ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

ANALYSIS OF EXCESS BIOLOGICAL PHOSPHORUS REMOVAL POTENTIAL OF ORGANIZED INDUSTRIAL DISTRICT WASTEWATER

M.Sc. THESIS

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ORGANİZE SANAYİ BÖLGESİ ATIKSULARININ AŞIRI BİYOLOJİK FOSFOR GİDERİM POTANSİYELİNİN İNCELENMESİ

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To my family,

FOREWORD

This master thesis where written during the time-period from spring 2012 until spring 2013, under the teaching supervision of Assoc. Prof. Dr. H. Güçlü İNSEL. I want to thank him for his support.

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I dedicated this thesis to my family.

November 2013 Özlem KETENCİ

(Environmental Engineer)

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ABBREVIATIONS

BCFS : Biological Chemical Phosphate Nitrogen Removal
BNR : Biological Nutrient Removal
BSCOD : Biodegradable Soluble Organic Matter
COD : Chemical Oxygen Demand
DNPAO : Denitrifying Phosphorus Accumulating Organisms
EBPR : Enhanced Biological Phosphorus Removal
GaOIZ : Gaziantep Organize Industrial Zone
HPO_4^{-2} : Hydrogen Phosphate
$H_2PO_4^{-}$: Dihydrogen Phosphate
H_3PO_4 : Phosphoric Acid
OIZ : Organize Industrial Zone
PAOs : Phosphorus Accumulating Organisms
PHA : Poly hydroxyl alkanoate
PHB : Poly-b-hydroxybutyrate
PHV : Poly hydroxyvalerate
PO_4^{-3} : Phosphate
Poly-P : Poly-Phosphate
SBRs : Sequencing Batch Reactors
SCVFA : Short Chain Volatile Fatty Acid
SRT : Sludge Retention Time
SS : Suspended Solids
TP : Total Phosphorus
WWTP : Wastewater Treatment Plant
VFA : Volatile Fatty Acid

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SUMMARY

The study which application is made for GaOID consist of two steps.With the intention of analysis of phosphorus removal potential of OID, design and operation datas which are taken from treatment plant are examined and evaluated for current situation.
In the second step of the study, researching of phosphorus removal potential of OID wastewater which is taken from inlet of the WWTP and biological mass are examined in ITU Environmental Engineering, Sedat Üründül Biotechnology Laboratory for the application of Enchanced Biological Phosphorus Removal: EBPR.

GaWWTP can treat the wastewater which is coming either from industry or domestic areas regarding to proper legislation of discharge standards. In current situation, wastewater discharge of the WWTP provide the all standards regarding to legislations of discharge standards except Total Phosphorus(TP).

Purpose of this study is both researching and examining of the biological phosphorus removal potential of GaOID WWTP and making an applicable technical solutions about related discharge standards. Results are summarizing as below :

1. GaOID WWTP is examined in terms of biological phosphorus removal. In current biological treatment systems, it is resulted that related discharge standard could not be provided without using chemicals(ferric chloride & lime).
2. There are three alternatives providing the total phosphorus (TP) discharge standards. Alternatives are as follow (a) control of standards about wastewater discharge to the channel (b) addition of chemicals (c) application of Enchanced Biological Phosphorus Removal process.
3. Characterization of wastewater is examined with detailed experiments. Degredable organic material is measured very high level in wastewater, this is clearly understood that this high level of degredable organic material is convenient for the application of EBPR process.
4. By the application of pilot scale of study with both wastewater from Ga OID WWTP's wastewater and biomass in İTÜ Environmental Engineering, Dr. Sedat Üründül Environmental Biotechnology Laboratory, regularity of discharge standard is provided.

ORGANİZE SANAYİ BÖLGESİ ATIKSULARININ AŞIRI BİYOLOJİK FOSFOR GİDERİM POTANSİYELİNİN İNCELENMESİ

ÖZET

Gaziantep Organize Sanayi Bölgesi (GaOSB) içindeki sanayi kuruluşlarından ve sosyal tesislerden kaynaklanan endüstriyel ve evsel nitelikli atıksuların yürürlükteki mevzuata uygun arıtılması için GaOSB atıksu arıtma tesisinin 1. Kademesi 2003 yılında işletmeye alınmıştır. GaOSB'nin hızlı gelişimine paralel olarak atıksu arıtma tesisinin 2. Kademe projesi ve inşaatı gerçekleştirilerek 2011 yılında yeni tesis de işletilmeye başlanmıştır. Atıksu arıtma tesisinde arıtılan sular Hancağız Barajı'nı besleyen Samözü Deresi'ne deşarj edilmektedir.

Atıksu arıtma tesisinde arıtılan sular, mevzuatta belirlenen kirletici parametrelere ait deşarj standartlarını Toplam Fosfor (TP) haricinde sağlayabilmektedir. Bu kapsamda, özellikle son zamanlarda TP parametresine ait deşarj kriterlerin sağlanamamasına ilişkin problemin nedenlerinin araştırılması ve buna ait tesis içi çözüm alternatiflerinin oluşturulması gerekliliği ortaya çıkmıştır.

GaOSB Atıksu Arıtma Tesisi'ne atıksu girişi 1., 2. ve 3. Bölgelerin atıksularını toplayan bir hatla cazibeli olarak tesise iletilmektedir. 3. Bölge'deki en son sanayi parseline kadar gelen 2000 mm çaplı kolektör hattı ile atıksu arıtma tesisine bağlanmaktadır. 4. Bölge atıksuları ise 1000 mm çaplı ayrı bir hatla tesisin giriş dağıtım yapısına ulaşmaktadır. Mevcut GaOSB Atıksu Arıtma Tesisi 1. 2. ve 3. bölgelere (toplam 1200 hektar alan) hizmet edebilecek şekilde 90000 m3/gün kapasiteli ve iki kademeli olarak tasarlanmıştır. Atıksu arıtma tesisi ünitelerinin I. Kademesi (Eski Sistem) 30000 m3/gün, II. Kademesi (Yeni Sistem) ise 60000 m3/gün atıksuyu arıtacak şekilde inşa edilmiştir

Tesis fiziksel, kimyasal, biyolojik arıtma (aerobik aktif çamur) ve çamur susuzlaştırma ünitelerinden oluşmaktadır. Fiziksel arıtma birimi ızgara, kum tutucu, atıksu dengeleme ünitelerinden oluşmaktadır. Bunu takip eden kimyasal arıtma hızlı karıştırma (koagülasyon), yavaş karıştırma (flokülasyon) ve çöktürme tanklarını içermektedir. Mevcut durumda kimyasal arıtma ünitesinde Demir Klorür (FeCL3) ve Kireç (Ca(OH2)) dozlaması yapılmaktadır. Biyolojik arıtmada ise havalandırma ve son çökeltme havuzları bulunmaktadır. Arıtma tesisinden çıkan arıtılmış sular, daha önce değinildiği gibi tesisin yakınından geçmekte olan Samözü deresine deşarj edilmektedir.

GaOSB atıksu arıtma tesisinden farklı zamanlarda (14 Mart 2012, 16 Nisan 2012) temin edilen atıksu numuneleri üzerinde öncelikle konvansiyonel karakterizasyon çalışmaları yürütülmüştür.

GaOSB atıksuyuna laboratuvar şarlarında EBPR prosesi uygulanmıştır. EBPR prosesinin GaOSB atıksu arıtma tesisinin işletme koşullarına benzer laboratuvar ölçeğinde bir pilot tesis (SBR) kurulmuştur (Insel ve diğ., 2006). Pilot tesis, GaOSB'den alınan aşı çamuru ile işletilmeye başlanmış ve 3 ay süre ile orijinal çökeltilmiş atıksu ile arıtma gerçekleştirilmiştir (Şekil 9). Atıksu beslemesi yapılmadan önce gerçek tesise benzer ön çökeltme işlemi uygulanmış, üst faz ile aktif çamur beslenmiştir. Ön çökeltme bekletme süresi 2 saat olarak ayarlanmıştır. Proses sıcaklığı ise ortalama 20 ◦C'ye ayarlanmıştır.

Aşırı Biyolojik Fosfor Giderimi (EBPR) prosesi kentsel atıksulardan fosfor gideriminde yaygın olarak kullanılmaktadır (ATV131, 2000; Randall ve diğ., 1992; Wentzel ve diğ., 1992). Özetle bu proseste, aktif çamurun kısmi anaerobik koşullara maruz bırakılarak fosfor depolama kapasitesinin üzerinde fosfor alımının sağlanması hedeflenmektedir. Anaerobik şartlarda, EBPR prosesini gerçekleştiren bakteriler (fosfor depolayan bakteriler: PAO) anaerobik koşullarda, hücre içinde depoladığı fosforu (Poly-P: PP) salarak kolay ayrışan organik maddeyi (Uçucu Yağ Asidi: UYA) bünyelerine almakta ve diğer mikroorganizmalara göre avantaj elde etmektedir. Sonraki aerobik koşullarda ise (oksijenin varlığında) depoladığı organik maddeyi (Polihidroksi Alkonat: PHA) tüketerek salmış olduğu fosforun çok daha fazlasını çoğalma ile birlikte hücre içinde depolayabilmektedir.

GaOSB atıksu arıtma tesisi için hazırlanan bu çalışma iki aşamadan oluşmaktadır. İlk tesis yetkililerinden alınan tasarım ve işletme verileri incelenerek atıksu arıtma tesisi mevcut fosfor giderme potansiyeli incelenmiştir. Çalışmanın ikinci aşamasında, tesis girişinden alınan atıksu ve biyolojik çamur ile İTÜ Çevre Mühendisliği, Sedat Üründül Çevre Biyoteknolojisi Laboratuvarı'nda Aşırı Biyolojik Fosfor Giderimi Prosesi (Enhanced Biological Phosphorus Removal: EBPR) uygulamasına yönelik pilot tesis işletilmiştir.

Gaziantep Organize Sanayi Bölgesi (GaOSB) sınırları içindeki sanayi kuruluşlarından ve sosyal tesislerden kaynaklanan endüstriyel ve evsel nitelikli atıksuların yürürlükteki mevzuata uygun arıtılması GaOSB Atıksu Arıtma Tesisi tarafından yerine getirilmektedir. Mevcut durumda, arıtma tesisinden deşarj edilen sularda, mevzuatta belirlenen kirletici parametrelere ait deşarj standartları toplam fosfor (TP) parametresi haricinde sağlanabilmektedir.

Bu çalışmanın amacı, GaOSB atıksu arıtma tesisi biyolojik fosfor giderim potansiyelinin incelenmesi ve ilgili deşarj standartlarının sağlanabilmesi için teknik uygulanabilir çözümün ortaya konmasıdır. Çalışmadan elde edilen sonuçlar aşağıda özetlenmektedir:

1. GaOSB Atıksu Arıtma Tesisi biyolojik fosfor giderimi açısından irdelenmiştir. TP parametresinin ilgili deşarj standardının kimyasal madde (demir klorür ve kireç) kullanmadan ve mevcut biyolojik arıtma işletmesi ile sağlanamayacağı sonucuna varılmıştır.

2. Deşarjda toplam fosfor (TP) parametresinin sağlanabilmesi için 3 alternatif bulunmaktadır. Bunlar (a) kanala deşarj standartlarının kontrolü (b) kimyasal madde ilavesi veya (c) Aşırı Biyolojik Fosfor Giderimi (EBPR) prosesinin uygulanmasıdır.

3. GaOSB atıksularına ait detaylı karakterizasyon çalışması yürütülmüştür. Atıksuda ayrışabilen organik madde yüksek seviyede ölçülmüş olup aşırı biyolojik fosfor giderimi (EBPR) prosesinin uygulanmasına elverişli olduğu anlaşılmıştır.

4. İTÜ Çevre Mühendisliği, Dr. Sedat Üründül Çevre Biyoteknoloji Laboratuvarı'nda kurulan pilot ölçekli düzenek ile GaOSB arıtma tesisinden alınan atıksu ve biyolojik çamur ile EBPR prosesi uygulanmıştır. Sonuçta, mevzuata uygun olması gereken parametreler için deşarj standartları sağlanmıştır.

1. INTRODUCTION

1.1 Relevance of Subject

The quantity of wastewater discharged into the receiving environments increases every day. This makes people to apply existing economic and development of new treatment systems or make changes to mandatory treatment systems.

Organized industrial districts located within industrial establishments and social facilities resulting from the treatment of industrial and domestic wastewaters for appropriate legislation in waste water treatment plants is being commissioned, in parallel with the development of wastewater treatment plants of OID speed gradually as the capacity increases designed and construction.

In the majority of the treatment plant, treated wastewater includes polluting parameters which are specified in legislation about discharge standards except the total Phosphorus (TP). In this framework, investigation and necessity of in-situ solution alternatives are occured due to the problems which concern the discharge criteria about TP parameters especially in more recent times.

1.2 Aim and Scope of the Study

The aim of this study is investigation about the potential phosphorus removal of OID’s wastewater and related to this parameter in order to be subjected the discharged water about the discharge standard.

This study has several steps which implements in GaOID. In the first step, the data taken from operation of facility, available phosphorus removal potential were examined for full scale wastewater treatment plant.

In the second step of the study, a bench-scale SBR system was operated using the real wastewater and biological sludge vaccine which are obtained from the wastewater treatment plant for Enhanced Biological Phosphorus Removal in

ITU Environmental Engineering, Sedat Üründül Environmental Biotechnology Laboratory. Phosphorus removal performance of full scale wastewater treatment plant and SBR system was compared.

2. LITERATURE REVIEW

2.1 Phosphorus Resources in Environment

Major sources of phosphorus are removal of human waste, domestic and industrial wastewaters and agricultural area discharge.

Phosphorus in waterbody may originate from either point (e.g. domestic and industrial wastewaters) or non-point sources (e.g. surface runoff from farms usinpg nutrient rich fertilisers.). Typical phosphorus concentrations in domestic wastewater range is 6-20mg/L with detergants contributing a significant proportion of phosphorus (Summary Report 1982, Boller 1987, Balmér&Hultman 1988). Nearly 70% of the total phosphorus in domestic wastewater is inorganic(orthophosphates and polyphosphates) with the reminder organically bound (Alexander & Stevens 1976). Orthophosphates (PO4-3, HPO4-2, H2PO4- and H3PO4) are easily assimilated by microorganisms, whereas other forms of phosphorus fractions in industrial are largely dependent of the type of industry.

Most authors agree that orthophosphates are dominating over other phosphorus compounds in domestic (municipal) wastewater:

Table 2.1 : Phosphorus compound structure in domestic wastewater (Jenkins(1971), Jenkins&Hermanowicz(1991)

Phosphorus Compound Group	(Jenkins; 1971) ppm (mgP/L)	(Jenkins & Hermanowicz; 1991) ppm (mgP/L)
Orthophosphates	5	3-4
Tripolyphosphates	3	2-3(tripoly and phyro together)
Pyrophosphates	1	-
Organic phosphates	<1	1
Total phosphorus	<10	<<7

Under normal conditions the concentration of phosphorus in natural waters are in balance. If phosphorus amount which enters the water can not assimilate by living organisms, there is excess phosphorus problem occurred. Excess phosphorus amount makes accelerating the growth of algae. The basic mechanism of algae growth in lakes is occurred by photosynthesis. Eutrophication can be controlled by preventing requirements for photosynthesis. Sunlight and carbon dioxide are uncontrolled factors for photosynthesis but, nitrogen and phosphorus can be controlled. It is known that atmospheric nitrogen can not be uptaken by blue-green algae. Water is the only phosphorus resource to use for the growth of algae. Therefore the most effective factor to prevent eutrophication is phosphorus removal.

2.2 Biological Phosphorus Removal in Indusrial Wastewaters

Internationally chemical phosphorus precipitation is typically the phosphorus removal method of choise for diary processing wastewater (Papagiannis,1996).

There is little literature available on successful application of diary processing wastewater(Comeau et. Al., (1996)&Kolarkski and Nyhuis, (1995)). Some pilot and full scale wastewater treatment plants have been cosntructed that can potentially remove phosphorus biologically, but have not achieved significant biological removal. Lack of EBPR activity was in some cases due to the operational conditions or no consideration was given to the wastewater organic substrate characteristics and nitrogen concentrations and their effect on EBPR(Enhanced Biological Phosphorus Removal) process (Donkin and Russel, 1997; Papagannis, 1996). It is generally accepted that short chain volatile fatty acids(SCVFA's), or readily biodegradable COD are required for biological phosphorus removal. Previous studies have shown that there is a significant amount of readily biodegredable COD presents in diary processing wastewater, most likely as sugar(Sozen and Orhon, 1999; Leonard, 1996). There is some doubt as to whether this could be converted to SCVFA in the anaerobic zone of a BNR system or seperate directly.

Some studies using glucose as the organic substrate have lead to the decomposition of EBPR in BNR reactors by encouraging the reproduction of competing bacteria that can sequester glucose directly in the anaerobic zone, without the subsequent storage of polyphosphate under aerobic conditions(Mino et. Al., 1998).

2.3 EBPR Technology

EBPR removal where a wastewater treatment biomass removes phosphorus beyond its anabolic requirements by accumulating intracellular polyphosphates (polyP) reserves. In addition to P removal for cell synthesis, further phosphorus (P) removal may also take place by chemical precipitation either with chemicals present in the wastewater or added to the treatment system.(Henze et. Al, 2008),

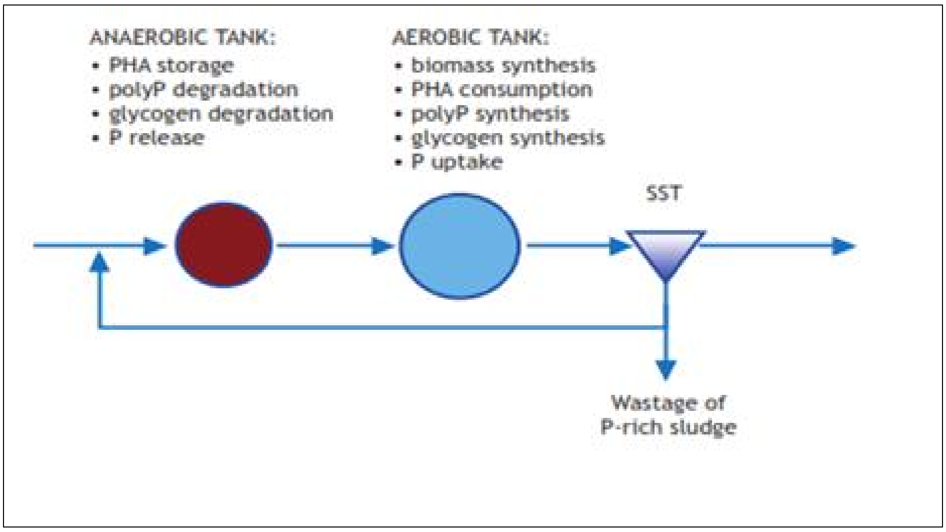

Figure 2.1 : Observations of behaviour of PAOs in an EBPR system (Metcalf and Eddy, 2003)

This is achieved by system design or operational modifications that stimulate, in addition to the “ordinary” heterotrophic organisms present in activated sludge, the growth of organisms that can take up large quantities of P and store them internally in long chains called polyphosphates (polyP); generically these organisms are called phosphorus accumulating organisms (PAOs; sometimes also called polyphosphate accumulating organisms).(Henze et. Al, 2008)

2.3.1 Mechanism of EBPR

EBPR is performed by PAO that are revealed to alternating anaerobic and aerobic and/or anoxic conditions. The process relies on several compounds: poly-ß-hydroxy-alkanoates (PHA), glycogen and poly-phosphate (poly-P) that during the anaerobic – aerobic or anoxic cycle, are accumulated and stored in granules inside the bacterial cell and subsequently degraded, as well as on compounds in the wastewater. (Henze et. Al, 2008)

Under anaerobic conditions the PAO take up easily biodegradable soluble organic matter (BSCOD) such as volatile fatty acids (VFA) from the wastewater and store this in intra cellular granules as PHA. The composition of PHA varies depending on the composition of the easily biodegradable compounds that are taken up. The energy required for the production of PHA under anaerobic conditions is supplied by degradation of previously stored intra cellular poly-P and degradation of previously stored intra cellular glycogen to PHB (poly-hydroxy-butyrate) (Smolders et. al. 1995).

The phosphate produced in the degradation of poly-P is released to the wastewater. The ionic balance in the cell is preserved by release of metal cations (usually K+ , Mg 2+), (Christensson 1997).

Under aerobic conditions the internal storage of PHA is used for energy and as C-source for growth and for synthesis of glycogen that is stored in intra cellular granules. At the same time phosphate and counter ions are taken up from the wastewater. The phosphate is polymerised to poly-P and stored in intra cellular granules(Smolders et. al. 1995).

A schematic presentation of the release and uptake of phosphate and uptake and consumption of organic matter by PAO is shown in Figure 2.2 (Christensson, 1997). Phosphate uptake also takes place under anoxic conditions, where nitrate is used as electron acceptor in stead of oxygen (Kerrn-Jespersen and Henze 1993). Degradation of PHA, accumulation of poly-P and synthesis of glycogen takes place during anoxic conditions, similarly to aerobic conditions. The nitrate is denitrified to nitrogen gas as in denitrification without phosphate uptake. One potential advantage with denitrifying phosphate uptake is efficient utilisation of C-source since phosphorus and nitrogen are removed simultaneously from the wastewater (Kuba et. al.1996a).

Several authors have compared phosphate uptake under aerobic and anoxic conditions. Kerrn-Jespersen and Henze (1993) observed lower P-uptake rates under anoxic conditions compared to aerobic conditions and concluded that PAO could be divided in two groups: One group capable of utilising only oxygen as electron acceptor and another group capable of utilising oxygen or nitrate as electron acceptor. Wachtmeister et. al. (1997) found lower P-uptake rates in batch tests under anoxic conditions compared to aerobic conditions and that activated sludge not previously exposed to anoxic conditions also had a small anoxic P-uptake. Although the results could be explained by two different groups of PAO the authors tentatively concluded that it was more likely that the PAO were from one population with different induced denitrification activity. Meinhold et. al. (1999) determined the fraction of denitrifying PAO (DNPAO) using different batch tests

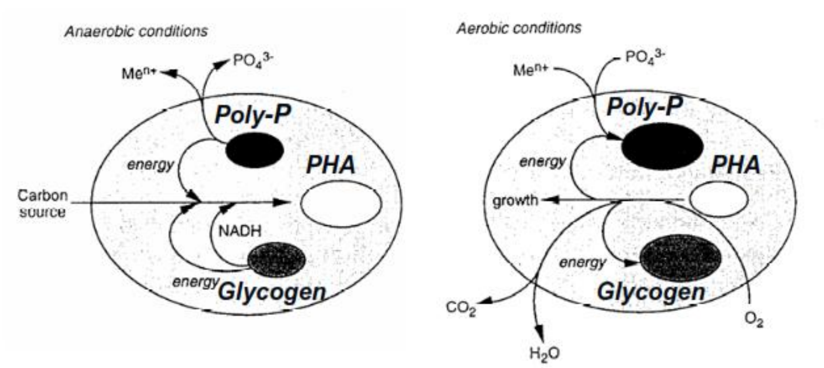

Figure 2.2 : Schematic presentation of EBPR. Uptake of C-source,production of PHA and release phosphate under anaerobic conditions (left). Uptake phosphate and degradation of stored PHA (right). (Christensson, 1997).

2.4 Wastewater Treatment Plant Configurations

2.4.1 Process configurations for biological P-removal

Based on the characteristics of the EBPR process various different process configurations have been developed. The processes can be divided in two main groups: mainstream processes and side-stream processes. Mainstream processes are characterised by the fact that the anaerobic phase is in the waterline of the process and the phosphate is removed while being inside the PAOs. In the side-stream process, the phosphate removal is performed in the sludge line of the process and the PAOs are only used to concentrate the phosphate which is finally removed through precipitation after release out of the PAOs. To this end, an anaerobic tank is placed in the sludge line to select for PAOs. In the latter case the biological process is only used to concentrate the phosphate in that section of the process where it is efficiently precipitated. Whereas the division between mainstream and side-stream processes is traditionally used, processes can also be divided in two groups according to the operating mode, i.e. continuous processes or batch processes. For the latter group especially the so-called sequencing batch reactors (SBRs) are often used for wastewater treatment processes. [Henze et. Al, 2008]

2.4.2 Side – stream processes

Based on observations by Shapiro (1965) at the Baltimore treatment plant, where phosphorus uptake was followed by its release at the bottom of secondary clarifiers, Shapiro proposed to expose return sludge to such conditions prior to return to the aeration basin in order to strip out phosphorus. This was a predecessor to the Phostrip process, patented by Levin (1966) and applied in the 1970's in the United States (Figure 2.3). The proprietary Phostrip became the most popular biological phosphorus removal process at that time. The side-stream flow is diverted to the anaerobic phosphorus stripper at a ratio of approximately 5-30% of the influent flow (Metcalf and Eddy, 1991; Brett, 1997).

2.4.2.1 Phostrip process

Besides phosphorus release the main purpose of the anaerobic stripper is sludge thickening. The retention time in this tank generally ranges from 8 to 12 hours (Metcalf and Eddy, 1991; Tetreault et al., 1986). The release of phosphorus in the stripper tank occurs with the same mechanisms as for an anaerobic-aerobic sequence in the activated sludge process described earlier. Addition of acetic acid or influent stimulates the phosphate release. Soluble phosphorus is transferred to the supernatant either by recycling the stripper underflow or by passing an elutriation stream (primary effluent, secondary effluent or supernatant return) through the stripper. The stripper overflow is then fed to a chemical tank where phosphorus is precipitated by lime addition (Metcalf and Eddy, 1991; Johansson, 1994; Brett, 1997). With the proprietary Phostrip design Levin (1965) did not yet understand the relation between anaerobic substrate storage and the concurrent phosphorus release, nor did it account for the detrimental effects of nitrate penetrating the anaerobic phase (Reddy, 1998). Initially these systems were operated at sludge ages so low that nitrification did not occur (Alexander et al., 1994). A modification of the original Phostrip design incorporates an anoxic reactor ahead of the aerobic reactor, with an internal recirculation from the aerobic to the anoxic phase, to minimise nitrate in the effluent from the aerobic reactor (Brett,1997). The first full scale applications of biological phosphorus removal were based on the side-stream process (Phostrip). The most important advantages were the controllability, reliable effluent phosphate concentrations of less than 1.5 mg/L (Metcalf and Eddy, 1991) and the production of a phosphate rich side product, eventually applicable for other purposes.

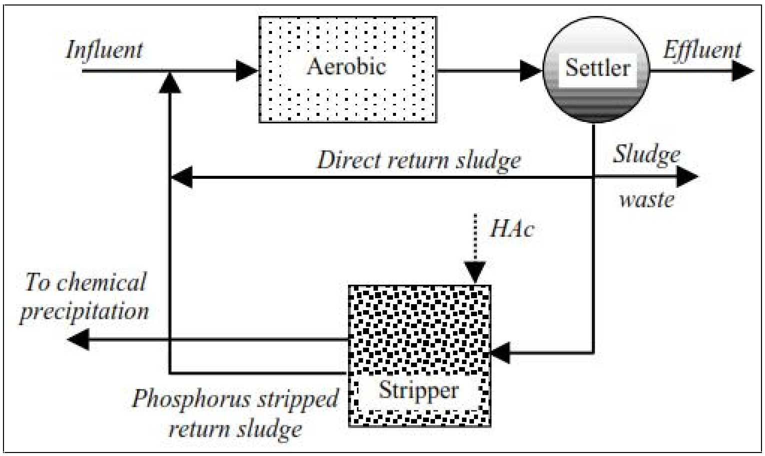

Figure 2.3 : Schematic presentation of Phostrip Process

Besides phosphorus release the main purpose of the anaerobic stripper is sludge thickening. The retention time in this tank generally ranges from 8 to 12 hours (Metcalf and Eddy, 1991; Tetreault et al., 1986). The release of phosphorus in the stripper tank occurs with the same mechanisms as for an anaerobic-aerobic sequence in the activated sludge process described earlier. Addition of acetic acid or influent stimulates the phosphate release. Soluble phosphorus is transferred to the supernatant either by recycling the stripper underflow or by passing an elutriation stream (primary effluent, secondary effluent or supernatant return) through the stripper. The stripper overflow is then fed to a chemical tank where phosphorus is precipitated by lime addition (Metcalf and Eddy, 1991; Johansson, 1994; Brett, 1997). With the proprietary Phostrip design (Levin (1965)) did not yet understand the relation between anaerobic substrate storage and the concurrent phosphorus release, nor did it account for the detrimental effects of nitrate penetrating the anaerobic phase (Reddy, 1998). Initially these systems were operated at sludge ages so low that nitrification did not occur (Alexander et al., 1994). A modification of the original Phostrip design incorporates an anoxic reactor ahead of the aerobic reactor, with an internal recirculation from the aerobic to the anoxic phase, to minimise nitrate in the effluent from the aerobic reactor (Brett,1997). The first full scale applications of biological phosphorus removal were based on the side-stream process (Phostrip). The most important advantages were the controllability, reliable effluent phosphate concentrations of less than 1.5 mg/L (Metcalf and Eddy, 1991) and the production of a phosphate rich side product, eventually applicable for other purposes. However, this process is labour intensive and the use of chemicals is very high. According to De Jong, (1999) a market for the by-products has not really been found, although changes are expected. It is thought that the application of this process will remain limited because of its high cost and complexity. Moreover, the necessity to add chemicals makes the process non sustainable. A variant to the traditional Phostrip process is the combination with the so-called Crystalactor where the precipitation unit is replaced with the crystallisation of phosphorus compounds in a fluidised bed reactor (Giesen, 1998).

2.4.2.2 The BCFS – process

By the Dutch Waterboard "Groot Salland", the Netherlands, the BCFS (translated from Dutch: biological chemical phosphate nitrogen removal) process has been developed. The process design is based on the ideas of the Phostrip process, but avoiding the large investments in extra infrastructure. The process is specially designed to optimise the activity of DPAOs (van Loosdrecht et al., 1998). Nitrification is optimised by operating the treatment plant at long SRT (45 days). The associated low sludge productions limits the capacity for intracellular polyphosphate accumulation in the sludge (van Loosdrecht, 1997c). Phosphorus that can not be accumulated in the sludge has is removed chemically. Therefore an in-line "stripper" is provided by placing baffles at the end of the anaerobic reactor compartment to induce a quiescent zone in which the sludge partly settles. The phosphate-rich supernatant can be pumped from the activated sludge tank and precipitated in the sludge thickener (vanLoosdrecht et al., 1997c, 1998). A practical application of this process configuration is implemented at the Holten WWTP in the Netherlands (Van Veldhuizen, 1999). A schematic representation of the process configuration is presented in Figure 2.4.

2.4.2.3 Renpho-and modified renphosystem

In the Renphosystem (Rensink et al., 1988), influent and direct return sludge come together in the anaerobic phase where phosphate is released. The mixed liquor then flows into an aerobic phase where phosphate is taken up and nitrification takes place.

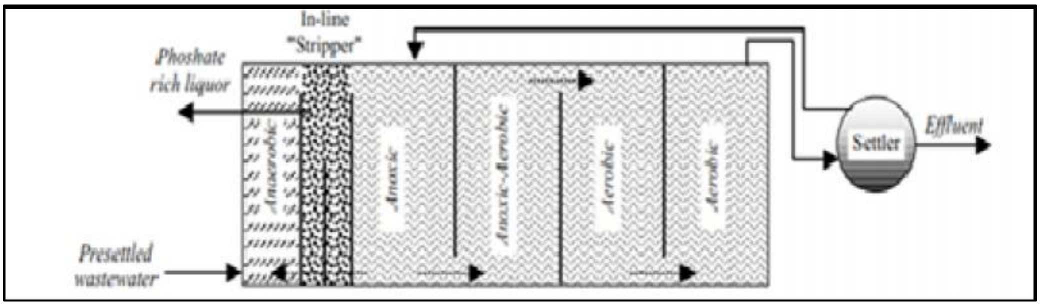

Figure 2.4 : Schematic presentation of Aeration Basin and secondary clarifier of Holtern WWTP implementing the BCFS® process (Van Valdhuizen et al,1999)

In the next, anoxic phase, the nitrate formed is reduced, electrons being provided by adding some fresh influent that contains readily biodegradable organic compounds.In a final additional aerobic phase the last traces of phosphate and organic matter are removed. After settling of the sludge, one part is returned to the front end of the plant and the second part is pumped into the anaerobic stripper where phosphate is released from the cells. The stripped cells are then pumped back to the first aerobic phase (Figure 2.5).

The supernatant of the stripper tank is generally sent through a Crystalactor (Rensink et al.,1997). In the stripper tank a detention time of 4 hours was sufficient. Dosage of acetate (10-20mg COD/g MLSS) stimulate phosphorus release and growth of PAOs (Rensink et al., 1997). The efficiency of the P-removal on the basis of ortho-phosphate and total phosphate amounted 97 and 87% respectively (Rensink et al., 1997). Although the nitrogen removal in the Renphosystem achieved values of 70% at low temperatures and 80% at high temperatures, the process configuration was not capable of reaching very low nitrogen values in the effluent. To allow for improved nitrification-denitrification, the Modified Renphosystem was designed comprising an additional phosphorus stripped sludge return to the anoxic reactor. This modified process design allowed for growth of DPAOs resulting in saving of COD and energy (Rensink et al., 1997). Both the Renphosystem and the modified Renphosystem are combined sidestream and mainstream processes. Because of the stripper tank, generally they are listed along with the side-stream processes.

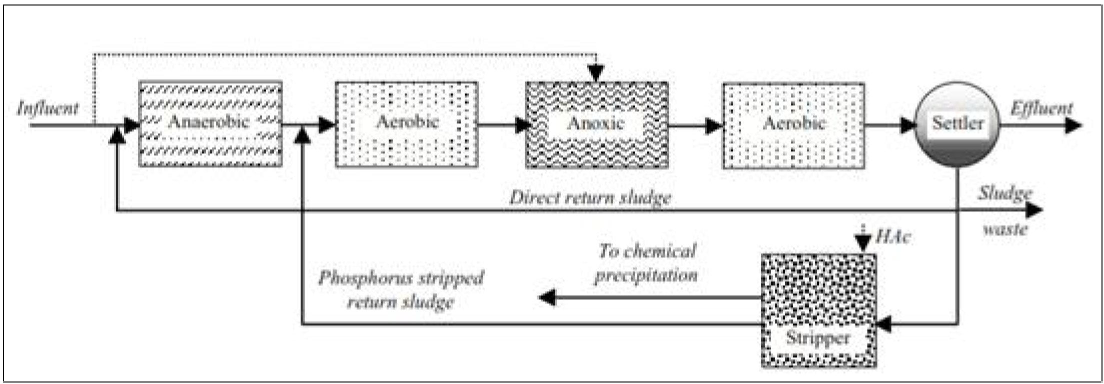

Figure 2.5 : Schematic presentation of Renphosystem

2.4.3 Main-stream process

2.4.3.1 Bardenpho and phoredox process

Barnard (1975) first achieved phosphorus removal in a mainstream process later called the Bardenpho process. A four phase anoxic-aerobic-anoxic-aerobic configuration, originally designed for nitrogen removal, was used. Sludge from the secondary clarifier and the mixed liquor from the first aerobic basin are recirculated to the first anoxic reactor (Figure 2.6). Although significant phosphorus removal was achieved, the effluent concentration was very sensitive to maintenance conditions. Looking back at the prerequisites for phosphorus removal, the Bardenpho process is violating the first rule, i.e. the feed stream has to come into contact with an oxygen and nitrate free stream. Since the first reactor in the Bardenpho TM configuration is an anoxic reactor, some nitrate will be present. Including an anaerobic reactor ahead of the first anoxic reactor in the BardenphoTM configuration, fed with sludge from this first anoxic reactor, created favourable conditions for phosphorus removal. This configuration is known as the five stage Bardenpho TM configuration, or the modified Bardenpho TM process. In South Africa and Europe this process is known as the Phoredox process.

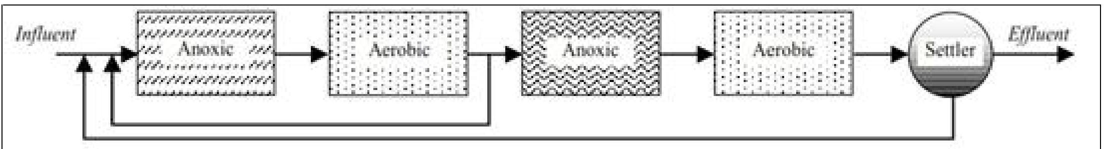

Figure 2.6 : Original 4 Stage-Bardenpho^{TM} Configuration

Further developments in South Africa led to additional modifications, i.e. a Modified or 3-phase Phoredox system where the post-denitrification and re-aeration steps are omitted. A description of such a plant in the Johannesburg area was presented where an effluent concentration of 2.1 mg PL was achieved (Pitman, 1983) and in Olifantsfontein where a 1.0 mg P/L level was reported by van Huyssteen et al.(1990).

2.4.3.2 The A/O and A2/O configurations

The proprietary A/O and A2/O processes, are very similar to the Phoredox concept, except that the anaerobic and aerobic stages are divided into a number of equally sized, completely mixed compartments.

2.4.3.3 Modified UCT process

Further modifications of the Phoredox plant were done by the research team of Prof. Marais at the University of Cape Town in South Africa. The main idea here was to return the activated sludge to the anoxic instead of the anaerobic phase to avoid any negative effects on the initial phosphorus removal efficiency by nitrate present in the return sludge. Here the nitrate-containing sludge is first introduced intoa denitrification reactor, after which the nitrate-free sludge/water mixture is partly recycled to the anaerobic tank (Figure 2.7).

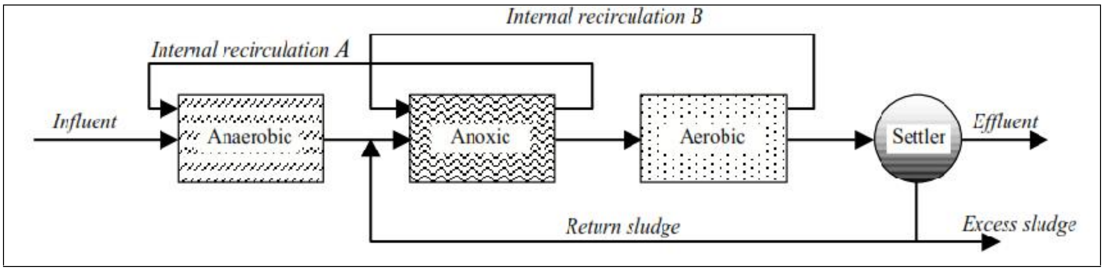

Figure 2.7 : Modified UCT Process

In the modified UCT configuration, the anoxic reactor from the UCT process is divided in two compartments. The anoxic reactor following the anaerobic phase receives the nitrates recycled with the return sludge. The mixed liquor is recycled to the anaerobic phase. The second anoxic reactor allows denitrification of the recycled mixed liquor from the aerobic phase. It has been shown that denitrifying bacteria can contribute significantly in the UCT-type process (Kuba et al., 1997a; van Loosdrecht et al., 1997c). Indeed, in these processes, organisms are cycled between anaerobic and denitrifying conditions, which stimulate the growth of PAOs in the availability of nitrate.

2.4.3.4 Viriginia initiative plant (VIP TM)

Operating the UCT process as a high rate system (MCRT of 10 days or less) resulted in superior phosphorus removal capability compared to the low rate UCT process (Daigger et al., 1987). Operation at a lower MCRT resulted in a greater net observed yield and thus increased sludge production. This concept was patented as a public domain patent by CH2M/HILL as the VIPTM process (Reddy, 1998). A staged reactor configuration is provided by using at least two complete mix cells in series for each zone of the biological reactor (Daigger et al., 1987).

2.4.3.5 Johannesburg process

With the process configuration proper to the Johannesburg process, nitrates are prevented from entering the anaerobic phase. Therefore the sludge return line first passes through an anoxic phase before entering the anaerobic phase (Figure 2.8.). Comparing this system with the UCT configuration reveals that the advantage mentioned by van Loosdrecht et al. (1997c) no longer exists because the organisms are not cycled anymore between anaerobic and denitrifying conditions.

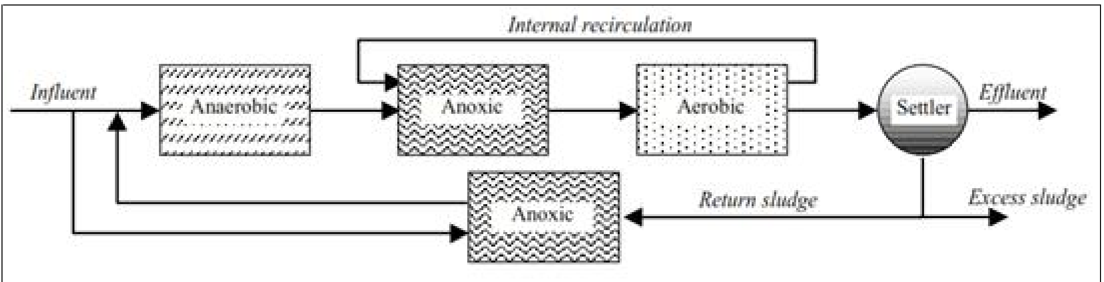

Figure 2.8 : Schematic presentation of the Johannesburg process

2.4.3.6 Two sludge system

In order to overcome difficulties related to optimising combined nitrogen and phosphorus removal, novel process configurations have been worked out using two sludges instead of a single sludge system. With these process configuration, slow growing nitrifiers and fast growing heterotrophs are separated (Wanner et al., 1992; Kuba et al., 1996b; Sorm et al., 1996). With the proposed process scheme (Figure 2.9) phosphorus release is performed under strict anaerobic conditions in a mixed tank. Most soluble organics are stored by PAOs and the fine and coarse particles are entrapped in the floc. A settler allows to separate a supernatant with high ammonia and phosphorus concentrations and a COD rich sludge. The supernatant is then nitrified in a fixed film reactor. This reactor type is preferred due to the very low yield of the nitrifiers. The COD rich sludge bypasses the nitrification reactor and is re-mixed with the nitrified effluent in an anoxic phase, where denitrification and biological phosphorus removal occur simultaneously. An aerobic phase is placed as last for safety reasons, in order to insure that the PAOs regenerate the poly-P and glycogen pool and to avoid rising problems in the final settler (Wanner et al., 1992).

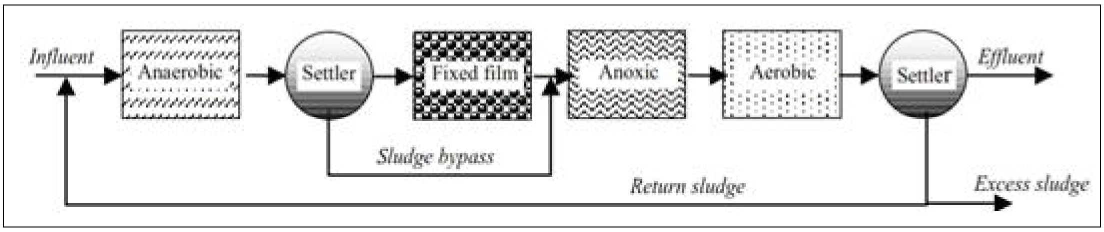

Figure 2.9 : Schematic presentation of a two sludge system for combined nitrogen and phosphorus removal (Wanner at al,1992)

2.4.3.7 Cycling – stream

Whereas for an important period of time continuous flow configurations have received most attention, cyclic process designs are gaining importance again because of their operating flexibility. Actually, continuous systems are derived from the simple fill-and-draw operation developed by Ardern and Lockett as early as 1914. These researchers established the concept of operating a single reactor basin using repetitive cycles of aeration, settling, effluent withdrawal and sludge recycle. To allow for continuous operating conditions, several reactors can be operated in parallel. Actually, in Belgium, two different cyclic process designs are in operation, namely the Unitank system (Gerards et al., 1996) and the Biodenipho TM process (Bundgaard et al., 1989). Because of the growing importance of these cyclic processes, the evolution of these cyclic designs is described in the following sections.

2.4.3.8 Oxidation ditch design

The oxidation ditch technology, or endless loop activated sludge reactor, played an important role in the development of the clarifier-less variable volume activated sludge systems. Within these systems, mixing and aeration is provided by means of horizontal axis paddles or rotating brush aerators. The concept can easily be compared with an induced river flow action. A clarifier is provided by means of a separate zone in the oxidation ditch. This zone is separated from the endless loop by means of baffles. Mixed liquor is allowed in this zone at regular time intervals. After sludge settling, the mixed liquor is withdrawn and new mixed liquor flows into this zone. Notable developments were reported by Pasveer and co-workers in the late 1950s and early 1960s (Irvine, 1996). To allow for higher flow rates, a separate settler was foreseen in later designs. To allow for phosphorus removal in an oxidation ditch system, an anaerobic reactor is placed upstream of the oxidation ditch (Reddy, 1998). In Figure 41 is visualised, though the distinct zones do not exist because of the very high internal recirculation rate. Wastewater typically circulates at velocities varying between 0.25 and 0.35 m/s (Metcalf and Eddy, 1991).

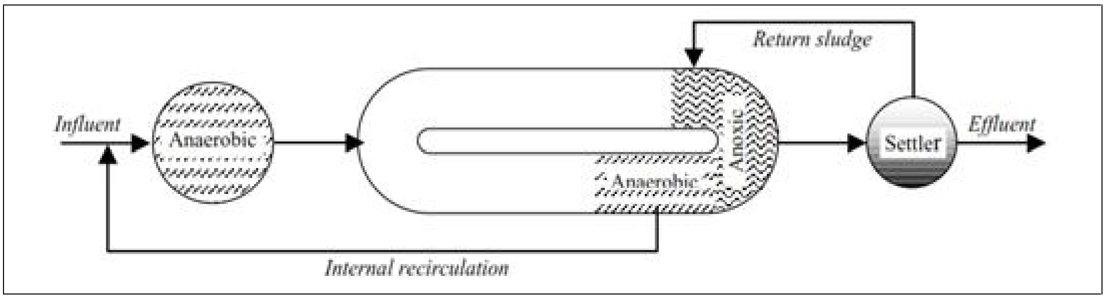

Figure 2.10 : Oxidation Ditch design for nitrogen and phosphorus removal (Reddy,1998)

Well known oxidation ditch processes comprising EBPR activity are the Carrousel 2000 (Janssen et al. 1996). The process contains an additional predenitrification phase following the anaerobic phase. A modification of the latter processes incorporates a selector instead of an anaerobic reactor ahead of the oxidation ditch to enhance growth of denitrifying PAOs (Janssen and van der Roest, 1996).

2.4.3.9 Biodenipho process

The Danish nutrient removal processes - Bio-Denitro TM and Bio-Denipho TM - are performed in phased isolation ditches which are continuous flow activated sludge systems with phased or intermittent operations (Bundgaard et al.. 1989). In Figure 42 the operating conditions of this process configuration are presented and explained below. Only the first half of the cyclic operation is presented, while the next half is performed with interchanged flow directions. The influent enters the anaerobic phase from where it passes through an anoxic phase during the first phase. The aerobic phase at that moment is not in line. This phase takes half an hour or can be operated on the basis of effluent ammonia concentration. Indeed, during this phase the influent is never subjected to aerobic conditions, nitrification does not occur. During the following phase, the mixed liquor from the anoxic phase flows to the aerobic phase allowing nitrification. This phase takes 1.5 hours or can be controlled now on the basis of effluent nitrate concentration. For the following phase the aeration in the anoxic phase is switched on to allow aerobic conditions. In the second half of the cyclic operation, what was the anoxic tank is now the aerobic tank and what was originally the aerobic tank is operated anoxically by switching off the aeration. This interchanging of flows and processes allows for uniform sludge concentration in both the aerobic and anoxic phases.

2.4.3.10Sequencing batch reactors (SBRs)

With the SBR design, the developments of the shallow oxidation ditch were translated to a deep rectangular basin. Mixed liquor now remains in the reactor during all steps of the activated sludge process, thereby eliminating the need for separate secondary sedimentation tanks (Metcalf and Eddy, 1991). For sequencing batch operating conditions different phases can be distinguished (Figure 12). The fill phase may be static, mixed or aerated, depending on treatment objectives. A static fill results in minimum energy input and high substrate concentration at the end of the fill phase. A mixed fill results in denitrification, if nitrates are present, and provides anaerobic conditions required for biological phosphorus removal. Aerated fills result in the beginning of aerobic reactions, a reduction in the

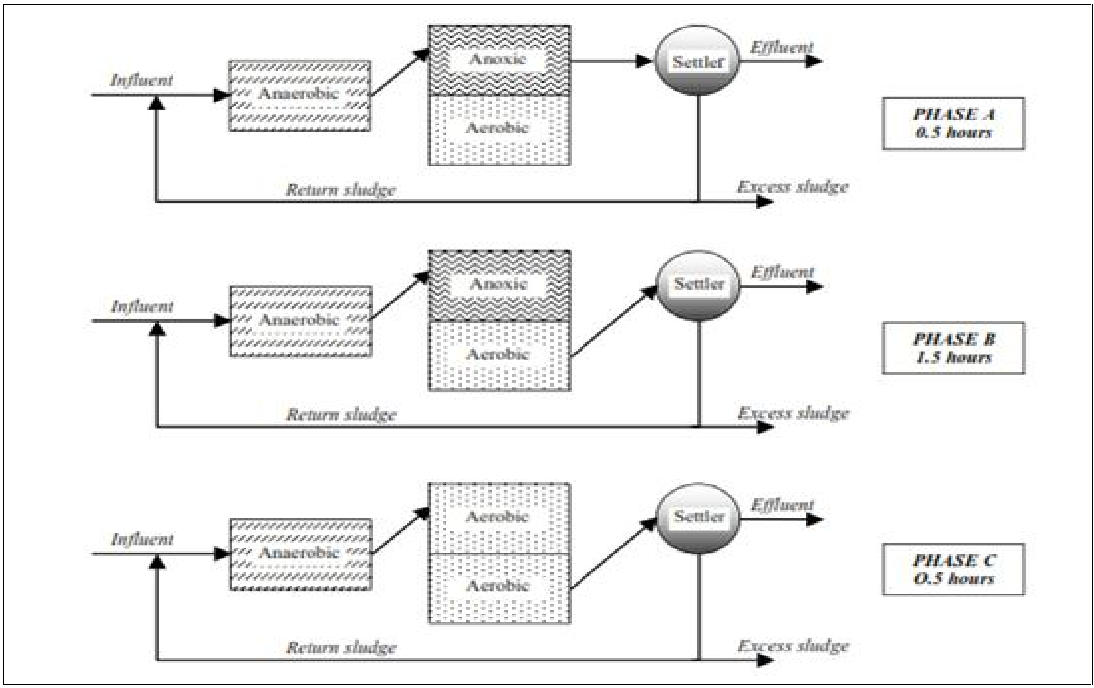

Figure 2.11: Schematic representation of the Bio-Denipho process (Bundgaard, 1989)

2.4.3.11 Sequencing batch reactors (SBRs)

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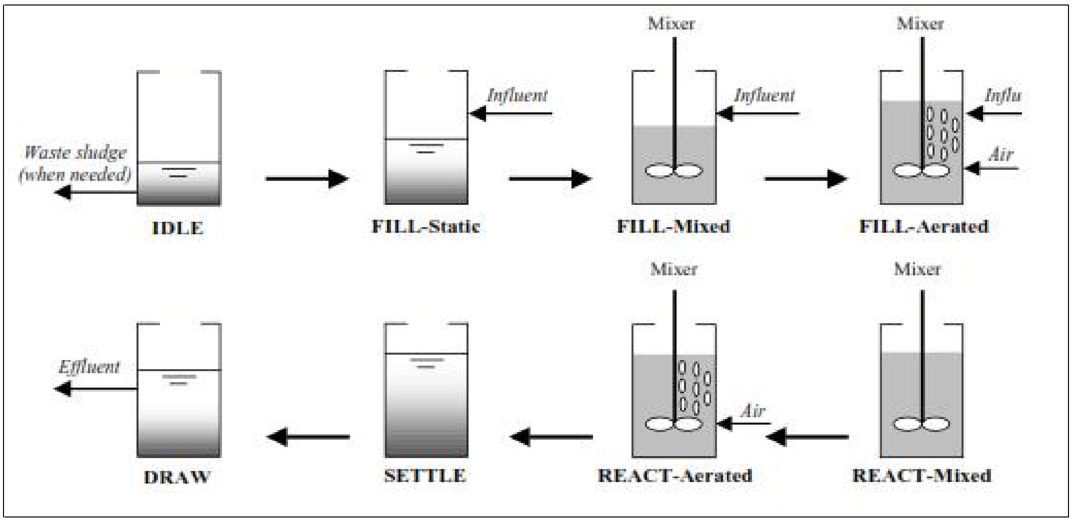

Figure 2.12 : Illustration of an SBR reactor during one complete cycle and definition of phases (Ketchum, 1996)

2.4.3.12 Cylic actived sludge system: (CASS TM)

According to Goronszy (1994), this SBR combines self-regulating selector and variable volume reactor technology, providing an effective means for the control of filamentous sludge bulking often encountered in cyclic process designs. The system consists of a basin which comprises three reactor volumes, all in continuous fluid communication (Figure 44). Volume I refers to the captive selector, volume II to the secondary phase and volume III to the main aeration zone. Sludge is continuously returned from volume III to I in order to maintain the appropriate substrate to biomass initial reaction conditions that favour growth of floc-forming micro-organisms (Goronszy, 1994). For typical domestic wastewater treatment applications, the sections are in the approximate proportions of 5%, 10% and 85% (www.sbrcass.com). During one cycle, the liquid level inside the reactor rises from a set bottom water level in response to a varying wastewater flow rate .The CASS-configuration is a superposition of a complete-mix system (volume III) and a plug-flowsystem (volume I). The general cyclic sequencing consists of fill-aeration, fill-settle, surface skim and fillidle. Cycles which drive EBPR include four and six hour periods with two and three hour sequenced air-on-off periods (Goronszy, 1994). There is little effect of residual nitrate on the EBPR performance due to the low nitrate concentration that remains in all volume sections of the basin through simultaneous nitrification-denitrification. Fermentation to produce VFAs, can be achieved by augmenting the air-off period (Goronszy, 1994).

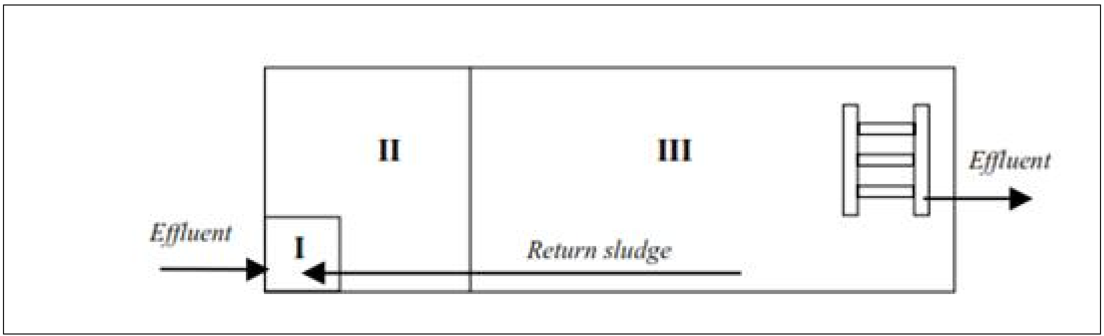

Figure 2.13 : Schematic representation of CASs^{TM} configuration (Goronszy, 1994) (Volume I : captive volume; volume II: secondary volume; volume III : oxidation zone)

2.4.3.13 Submerged biofilm sequencing biofilm reactor (S-SBR)

Whereas initially it was thought submerged biofilm reactors (SBR) were only efficient in organic and nitrogen removal, ammonia removal by nitrification in particular, Wang et al. (1998) were able to obtain good EBPR activity using an S-SBR.

2.5 Advantages and Disadvantages of the Different EBPR Process Configurations

In the above paragraphs different process configurations have been elaborated on. Many different process configurations have been proposed by researchers and engineering companies. Although it is not easy to find true comparisons between these configuration in literature, based on pilot or full scale applications, some general advantages and disadvantages of the different configurations are listed below (Table 2.2.)

Table 2.2 : Advantages and disadvantages of different EBPR process configurations (Medcalf and Eddy, 1991)

Process	Advantages	Disadvantages
Phostrip	• Can be easily in corporated into existing systems • Process flexibility • Phosphorus removal does not depend on the BOD/P ratio	• Due to necessity of adding chemicals, the process is not suitable • An additional reactor is needed for stripping • Lime scaling may be a maintenance problem
Bardenpho^{TM}	• Produces least sludge of all EBPR configurations • The wasted sludge has a high phosphorus content, thus a fertiliser value.	• Large internal cycle increases pumping energy and maintenance requirements • High BOD/P ratio required
A^2/O	• The wasted sludge has a high phosphorus content, thus a fertiliser value.	-
UCT	• Improved EBPR activity in combination with nitrification	• Large internal cycle increases pumping energy and maintenance requirements
VIP^{TM}	• Allows of high rate operation in comparison to UCT configuration	• Large internal cycle increases pumping energy and maintenance requirements
Cyclic Process	• Process are simple to operate • Process flexibility • No wash out of sludge by hydraulic surges	• To allow for continuous operation several parallel systems need to be operated.

3. MATERIAL METHODS

3.1 Gaziantep Organized Industrial District and Wastewater Treatment Plant Information

Gaziantep Organized Industrial District (GaOID), founded in 1969, the decision of the Council of Ministers, the Ministry of industry and Trade Ministry, Province, municipalities, special provincial administration, Chamber of Commerce, Chamber of Commerce, Association of Business Chambers and Industry organized industrial zone industrialists' Association, with the participation of Turkey in the first organized industrial was established.

Textile and food sector companies mainly carry on a business in the area. In all industrial from GaOID in the textile industry has 47% proportion, and 17% proportion belongs to food industry. Except textile and food industry, other industries proportion of all is following as, machine (7%), chemicals (7%), plastic (6%), packaging (4%) and construction (% 2). The remaining 10% proportion has

the sum of the other activities.

1., 2, and 3. Area’s wastewater is conveyed to GaOID wastewater treatment plant by the help of collecting pipe with gravity flow by the help of collecting pipe to treatment plant. Up to the last industrial bloc, collector pipeline which has 2000 mm diameter connect to the treatment plant. 4. Area’s wastewater reach to the influent distribution structure with another line which has 1000mm diameter pipeline (Figure3.1). Current GaOID WWTP is designed in two stage for providing treatment for 1. 2. and 3. areas (total area is 1200 hectars) which maximum flowrate is 90.000 m3/day. The WWTP was constructed to treat as in first stage for 30,000 m3day and second stage for 60000 m3day treatment capacity. This was indicated as “ESKİ SİSTEM” and “YENİ SİSTEM” in Figure 3.1, respectively.

Facility occurs from physical, chemical, biological treatment (aerobic activated sludge) and consists of a sludge dewatering units. Physical treatment unit consists of screens, sand trap, wastewater balancing units. Following chemical treatment rapid mixing (coagulation), slow mixing (flocculation) and settling tanks. In the current case iron chloride (FeCL3) chemical treatment unit and lime (Ca(OH2)) dosing was planned, however no chemical treatment is applied. In biological treatment, there are aerated activated sludge unit together with secondary clarifiers. The treated from water treatment plant, as mentioned previously are discharged to Samözü River. The flow and mass balances over wastewater treatment units can be seen from Figure 3.2.

Figure 3.1 : Satellite Image of GaOID Wastewater Treatment Plant

Table 3.1: Capacities of units belong to wastewater treatment plant

	1st Stage	Total
Units of WWTP	30,000 m^3/day	90,000 m^3/day
Grit Chamber	2 items	4 items
	208 m^3	416 m^3
Equalization Tank	1 item	2 items
	4820 m^3	9640 m^3
Coagulation	4 items	8 items
	160 m^3	320 m^3
Floculation	4 items	8 items
	680 m^3	1360 m^3
Chemical Precipitation	4 items	8 items
	5610 m^3	11230 m^3
Activated Sludge	1 item	2 items
	30000 m^3	90000 m^3
Secondary Settling Tank*	2 items	4 items
	1192 m^2	5042 m^2
Sludge Thickening*	3 items	6 items
	200 m^2	400 m^2
Sludge Dewatering	4 belt press**	4 belt press**
	20 m^3/sa	20 m^3/sa
		2 decanter
		55 m^3/sa

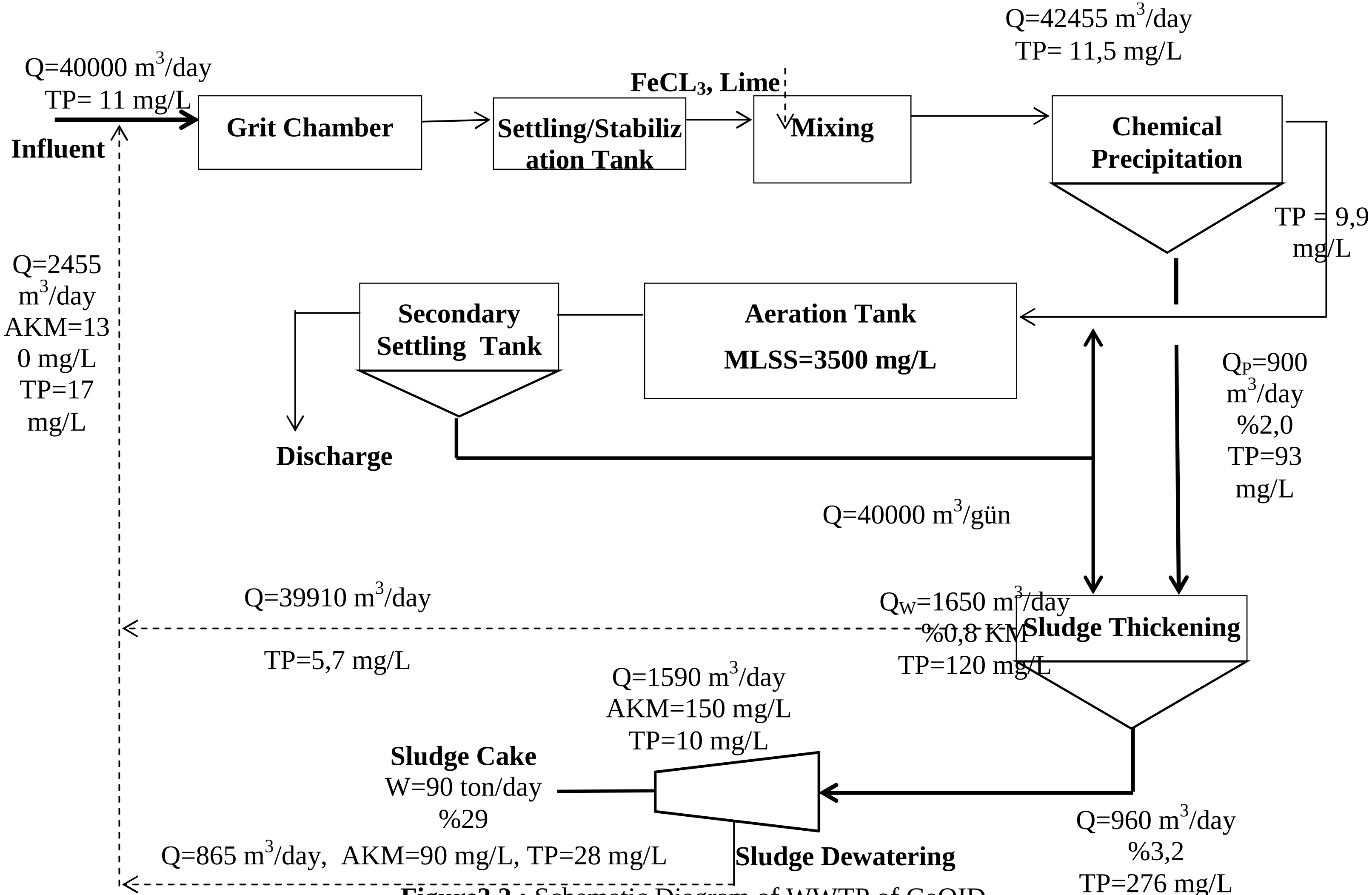

Figure3.2 : Schematic Diagram of WWTP of GaOID

3.2 SBR System Operation

When influent wastewater of GaOSB is examined, it can be observed that the biodegradable organic matter concentration is abundant for EBPR Process. Scope of this study, excess biological phosphorus removal (EBPR) processes will be provided by the operation of SBR system. The SBR plant was operated with the consequtive anaerobic and aerobic cycles which is expected to trigger EBPR process.

In the present study, the experimental work was performed with comprising of two cycles in an anaerobic-aerobic laboratory scale SBR. The first two sets of experiments were performed using industrial wastewater with original phosphorus contents. Thereafter three sets of experiments were performed with gradually increasing amount of phosphorus in order to test the EBPR capacity at high TP influent.

3.2.1 Operating Conditions

In this section, EBPR Process was applied to GaOID wastewater at laboratory. Similar conditions of SBR system were set compared to the GaOID wastewater treatment plant (INSEL et al., 2006). Pilot Plant has been started to operate with activated sludge inoculum which has taken from GaOID wastewater treatment plant, then for four and a half months it is operated with original settled wastewater to treat. (Figure 3.1). Wastewater sedimentation process was applied prior to the following activated sludge unit. Preliminary sedimentation retention time was set to 2 hours. The process temperature was adjusted to 20◦C which reflects the yearly average conditions of OID. The SBR system Food/Microorganism (F/M) ratio was adjusted to 0.21 kgCOD/kgMLSS which also reflects the terms of operation. The following periods of the SBR system was given for the SBR system:

1. Mixed Filling (T_F = 20 min.)
2. Mixing (T_M = 100 min.)
3. Aeration (T_A = 480 min.)
4. Sedimentation (T_S = 90 min.)
5. Discharge (T_D = 30 min.)

SBR system cycle time TC = 12 hours (TC = TF + TM + TA + TS + TD) filling the is for 2 times a day. VT = total volume of reactor SBR system 4.0 L and 1.0 L wastewater feed in each cycle. The concentration of dissolved oxygen in the aeration phase (TA) on a measured level of 3.0 mgO2/L which is sufficient for biochemical reaction.

To fill the wastewater into the reactor is supplied within a small pump. The filling process starts with pump which steps in the first timer. The filling phase finishes when level sensor in the reactor to be in contacts with wastewater. Wastewater is mixed by giving air blower through mixers in aerobic medium. The drawing process starts with pump which steps in the second timer. The filling phase ends when level sensor in the reactor to be cut in contact with wastewater. The mixer which is used for mixing the reactor is consisting in the third timer. Due to the different options on the mixer, speed of the mixer can be adjusted for the purpose. Timer controls the mixing process both the stepping in and the completion. In this study,the mechanism used in is showed in Figure 3.3 and schematic diagram of WWTP Figure 3.2 is also given in.

End of the drawing phase reactor volume is 3 liters of wastewater. As for end of the filling phase reactor volume becomes 4 liters of wastewater. For each time, there are 3 liters of wastewater exist which are including suspended sludge from the previous cycle in reactor. 1 liter of wastewater feed to the reactor for each new cycle in phase of filling.

At the end of the Pilot reactor SBR system, 2 months (V = 4.0 L) concentration of mixed liquor suspended solids (MLSS) is 2100 mg/L and mixed liquor volatile suspended solids (MLVSS) concentration is 1695 mg/L. These values corresponds to ratio of 80% MLVSS/MLSS.

The reactor is operated with 15 days of sludge age. A mixture of 267 ml from end of the aerobic phase has taken in reactor per day.

The best efficiency of the reactor is provided considering the sludge age of 15 days and hydraulic retention time of 12 hours. When optimum sludge age is chosen, taken sludge could calculate as following: 4L total volume is dived to sludge age as 15 days. At a resul, taken sludge should be 267 ml. And if the crosscheck is needed, we could also calculate sludge age from taken sludge volume.

Figure3.3 : Operation of pilot SBR System

From the table 3.3. Total COD after 2 hours settling is 1246 mgCOD/L.

Qx= 1246 mgCOD/L x 1L x 2 x 0.4gr SS / gr COD = 996,8 mg =~1000mg/L.
0,26 ml x 2000mg/L= 520 mg. And for 2 cycle, TSS could calculate as 2 x 30 mg/L =60 mg/L , SRT= VxX /Px = (2000mg/L x 4L) / (520mg+60mg) = 13,80 days.

It is accepted 15 days of sludge age.

Filled with 2 liters of wastewater per day as a result of the two cyle of reactor(each cycle time is 12 hours). If wastewater flow rate of 2-litres is divided to 4-litres reactor volume, the result coming out as, 2/4 = 0.5 days (12 hours).

3.3 Analytical Procedure

In this study, the experiments are testing by the samples of taken for continuous, daily and in-cycle experiments. Daily experiments made on taking samples from the end of aerobic and anaerobic phases. In addition, the samples are measured for how to change the parameters in-cycle by time intervals.

The methods used for quantative measurement of the relevant analytical parameters are describe in this part.

Table 3.2 : Regarding to both Date and Day of SET's opreation period of SBR

Name of SET	Start Date	End Date	Duration (Day)
SET-1	29.03.2012	23.04.2012	25
SET-2	24.04.2012	14.05.2012	20
SET-3	15.05.2012	12.06.2012	29
*a)**	*15.05.2012*	*23.05.2012*	-
b)+7 mg/L P	*24.05.2012*	*29.05.2012*	-
c)+10 mg/L P	*30.05.2012*	*31.05.2012*	-
d)+13 mg/L P	*01.06.2012*	*03.06.2012*	-
e)+18 mg/L P	*04.06.2012*	*12.06.2012*	
SET-4	13.06.2012	19.07.2012	37
SET-5	20.07.2012	13.08.2012	25

***** There is no additional Phosphorus amount.

All analytical methods where possible were performed as in described in Standard Methods (APHA,2005), otherwise they were based on extablished techniques presented in a literature and used by other researchers.

3.3.1 Treatability Basis Wastewater Characterization:

Wastewater is used in the reactor as a carbon source. Certain amounts of wastewater (60 liters as in the form of the 2skips of 30liters) comes from Gaziantep OID WWTP and to specify for the period of each incoming wastewater is used in the SET (Table 3.2)statement. Numbers were added for each study, respectively. For example; SET1 is refered the reactor reflecting the working conditions and experiments has within feeding first wastewater sample. The conditions are used in the experiments are given in.

Two wastewater samples from GaOSB treatment plant which were taken at different dates (March 14, 2012, 16 April 2012) is primarily the work of conventional characterization. Biological treatment is needed to reflect the real conditions of treatment plant, so firstly wastewater is subjected to as primary sedimentation in laboratory with 2 hours primary sedimentation in Imhoff Settling Cones as shown in (Figure 3.4.a). Conventional characterization examination has been carried out and the results obtained from the upper phase and the results are in table below: (Table

3.4). For examination of biological phosphorus in detailed, there could need to measure COD fractions of wastewaters (Melcer et al., 2003; Vanrolleghem et al., 2003). Accordingly (after primary sedimentation) for the wastewater is subject to biological treatment, treatability based wastewater characterization study was performed. A respirometric test was applied to detect the COD fractionation. In this respect the the biomass and pre-settled wastewater was mixed and the oxygen uptake rate test was applied. as shown in Figure 3.4 (b). The measurement frequency OUR was sample per minute.

Figure 3.4 : Labrotary Setups (a) Imhoff Cone (b) Applitek Ra-1000 Respirometer

Respirometric (oxygen uptake rate: OUR [mg/L/hour]) measurements were carried out by adding wastewater to activated sludge in aerobic conditions. The F/M ratio was set to 0,21 kgCOD/kgMLSS in order to reflect real conditions of WWTP. COD fractions, discrete respirometric (OUR) conducted experiments with the help of the instrument Applitek, Ra-Combo 1000 was measured. The resulting experimental data are shown in Figure 3.5. At t = 0 the OUR profile according to the activated sludge wastewater fed and OUR's profile was observed. Accordingly, from the beginning of the try after 60 minutes, which may be Volatile fatty acids (VFA) and Fermented COD, SF is completely consumed. Removal of slowly biodegradable COD remaining (XS) lasted is 600 minutes. In the following time, OUR level 8 mg/L/hour indicates the endogenous daecay phase without external carbon source. Therefore, a completely organic matter depletion 600 minutes (10 hours). (Table3.4)

The oxygen consumption rate of a discrete experiment (OUR) were analyzed with the simulation program (INSEL et al., 2003) Table 3.6', also called COD fractions. Biological phosphorus removal (EBPR) processes for Essential fatty acids (VFA) and fermented, which is of great importance in the COD (SF) fraction (Randall et al., 1992; Wentzel et al., 1992).

Tablo 3.3 : Conventional Wastewater Characterization with Sedimentation (İTÜ)

Parameter	Unit	Sample # 1 (14 March 2012)		Sample # 2 (16 April 2012)	
		Raw	After 2hs Settling	Raw	After 2hs Settling
Total COD	mg/L	1020	550	2245	1246
Soluble COD	mg/L	*	*	500	488
TSS	mg/L	*	190	260	180
VSS	mg/L	*	165	210	150
TP	mg/L	10,9	9,3	13,0	8,6
PO_4-P	mg/L	*	*	6,1	5,7

Compared with the data from the literature, which can be fermented COD rate in wastewater (residential/urban wastewater with 5-15%) in Gaziantep organized industrial district’s wastewater (GaOSB) is very high (29%). This will affect positively the efficiency of COD have a high fraction of EBPR. The anaerobic conditions of activated sludge, which can be fermented COD by volatile fatty acids (VFA). The process of with 1.0 mg phosphorus removal via EBPR requires approximately 8-10 mgCOD/L equivalent of easy biodegradable organic material (VFA) (Casey et al., 1996).

Tablo 3.4. COD Fractions in influent wastewater before biological treatment

	Unit	Value	Fraction (%)
Total COD, C_T	mgCOD/L	1246	-
Soluable COD, S_T	mgCOD/L	488	39
Degredable COD, C_S	mgCOD/L	873	70
Volatile Fatty Acid, VFA	mgCOD/L	25	2
Fermantable COD, S_F	mgCOD/L	363	29
Hydrolysable COD, X_S	mgCOD/L	484	39
Inert Soluable COD, S_I	mgCOD/L	100	8
Partical Inert COD, X_I	mgCOD/L	274	22
Total Phosforus, TP	mgP/L	8.62	-
Ortho Fosphate, PO_4	mgP/L	5.70	-

The oxygen consumption rate of a discrete experiment (OUR) were analyzed using biodegradation model (INSEL et al., 2003) Table 3.6 summarizes the influent COD fractions determined with the aid of respirometric analysis and COD mass balance. Biological phosphorus removal (EBPR) processes for volatile fatty acids (VFA) and fermented, is of great importance in the COD (SF) fraction (Randall et al., 1992; Wentzel et al., 1992). Compared with the data from the literature, which can be fermented COD rate in wastewater (residential/urban wastewater with 5-15%) in Gaziantep organized industrial district's wastewater (GaOID) is very high (29%). This affected positively the efficiency of COD have a high fraction for EBPR. The anaerobic conditions of activated sludge, which can be fermented COD by volatile fatty acids (VFA). The process of with 1.0 mg phosphorus from EBPR (extreme) in order for the biological in approximately 8-10 mgCOD/L equivalent to easy biodegradable organic material (VFA) there is a need to (Casey et al., 1996).

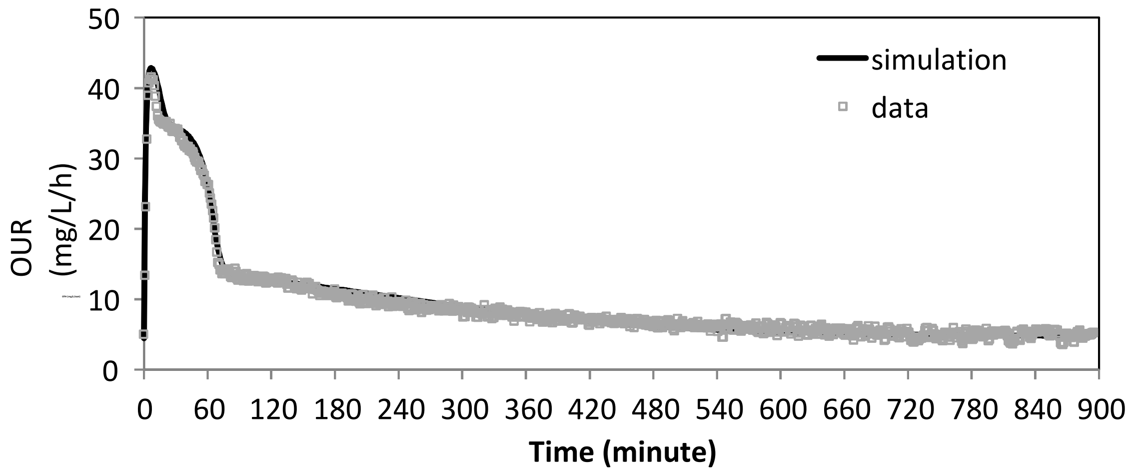

Figure 3.5 : Oxygen utilization rate (OUR) measurement

3.3.2 Analytical Methods:

The analytical parameters mesured are those that are required to describe the performance of biological nutrient removal and chemical characteristic of wastewater. Measurement of intracellular storage glycogen, poly-β-hydroxybutyrate and poly-β-hydroxyvalerate describe the methabolic storage processes occuring during biological phosphorus removal.

4. RESULTS AND DISCUSSION

4.1 Wastewater Treatment Performance

A statistical evaluation for influent and effluent wastewater characterizations were summerized with respect to the dates from 16.08.2011 to 11.01.2012 (Table 4.1). The details of the operational data can be found in Appendix 1. The treated wastewater should comply with discharge which takes place in Table 4.2 standards In brief, all the measured parameters match with discharge standard (SKKY 2004, Table 19). To comply with the satndards is needed and the main aim for that study The total phosphorus concentration can be calculated as 9,9±2,4 mg/L in influent, and also between 5,7±1,4 mg/L in effluent of the WWTP. For current situation, average yield of TP can be calculated as 42%. However, to match with standard without chemical additionthe TP should be around 80%.

Tablo 4.1 : Statistical evaluation of influent and effluent characterization of WWTP (16.08.2011-11.01.2012)

Parameter	Unit	Influent*		Effluent*	
		Mean Value, μ_x	Std. Deviation, σ_x	Mean Value, μ_x	Std. Deviation, σ_x
Average Daily Flowrate	m^3/day	38735	1211	-	-
COD	mg/L	1211	201	110	20
TSS	mg/L	784	365	34	22
TKN	mg/L	78	8,9	9,7	3,2
TP	mg/L	9,9	2,3	5,7	1,4

*Number of Data, N=30.

Tablo 4.2 : Discharge Standards for treated wastewater (Table 19; SKKY, 2004)

PARAMETER		Composite	Sample
	UNIT	2 Hours	24 Hours
Chemical Oxygen Demand (COD)	(mg/L)	400	300
Total Suspended Solid (TSS)	(mg/L)	200	100
Oil & Grease	(mg/L)	20	10
Total Phosphorus, TP	(mg/L)	2	1
Total Chromium	(mg/L)	2	1
Chromium (Cr^{+6})	(mg/L)	0,5	0,5
Lead (Pb)	(mg/L)	2	1
Total Cyanide (CN^-)	(mg/L)	1	0,5
Cadmium (Cd)	(mg/L)	0,1	-
Ferre (Fe)	(mg/L)	10	-
Floride (F^-)	(mg/L)	15	-
Cooper (Cu)	(mg/L)	3	-
Zinc (Zn)	(mg/L)	5	-
Mercury (Hg)	(mg/L)	-	0,05
Sülfat (SO_4)	(mg/L)	1500	1500
Total Kjeldahl Nitrogen	(mg/L)	20	15
pH	-	6-9	6-9

4.1.1 Calculation of Biological Phosphorus Removal Capacity

Statistical assessment for pollutant parameters in influent and effluent flow of GaOID's WWTP take part in Table 4.1. Total COD and total phosphorus amounts are calculated for the influent flow in raw wastewater respectively 1211±201 and 9,9±2,3 mg/L during the dates of 16.08.2011-11.01.2011. In addition, the eflluent COD and TP concentrations for effluent flow is measured respectively 110±20 and 5,7±1,4 mgP/L by the GaOIZ's WWTP. Average performance can be calculated for the parameters of COD and TP as 91% and 42%, respectively.

Stoichiometric calculations are given to the current situation about total phosphorus concentration for effluent flow. Mean value of COD and TP in above table are considered for the calculation. According to the above approach;

1. It is demonstrated that influent COD value has 70% degredable composition with the help of experiments with this scope of study (See Section 3). Consideration of mean wastewater characterization inlet of aeration tank, biologically degredable organic compound amount could calculate as 680 mgCOD/L.
2. Regarding to total phosphorus concentration of influent flow is TP=9,90 mgP/L, $TP_{biomass}$=4,28 mgP/L will be incorporated in biomass(activated sludge). With the help of mass balance equation effluent total phosphorus amount could calculate as, Effluent TP= $TP_{influent}$-$TP_{biomass}$= 9,90-4,28= 5,60 mgP/L.
3. The results correspond to measured concentration (5,7 mg/L) of mean value of effluent flow (Table 4.1).

To come up to discharge standards with current inlet conditions, there are three solution alternatives. Followings could be applied as; (1) for TP Parameter, lower sewer discharge pre-treatment standards application and control, (2) continuously chemical substance dosing, (3) application of excess biological phosphorus removal process.

Phosphorus values and analysis for instant effluent samples which is taken by GaOID's WWTP is shown in Table 4.3. Regarding to measured values, there is variation between both raw and filtered wastewater due to the phosphorus content of TSS. In addition, there is 3,81-3,42=0,39 mgP/L amount of phosphorus is found in effluent wastewater. Biological removal of phosphorus is not possible since it is in organic form. So even aplication of EBPR process, it is expected to attain minimum 0.39 mgP/L that correspond to organic phosphorus in treated wastewater.

Tablo 4.3 Wastewater treatment plant effluent phosphorus fractionation.

Parameter	Unit	Concentration	
		Raw	Filtered (0,45 µm)
TP	mg/L	4,51	3,81
PO_4-P	mg/L	3,65	3,42

4.2 SBR Performance

In this section, the performance of SBR system was discussed. During the fill/mixed phase of SBR system, the biomass releases the phosphorus under anaerobic conditions. Figure 4.1. illustrates the PO4-P profile in an SBR cycle considering the the phase durations. Regarding to the profile wastewater which has 8,5 mg/L concentration of total phosphorus, when feeding 1,0 L wastewater into the 3,0 L reactor volume of wastewater, the phosphorus is expected to reach 3,0-4,0 mgP/L (without EBPR). At the end of the anaerobic phase the phosphate reached up tp 10 mg/L.Thus, the remaining 7,0 mg/L P shows the released phosphate by biomass. In the following aerobic phase the phosphate was consumed and reached to 1.0 mgP/L. The phosphate uptake rate can be calculated as 0,7mgP/gVSS/hour.

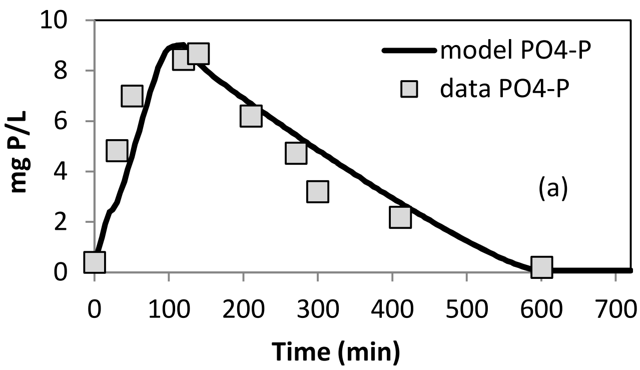

Figure 4.1: PO4-P measurements in SBR cycles

This indicates a good EBPR capability with the performance higher than 90%
Influent and effluent characterization of SBR system is shown in Table 4.4. COD and TP concentrations for influent flow is measured respectively 1246 mg/L and 8,6 mgP/L in SBR System. In this sequel, COD and TP concentrations for effluent flow is measured respectively 150 mg/L and 1,16 mgP/L in SBR System Average Total COD and total phosphorus yields may calculated respectively 89% and 87% in 25 April 2012.

Table 4.4 : Influent and effluent characterization of SBR system (25 April 2012)

Parameter	Unit	Influent	Effluenty	Efficiency(%)
Total COD	mg/L	1246	150	89
Solueble COD*	mg/L	488	120	75
Suspended Solid, TSS	mg/L	180	20	-
Total Phosphorus, TP	mg/L	8.6	1.16	87
Ortho Phosphate, PO_4-P	mg/L	5.7	0.85	-

Table.4.5 : Performance of SBR for EBPR (Presettled for 2hours) Influent Characterization of SBR System

SET	Duration Day	COD mg/L	COD $_{sol}$ mg/L	TSS mg/L	VSS mg/L	TP mgP/L	SP mgP/L	PO_4-P mgP/L
SET-1	25	1895	1195	415	385	10.1	8.1	5.7
SET-2	20	2050	1305	415	385	17.8	14.5	12.7
SET-3	29	2050	1305	415	385	20.6	17.2	15.7
SET-4	37	2050	1305	415	385	23.3	20.0	18.7
SET-5	25	1735	1320	435	390	28.8	27.7	23.7

The influent and effluent wastewater characterization for SBR system were shown in Table 4.5 summarizing the different influent conditions of the experimental SETs. The COD concentrations for influent wastewater were measured as 1895, 2050, 2050, 2050, 1735 mg/L. The TP concentrations in influent wastewater were measured as 10.1, 17.8, 20.6, 23.3, 28.8 mgP/L.

By analysing the process performance, the SBR secured relatively stable EBPR performance. In this respect, the COD concentrations in the effluent were measured as 220, 215, 240, 250, 195 mgCOD/L. In addition, the TP in the effluent was experimented to be 2.0, 2.5, 2.3, 2.0, 2.5 mgP/L.

The process performance of the SBR can be calculated as 90% in average. On the other hand, the effluent PO4-P concentrations were measured in the range of 0.8-1.9 mgP/L. The difference between TP and PO_4-P can be attributed to the contribution of TP from effluent TSS that escapes from the final clarification period of SBR.

Table.4.6 : Performance of SBR for EBPR (Presettled for 2hours) Effluent Characterization of SBR System

SET	Duration Day	TCOD mg/L	COD_{sol} mg/L	TSS mg/L	TP mgP/L	PO_4-P mgP/L
SET-1	25	220	170	35	2.0	0.8
SET-2	20	215	180	30	2.5	1.9
SET-3	29	240	185	40	2.3	1.5
SET-4	37	250	180	25	2.0	1.7
SET-5	25	195	150	30	2.5	1.8

The SBR operation showed that the phosphorus removal performance was increased from 41% up to 90% via metabolic activation of PAOs by including anaerobic mixing zone prior to aerobic activated sludge of save chemicals for removal of phosphate from an industrial wastewater.system. This also provides great advantage to decrease in chemical addition, in turn operational costs.

5. CONCLUSION

The conclusions derived from the study are summarized as follows:

- The COD based influent characterization is of great importance selecting the activated sludge configuration to achieve the discharge standards. Thus detailed influent wastewater characterization should be devoted for the selection of process configuration.
- First, biodegradation footprint envisaged the applicability of enhanced biological phosphorus removal process. The availability of readily biodegradable COD (VFA; fermentable COD) enabled the EBPR process in industrial wastewater originated from Organized Industrial District. The respirometric test enabled to determine the biodegradable COD fraction in the order of 70%.
- Without chemical addition, traditional activated sludge configuration achieved nearly 41% phosphate removal ratio. This removal ratio coresponds to the metabolic P requirement of ordinary heterotrophic biomass. This removal ratio was double-checked with the P-uptake due to biodegradable COD utilization.
- The lab scale SBR test conducted with real wastewater showed that the phosphate removal could be increased from 41% to 90% by incorporating anaerobic mixing period prior to aerobic conditions. In this respect, the EBPR could be achieved in the wastewater originated from mixed organized industrial district.
- As a future study, a model based evaluation should be applied to wastewater treatment plant for process optimization without the need of chemical addition.

REFERENCES

Alexander G.C. and Stevens R.J. (1976) Per capita phosphorus loading from domestic sewage. *Water Research vol.10*, pp**. 257-769.**

APHA, (2005) Standard Methods for the Examination of Water and Wastewater (21st ed.),

American Public Health Association Inc., Washington, DC, USA.

ATV-131E (2000) German ATV-DVWK Rules and Standards, Dimensioning of Single-Stage, Activated Sludge Plant, Hennef, Germany.

Alexander, W.V., Kolbe, F.F., Pybus, P.J., Louw, A. and Terblanche, J. (1994) Theoretical and case study comparison between side stream and main stream biological nutrient removal systems. In Nutrient removal from wastewaters , (ed. Horan, Lowe and Stentiford), *Technomic Publishing*,Lancaster-Basel, pp. **215-226**

Barnard, J.L. (1975) Biological nutrient removal without the addition of chemicals. *Wat. Res.***,** 9, pp. **485-490**

Boller M. (1987) Nutrient removal from wastewater. Documentation of 7th European Sewage and refuse Symposium, EWPCA Munich 1987,pp. **253-278**

Brett, S. (1997) Phosphorus removal and recovery technologies (CEEP), Selper Publications, London, Great Britain

Bungaard, E., Andersen, K.L. and Petersen, G. (1989) Bio-Denitro and Bio-Denipho system – experiences and advanced model development: the Danish system for biological N and P removal**.** *Wat. Sci. Tech.***,** 21(Brighton), **1727-1730**

Comeau Y., Lamarre D., Roberge M., Desjardins G., Hande C. and Mayer R. (1996) Biological nutrient removal from a phosphorus-rich pre-fermented industrial wastewater. Water Science and Technology, 34 (1-2), **169-177**

Christensson M. (1997) Enhanced biological phosphorus removal. Carbon sources, nitrate as electron acceptor, and characterization of the sludge community. PhD Thesis. Department of Biotechnology, Lund University, Sweden.

Çınar, Ö., Daigger, G.T. and Graef, S.P. (1998) Evaluation of IAWQ Activated Sludge Model No.2 using steady-state data from full scale wastewater treatment plants, Wat. Environ. Res., 70(6), **1316-1224**

De Jong, P. P-verwijdering op rwzi's (1999) . Symposium "Fosfaatverwijdering, 5 jaar ervaring - en hoe nuverder?!, NVA Programmagroep 3, Appeldoorn, The Netherlands**.**

Donkin M.J. and Russel J.M. (1997) Treatment of a milkpowder/butter wastewater using the AAO activated sludge configuration. *Water Science and Technology, 36 (10),* **79-86 89**

Gerards, R., Delplace, P. and Vriens, L. (1996) The UNITANK(R) technology for treatment of industrial and municipal wastewater. Proc. 1st IAWQ Spec. Conf. Sequencing Batch Reactor Technology, Munich, Germany, **61-68**

Giesen, A. (1998) Crystallization Process Enables Environmental Friendly Phosphate Removal at Low Costs. International conference on phosphorus recovery and recycling, Warwick University, UK

Goronszy, M.C. (1994) Coupled nitrogen and phosphorus removal in a cyclic activated sludge system. In Nutrient removal from wastewaters, (ed. Horan, Lowe and Stentiford), *Technomic Publishing*, Lancaster-Basel, **347-363**

Henze M., Dupont R., Grau P. and De La Sola A. (1993) Rising sludge in secondary settlers due to denitrification. Wat. Res. 27(2), **231-236**

Insel G., Sin G., Lee D.S., Nopens I., Vanrolleghem PA. (2006) A calibration methodology and model-based system analysis for nutrient removing SBRs under reduced aeration, *J. Chem. Tech. Biot. 81(4)*, **679-687.**

Insel G., Orhon D., Vanrolleghem P.A. (2003) Identification and modelling of aerobic hydrolysis mechanism-application of optimal experimental design, J. *Chem.Tech. Biotech.*, 78(4), **437-445.**

Irvine, R.L. (1996) Controled unsteady state processes and technologies - an overview. Proc. 1 st IAWQ Spec.Conf. Sequencing Batch Reactor Technology**, 1-6**

Janssen, P.M.J. van der Roest, H.F. and Eggers, E. (1996) The Carrousel and the Carrousel-2000 systems: A guarantee for total nutrient removal., *Eur. Wat. Poll. Control*., 6(2), **10-16**

Janssen, P.M.J and van der Roest, H.F. (1996) Winning combination. Water Quality International, Sept-Oct**., 1214**

Johansson P. (1994) SIPHOR a kinetic model for simulation of biological phosphate removal. Doctor theasis published in Department of Water and Environmental Engineering

Ketchum, L.H. (1996) Design and physical features of SBR reactors. Proc. 1st IAWQ Spec. Conf. Sequencing Batch Reactor Technology**, 7-14**

Kolarski R. and Nyhuis G. (1995) The use of sequencing batch reactor technology for the treatment of hish-strength dairy process waste. 50th Purdue Industrial Waste Conference Proceedings**, 485-494**

Kuba, T., van Loosdrecht, M.C.M., Brandse, F.A. and Heijnen, J.J. (1997a) Occurrence of dentirfiying phosphorus removing bacteria in modified UCT-type wastewater plants. Wat. Res., 31(4), **777-786**

Kuba T., Wachtmeister A., Loosdrecht M.C.M. van and Heijnen J.J. (1994) Effect of nitrate on phosphorus release in biological phosphorus removal systems. *Water Sci. Tech. vol 30, No 6, pp*. **263-269.**

Leonrd, A. M. (1996) Activated sludge treatment of diary processing wastewaters: The role of selectors for the control of sludge bulking. PhD Thesis, Institute of Technology and Engineering, Massey University, Palmerston North, New Zealand.

Levin G.V. (1966) Sewage treatment process US Patent 3236766

Levin G.V. and Shapiro J (1965) Metabolic uptake of phosphorus by wastewater organisms. *Journal of Water Pollution Control Federation, vol 37 pp* **800**

Mark C. Wentzel, Yves Comeau, George A. Ekama, Mark C.M. van Loosdrect and Brdjanovic (2008) Biological Wastewater Treatment Principles, Modelling and Design : Enhanced Biological Phosphorus Removal.

Meinhold, J., Arnold, E and Isaacs, S., (1999) Effect of Nitrite on anoxic phosphate uptake biological phosphorus removal activated sludge, waster research, 33(8), **1871-1883**

Melcer H., Dold P, Jones R.M, Bye C.M., Takacs I., Stensel H.D., Wilson A.W., Sun P., Bury P. (2003) Methods for wastewater characterization in activated sludge modeling, Water Environment Federation, Alexandria, VA, USA.

Metcalf and Eddy, Inc. (1991) Wastewater Engineering: Treatment, Disposal and Reuse. 4trd Edn., McGraw-Hill, New York

Metcalf and Eddy, Inc. (2003) Wastewater Engineering: Treatment and Reuse. 4th ed., McGraw-Hill, New York.

Mino T., Van Loosdrecht M.C.M and Heijnen J.J (1998) Microbiology and biochemistry of enchanced phosphate removal process. *Water Research***, 34 (11) 3193-3207**

Papagiannis T. G. (1996) Biological nutrient removal from diary process wastewater. Master of Science Thesis, University of Illinois at Urbana-Champaign, USA

Pitman, A.R., Venter, S.L.V. and Nicholls, H.A. (1983) Practical experience with biological phosphorus removal plants in Johannesburg. In Phosphate removal in biological treatment processes. (ed. Wiechers), Pergamon Press, **233-259**

Randall, C.W., Stansel, H.D. and Barnard, J.L. (1992) Design of activated sludge biological nutrient removal plants. In Design and retrofit of wastewater treatment plants for biological nutrient removal. (ed.Randall), *Technomic Publishing Co. Inc.*, **125-126**

Reddy, M. (1998) Biological and chemical systems for nutrient removal. WEF, special publication

Rensink, J.H., van der Ven, J., van Pamelen, G., Fedder, F. and Majoor, E. (1997) The modified Renphosystem: a high biological nutrient removal system. *Wat. Sci. Tech.,* 35(10), **137-146**

Rensink, J.H., Donker, H.J.G.W. and Anink, D.M.E. (1988) Vergaande P-en N-verwijdering uit huishoudelijk afvalwater met terugwinning van fosfaat. H2O, 21, **240-242 (In Dutch)**

Smolders, G.J.F., van Loosdrecht M.C.M and Heijnen, J.J., (1995) A metabolic model for biological phosphorus removal process, *Water Science and Technology,* **31(2), 79-93**

Sorm, R., Bortone, G., Saltarelli, R., Jenicek, P., Wanner, J. and Tilche, A. (1996) Phosphate uptake under anoxic conditions and fixed film nitrification in nutrient removal systems. *Wats. Res.., 30***, 2748-2760**

Sözen S., and Orhon D.(1999) The effect of nitrite correction on the evaluation of the rate of nitrate utilization under anoxic conditions. *Journal of Chemical Technology and Biotechnology, 74***, 790-800**

Su Kirliliği Kontrol Yönetmeliği (2004) TC Çevre ve Şehircilik Bakanlığı, Ankara

Tetreault M.J. Benedict A.H., Kaempfer C. and Barth E.F. (1986) Biological phosphorus removal: a technology evaluation. *Journal Water Poll. Contr. Fed. vol.58, No 8, pp***. 823-837.**

Wang, B., Li, Wang, J.L.-L., Nie, M. and Ji, L. (1998) Mechanism of phosphorus removal by SBR submerged biofilm systems. *Wat. Res., 32(9),* **2633-2638**

Wanner, J., Cech, J.S. and Kos, M. (1992) New process design for biological nutrient removal *Wat. Sci. Tech., 25(4/5)***, 445-448**

Van Huyssteen, J.A., Barnards, H.l. and Hendriksz, J.(1990) The Olifanstsfontein nutrient removal plant. *Wat. Sci. Tech., 22(7/8)***, 1-8**

Van Loosdrecht, M.C.M., Brandse, F.A., De Vries, A.C. (1998) Upgrading of wastewater treatment procesess for integrated nutrient removal - the BCFS process. *Wat. Sci. Tech., 37(9),* **137-146**

Van Loosdrecht, M.C.M., Brandse, F.A., De Vries, A.C. (1997c) Environmental impacts of nutrient removal processes: case study**.** *J. Environ. Eng., 123***, 33-40**

Van Veldhuizen, H.M., van Loosdrecht, M.C.M. and Heijnen, J.J. (1999) Modelling biological phosphorus and nitrogen removal in a full scale activated sludge process. *Wat. Res., 33(16)***, 3459-3468**

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