	-8.40

4.3 Extended Aeration Activated Sludge (EAS) Process Results

Extended aeration activated sludge (EAS) process does not contain primary sedimentation tanks. However, this process has long solids retention times (SRT), which are commonly more than 20 days. In this study, SRT of the EAS was chosen as 20 days.

The flow diagrams presented between Figures 4.7 and 4.9 present the third iteration results of EAS process with three different treatment capacities as 1000 m^3/d, 10,000 m^3/d, and 100,000 m^3/d. They also include influent and effluent wastewater characteristics, BOD and TSS values, WAS as stream number 6, sludge production as stream number 13, and finally recycled stream results as stream number 14.

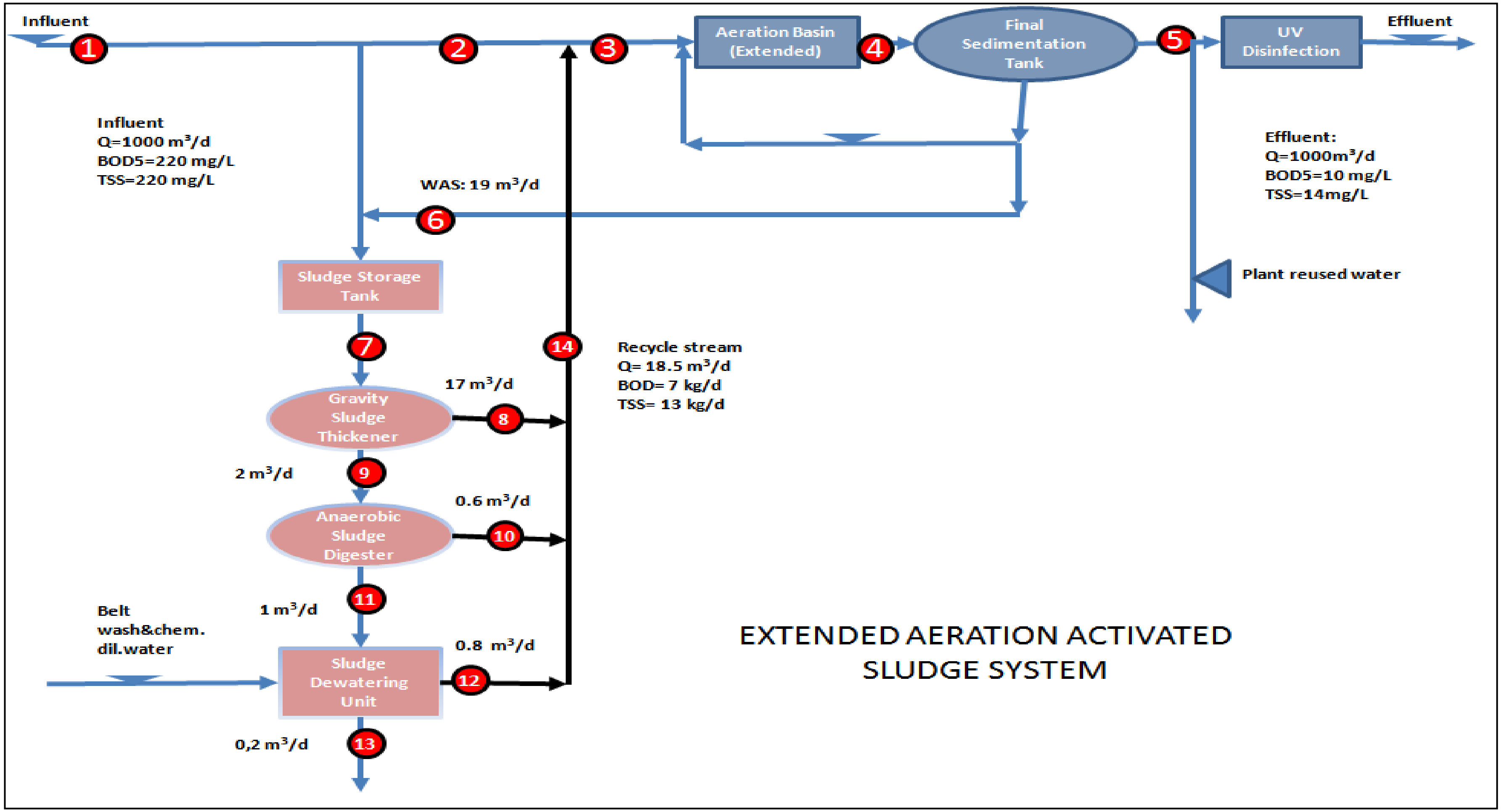

Figure 4.7 Third iteration results for EAS process with a treating capacity of 1000 m^3/d

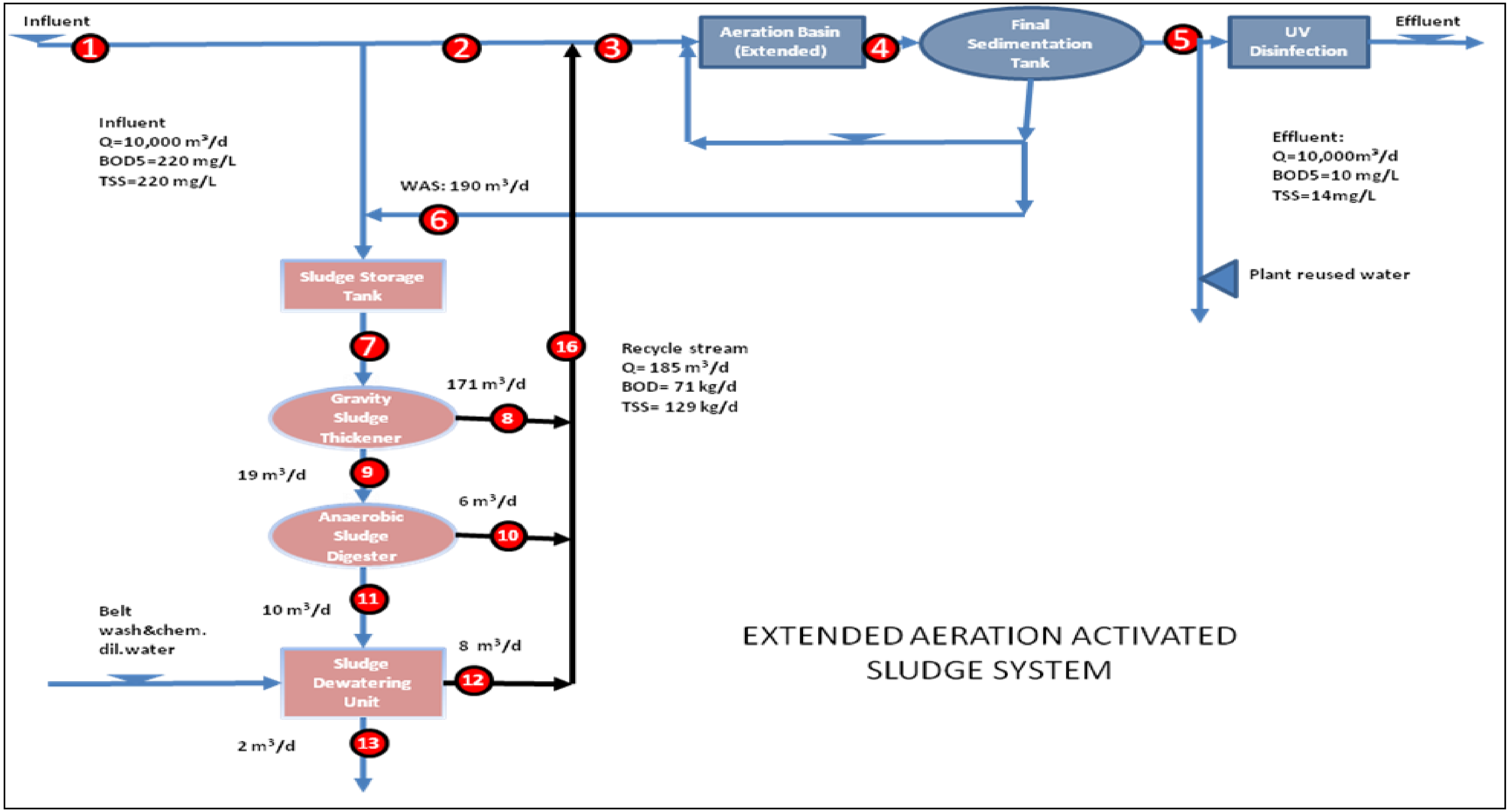

Figure 4.8 Third iteration results for EAS process with a treating capacity of 10,000 m^3/d

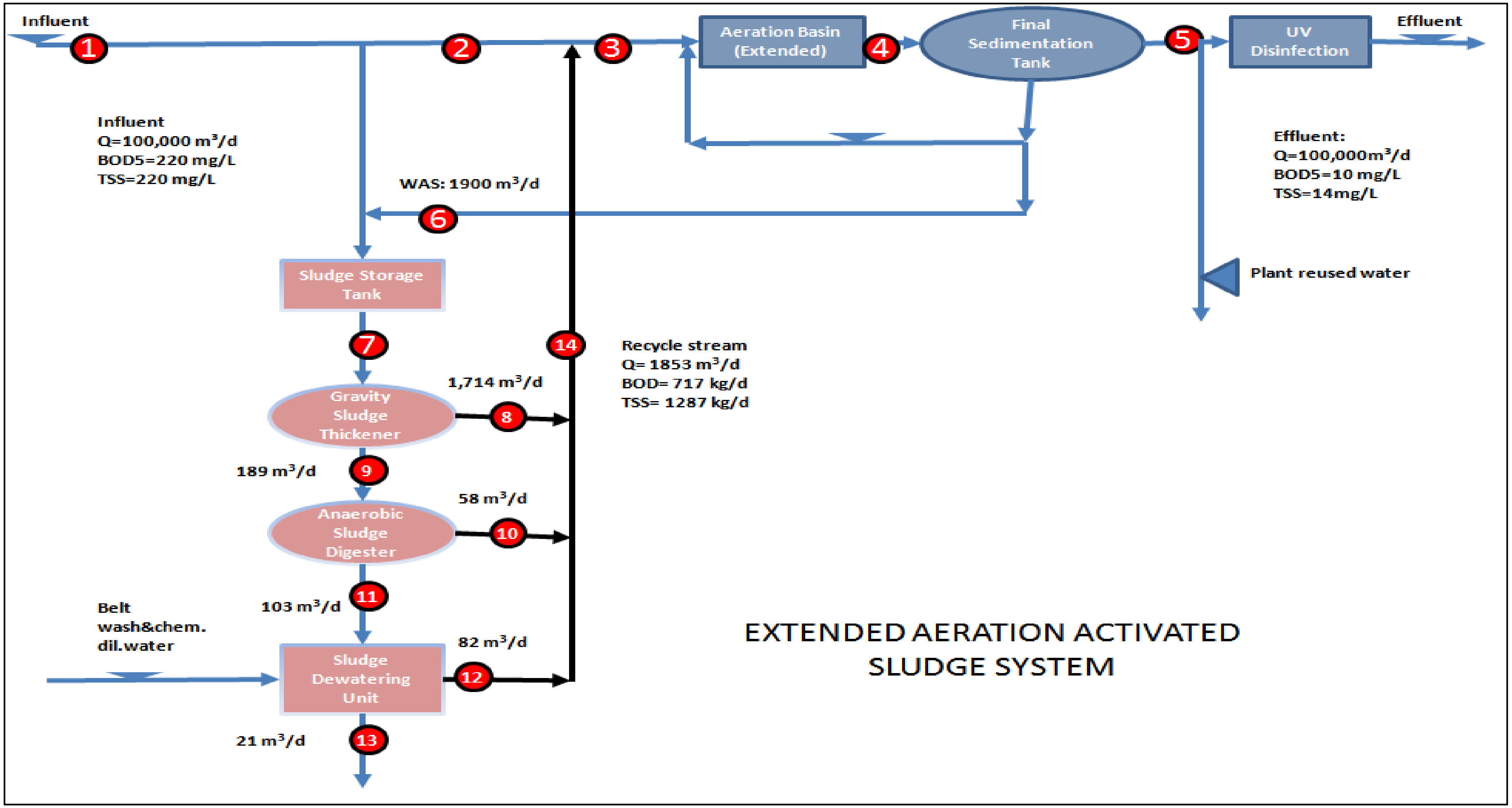

Figure 4. 9 Third iteration results for EAS process with a treating capacity of 100,000 m^3/d

The differences in the iteration results of the recycled stream (stream number 14) for 1000 m^3/d, 10,000 m^3/d, and 100,000 m^3/d flow-rates are presented in Table 4.10, Table 4.11, and Table 4.12, respectively.

Table 4.10 Iterations of 1000 m^3/d Flowrate for EAS

	1.iteration	**2.iteration**	**3.iteration**	**Difference(%)**
Flow (m^3/d)	53.94	18.50	18.54	0.2
BOD (kg/d)	73.74	7.03	7.17	2.0
TSS (kg/d)	8.86	12.61	12.87	2.1

Table 4.11 Iterations of 10,000 m^3/d Flowrate for EAS

	1.iteration	**2.iteration**	**3.iteration**	**Difference(%)**
Flow (m^3/d)	539.25	185.01	185.37	0.2
BOD (kg/d)	737.04	7.28	71.68	2.0
TSS (kg/d)	88.84	126.17	128.63	1.9

Table 4.12 Iterations of 100,000 m^3/d Flow-rate for EAS

	1.iteration	**2.iteration**	**3.iteration**	**Difference(%)**
Flow (m^3/d)	5392.45	1850.09	1853.92	0.2
BOD (kg/d)	7370.38	702.79	716.95	2.0
TSS (kg/d)	888.38	1261.73	1287.31	2.0

WERF Manuel (2010) has summarized the approach to estimating solids production by using a mass balance for the entire treatment plant that relates solids production to design parameters for each treatment process. As key parameters, Flow-rate, TSS, and BOD, and the process assumptions are used in the calculations. According to Manuel (WERF, 2010), the recycle streams can be included in one of two ways. The first is that engineers assume that a fixed percentage of solids or BOD is recycled from downstream processes to the head of the plant. They iterate the solids balance until the recycled quantities assumed at the head of the plant equal the sum of recycled quantities computed for each process. This approach was followed in this thesis. The second one is to estimate the treatment plant’s net solids production based on historical data, anticipated influent strength, or experience at similar facilities. To determine the amount of solids leaving the treatment plant, and typically apply it to the output end of the dewatering process, the second approach is preferred and then solids loading to a specific process via the mass balance can be back-calculated. Mass balance is defined as an iterative process and the first establishes the recycle flow and concentration. If the second iteration’s results are not within 5% of those of the first iteration, then the Manual recommend the engineers do a third iteration. It is also recommended to set up a spreadsheet that incorporates the various formulas needed for numerous iterations (WERF Manual, 2010).

Metcalf and Eddy (2004) have emphasized the importance of mass balance as in aforementioned above. They also stated that when the incremental change in return quantities is less than 5 percent, the iteration should be finalized (Metcalf & Eddy, 1991).

CHAPTER FIVE
CONCLUSIONS and RECOMMENDATIONS

5.1 Conclusions

The most current ways of sludge processes like digestion, thickening and dewatering create recycle streams to be moved to the top of the plant. So it causes a serious loading, which have to be treated. This lead to engineers make focus on discharge legislation. Therefore, influent and effluent wastewater properties are measured in practice (Puig, 2008). In addition, for a successful operation of WWTPs, it is required to know main components of the streams. Unit by unit, the important data have to be studied. In this study, Microsoft Excel spread sheets for mass balance calculations were prepared to solve all main streams and their characteristics regarding different biological wastewater treatment process at different treatment capacities. Main findings from the study are summarized in this chapter.

The recycled from downstream processes to the head of the plant were determined by the iteration method regarding the solids balance until the recycled quantities assumed at the head of the plant equal the sum of recycled quantities computed for each process. The conventional activated sludge process (CAS), extended aeration activated sludge process (EAS), and biological nutrient removal processes (BNR) were selected as biological wastewater treatment process and the calculations were done for three different flow-rates: 1000 m^3/d, 10,000 m^3/d, and 100,000 m^3/d. When the incremental change in return quantities is less than 5 percent, the iteration was finalized for all processes and capacities.

According to these computations; extended active sludge and BNR processes are more successful than the conventional active sludge system. It is due to the SRT changing. The longest SRT was chosen as 20 days for EAS and this is the most stable system in the iterations. The second one is BNR, its’ SRT was kept as 12 days and that was also more stable than conventional activated sludge system. The comparison of recycled flows, BOD and TSS are presented at between Tables 5.1 and 5.3. Extended Active Sludge System was very consistent and the difference percentages are under the %2.

Table 5.1 Comparison of Recycled Flows (m^3/d)

	1000 m^3/d	10,000 m^3/d	100,000 m^3/d
CAS (m^3/d)	27.5	139.87	4405.3
EAS (m^3/d)	18.54	185	1854
BNR (m^3/d)	52.3	517.3	5172.5

Table 5.2 Comparison of Recycled BOD (kg/d and mg/L)

	1000 m^3/d	10,000 m^3/d	100,000 m^3/d
CAS (kg/d)	10.76	67.64	1582.8
CAS (mg/L)	10.76	6.764	15.828
EAS (kg/d)	7.17	71.68	717
EAS (mg/L)	7.17	7.168	7.17
BNR (kg/d)	234.8	2334.5	23,330
BNR (mg/L)	234.8	233.45	233.30

Table 5.3 Comparison of Recycled TSS (kg/d and mg/L)

	1000 m^3/d	10,000 m^3/d	100,000 m^3/d
CAS (kg/d)	21.63	142.5	3112.4
CAS (mg/L)	21.63	14.25	31.124
EAS (kg/d)	12.87	128.6	1287.3
EAS (mg/L)	12.87	12.86	12.873
BNR (kg/d)	185.8	1844.2	18,419.6
BNR (mg/L)	185.8	184.42	184.196

When comparing the sludge production, EAS process produced the less sludge than the CAS and BNR processes as shown in Table 5.4. The second one regarding the less sludge production is BNR process depending on the SRT chosen in the design. Also, the role of yield (Y) coefficient is important. Y is the maximum yield coefficient defining the ratio of maximum mass of cells formed to the mass of substrate utilized. In this study, Y is taken into account as 0.5 kg mass cell/ kg BOD removed for CAS and EAS processes, while it was 0.6 5 kg mass cell/ kg BOD removed for BNR process.

Table 5.4 Comparison of sludge production

	1000 m^3/d	10,000 m^3/d	100,000 m^3/d
CAS (m^3/d)	0.58	4.34	77
CAS (kg/d)	145	1085	19250
EAS (m^3/d)	0.2	2	21
EAS (kg/d)	50	500	5250
BNR (m^3/d)	0.4	4.3	43
BNR (kg/d)	100	1075	10750

5.2 Recommendations

In this thesis, the spreadsheets prepared for mass balance calculations for CAS, EAS, and BNR processes can be used for different treatment flow-rates and also can be improved for the other biological wastewater treatment processes. It is useful tool for practical applications. However, it needs a steady-state model calibration regarding the parameters responsible for the long-term behavior in wastewater treatment plants (WWTPs). The spreadsheets should be calibrated by using a full-scale WWTP data for checking purpose.

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APPENDIX

Symbols

AerD: Anaerobic Digestion
AD: Aerobic Digestion
ANNAMMOX: Anaerobic AMMonia OXiders
AOB: Ammonia Oxidising Biomass
AS: Activated Sludge
BNR: Biological Nutrient Removal System
BOD: Biological Oxygen Demand
CAS: Conventional Activated Sludge
DO: Dissolved Oxygen
EAS: Extended Aeration Activated Sludge
HRT: High Retention Time
kd: Endogenous Decay Rate
MLSS: Mixed Liquid Suspended Solids
NH_4-N: Ammonium Nitrogen
NO_3-N: Nitrate Nitrogen
OHOs: Ordinary Hetetrophic Organisms
Org-N: Organic Nitrogen
PAO: Phosphorus Accumulating Organisms
POP: Persistent Organic Pollutants
RAS: Return Activated Sludge
sp gr: Specific Gravity
SRT: Sludge Retention Time
TN: Total Nitrogen
TP: Total Phosphorus
TSS: Total Suspended Solids
VFA: Volatile Fatty Acids
VSS: Volatile Suspended Solids
WAS: Waste Activated Sludge

WWTP: Waste Water Treatment Plant

Y: Yield Coefficient