DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PERFORMANCE ANALYSES IN BIO-P PROCESS

by

Birkan AKYOL

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İZMİR

PERFORMANCE ANALYSES IN BIO-P PROCESS

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M. Sc THESIS EXAMINATION RESULT FORM

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PERFORMANCE ANALYSES IN BIO-P PROCESS

ABSTRACT

Removal of nutrients from wastewaters is becoming a substantial environmental concern in order to protect water bodies from eutrophication. So, nutrient limits are taking place in regulations and for this purposes many of the wastewater treatments plants are being constructed.

Biological phosphorus removal process is preferred because of its low investment and operational costs. However, this process is very complex and affected by many factors. Treatment plant operators and designers do not have adequate information about biological phosphorus removal process. In this study, a performance analyses was conducted in a sewage treatment plant under operation by investigating BPR mechanisms and effects of environmental factors. First, treatment plant performance is determined under current operation. It was found that P and N removal efficiencies were in the range of 40-50 percent. COD/TP, BOD5/TP and rbCOD values were determined and compared with literature values. It is found that performance of treatment plant did not increase by the increasing of these values. This indicates that PAOs are not present or dominant in activated sludge. To promote this assertion, phosphorus was measured in influent and effluent of anaerobic reactor and it was observed that phosphorus was not released. In following studies, it was investigated whether anaerobic-aerobic conditions were present for growth of PAOs. Mass balance equation was established around anaerobic reactor to determine the adverse effect of recycle NO3-N and dissolved oxygen concentrations on system performance. ORP, dissolved oxygen and pH were measured in oxidation ditch and anaerobic reactor. SRT that is another parameter affecting system performance is also investigated.

It was concluded that anaerobic rector had been acting as anoxic because of high recycle NO3-N and dissolved oxygen concentrations. So, required environmental conditions for PAOs were not provided and excess sludge was not wasted in daily basis. This situation caused that phosphorus discharge limit was not met in BWTP.

Keywords: Biological nutrient removal, bio-P process, oxidation ditch, performance analyses

BIO-P SÜRECİNDE PERFORMANS ANALİZİ

ÖZ

Nutrientlerin atıksulardan uzaklaştırılması su kütlelerinin ötrofikasyondan korunması amacıyla önemli bir çevresel mesele haline gelmektedir. Böylece nutrient limitleri yönetmeliklerde yer almakta ve bu amaçla birçok atıksu arıtma tesisi inşa edilmektedir.

Biyolojik fosfor giderimi düşük yatırım ve işletme maliyetleri yüzünden tercih edilmektedir. Bununla beraber bu süreç çok karmaşık olup birçok faktör tarafından etkilenmektedir. Arıtma tesisi işletmecileri ve tasarımcıları biyolojik fosfor giderimi ile ilgili yeterli bilgiye sahip değildirler. Bu çalışmada işletmede olan bir atıksu arıtma tesisinde biyolojik fosfor giderim mekanizmaları ve etkileyen faktörler incelenerek performans analiz çalışması yürütülmüştür. İlk olarak mevcut şartlar altında arıtma tesisi verimi belirlendi. N ve P giderim verimlerinin yüzde 40 ile 50 arasında olduğu gözlendi. KOİ/TP, BOi5/TP ve rbKOİ değerleri belirlenip literatür değerleri ile karşılaştırıldı. Bu değerlerin artmasıyla arıtma tesisi performansının artmadığı gözlendi. Bu durum fosfor depolayan organizmaların aktif çamur içinde mevcut veya baskın olmadığına işaret etmektedir. Bu savı güçlendirmek amacı ile anaerobik reaktör giriş ve çıkışında fosfor ölçümü yapıldı ve fosforun salınmadığı gözlendi. Takip eden çalışmalarda fosfor depolayan organizmaların çoğalması için gerekli olan anaerobik-aerobik şartların mevcut olup olmadığı incelendi. Geri devir NO3-N ve çözünmüş oksijen konsantrasyonlarının sistem performansı üzerindeki etkisini belirmek için anaerobik reaktör etrafında kütle denkliği kuruldu. Oksidasyon hendeğinde ve anaerobik reaktörde redoks potansiyeli, çözünmüş oksijen ve pH ölçümü yapıldı. Süreç performansını etkileyen bir diğer parametre olan KAS da incelendi.

Geri devirle anaerobik reaktöre gelen yüksek NO3-N ve çözünmüş oksijen konsantrasyonları nedeniyle anaerobik reaktörün anoksik olarak davrandığı gözlendi. Böylece fosfor depolayan organizmalar için gerekli şartlar sağlanmamakta olup, bunun yanında fazla çamur da günlük olarak sistemden atılmamaktadır. Bu durum BAAT’ de fosfor deşarj limitinin sağlanamamasına neden olmaktadır.

Anahtar Kelimeler: Biyolojik nutrient giderimi, bio-P süreci, oksidasyon hendeği, performans analizi

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Water is necessary and indispensible substance for all creatures' life throughout history. It is very important to maintain the life. However, water resources are exposed to contamination by various factors. Nowadays, water pollution is a major problem in the global context.

The effects of water pollution are not only devastating to people but also to animals, fish, and birds. Polluted water is unsuitable for drinking, recreation, agriculture, and industry. It diminishes the aesthetic quality of lakes and rivers. More seriously, contaminated water destroys aquatic life and reduces its reproductive ability. Eventually, it is a hazard to human health. Nobody can escape the effects of water pollution (Water pollution, n.d.). If measures are not taken, it will be impossible to turn around.

To prevent water pollution, the greatest precautions to be taken is discharge the wastewater to receiving water bodies after treatment. Also, the characteristics of the receiving waters and discharge standards must be taken into account.

Historically, treatment requirements were determined by the need to protect the oxygen resources of the receiving water, and this was accomplished primarily through the removal of putrescible solids and dissolved organics from the wastewater before discharge. In more recent years, considerable emphasis has been placed on also reducing the quantities of nutrients discharged, i.e., nitrogen and phosphorus, because they stimulate growth of algae and other photosynthetic aquatic life, which lead to accelerated eutrophication, excessive loss of oxygen resources and undesirable changes in aquatic populations (Randall, Barnard & Stensel, 1992).

The potential impact of discharged nutrients on the oxygen resources of receiving waters can best be illustrated by looking at the amounts of organic matter that can be generated by the nutrients compared to the amount of organic matter in untreated sewage. The COD of raw sewage in United States is typically about 400 mg/L, whereas the phosphorus content is 6 to 10 mg/L, depending on whether or not a phosphate detergent ban is in place, and the nitrogen content is 30 to 40 mg/L. If one kilogram of phosphorus was completely assimilated and used by algae and used to manufacture new biomass from photosynthesis and inorganic elements, biomass of 111 kilograms with a COD of 138 kilograms would be produced. Thus the discharge of 6 mg/L phosphorus could potentially result in COD production equivalent to 828 mg/L, or more than double COD of the organic matter in the untreated sewage (Randall et al., 1992).

Controlling phosphorus discharged from municipal and industrial wastewater treatment plants is a key factor in preventing eutrophication of surface waters. Phosphorous is one of the major nutrients contributing in the increased eutrophication of lakes and natural waters. Its presence causes many water quality problems including increased purification costs, decreased recreational and conservation value of an impoundments, loss of livestock and the possible lethal effect of algal toxins on drinking water (Phosphorus removal from wastevater, n.d.).

Both nitrogen and phosphorus are the limiting nutrients controlling the eutrophication. However, according to the receiving water environment, removal of the one may be more important than the other. Phosphorus is the limiting nutrient in freshwater environments, whereas nitrogen is limiting in estuarine and marina waters.

Ecosystems receiving more nitrogen than the plants require are called nitrogen-saturated. Saturated terrestrial ecosystems contribute both inorganic and organic nitrogen to freshwater, coastal, and marine eutrophication, where nitrogen is also typically a limiting nutrient. However, because phosphorus is generally much less soluble than nitrogen, it is leached from the soil at a much slower rate than nitrogen.

Consequently, phosphorus is much more important as a limiting nutrient in aquatic systems (Eutrophication, n.d.).

In practice, growth prevention thus only needs a lowering of phosphate availability. Experiments with large water reservoirs have shown that no eutrophication occurs when the phosphorus concentration is reduced to 8-10 μg P/l, even when the nitrogen concentration amounts to 4-5 mg N/l (Baetens, 2000).

Because of the reasons mentioned above, phosphorus removal from wastewaters is very important with regard to prevention of water pollution. Today water resources are contaminated very fast by human activities and carbon removal from wastewaters is not adequate alone.

Phosphorus removal is achieved by two means. One of them is chemical precipitation and the other one is biological phosphorus removal. Chemical treatment is based on the addition of metal salts to wastewater and this method has been used commonly for a long time. Biological phosphorus removal is dependent on the growth of specialized phosphate accumulating organisms (PAOs), which store phosphorus as polyphosphate (poly-P).

In recent years, biological phosphorus removal systems have been more commonly used than chemical phosphorus removal. From a recovery point of view, biological phosphorus removal is much more promising. Phosphorus is concentrated in such a way in the activated sludge that is recovery is relatively easy. However, biological phosphorus removal is one of the most complex processes involved in the activated sludge process. But this complexity has not been an obstacle to its application in practice, even when this process was just starting to be used and there was little knowledge on the exact bases of bio-P. Today, the bio-P process is a reliable and well understood process for wastewater treatment (Janssen, Meinema & van der Roest, 2002).

Biological phosphorus removal has more advantages compared to the chemical treatment of phosphorus. This has a positive effect on preferring and using biological phosphorus removal.

Problems associated with chemical precipitation include high operating costs, increased sludge production, sludge with poor settling and dewatering characteristics, and depressed pH. Biological phosphorus removal (BPR) systems can offer the benefits of reduced sludge production, improved sludge settleability and dewatering characteristics, reduced oxygen requirements, and reduced process alkalinity requirements. However, pilot-testing and traditional methods for kinetic parameter determination are complex and time consuming, which can make the evaluation of BPR processes too costly for smaller treatment facilities (Park, Wang &Novotny, 1997**).**

Phosphate removal is currently achieved largely by chemical precipitation, which is expensive and causes an increase of sludge volume by up to 40% (Phosphorus removal from wastevater, n.d.).

Biological phosphorus removal depends on special organisms referred to PAOs. Mixed liquor recycled through anaerobic and aerobic environment to growth and active PAOs. The phosphorus is released in anaerobic zone and up taken in aerobic zone; and thrown out by excess sludge. This process is too complicated in design and operation that there are too many factors affecting the process. However designers and operators do not have detail information about the process.

The objective of this study is to review the biological phosphorus removal process to clarify affecting factors both in design and operation and to demonstrate it in a real system; and finally to propose certain recommendations about the process.

In order to assess the performance of plant having BPR process, the following procedure is recommended to be come out.

1. First wastewater characteristics are considered. To this end, influent COD, BOD_5, rbCOD, TP concentrations are measured and COD/TP, BOD_5/TP, rbCOD/ TP ratios are determined.

2. Anaerobic reactor is considered. Anaerobic contact time is determined. ORP, dissolved oxygen and NO_3-N is measured in anaerobic tank. Recycle NO_3-N and dissolved oxygen concentrations are measured to determine the effect on available rbCOD for PAOs.

3. Aerobic zone is considered. Oxygen levels and ORP in aerobic reactor is measured. System is investigated whether it is operated under nitrification. Reactor shapes, requirement of denitrification in terms of system are also investigated.
4. SRT is determined and compared with system performance.

Steps presented above are required to evaluate system performance. If they are applied to sewage treatment plant, impacts of the factors on system performance and the system behavior against them can be understood clearly.

CHAPTER TWO

LITERATURE REVIEW

2. 1 Introduction

History of sanitation dates back at least 7000 years. Sanitary appeared to prevent disease and infection. First studies on sanitary belongs to Babylonians, Egyptians, Greeks, and Romans. Especially in ancient Roma, it is known that the many of sanitary systems were constructed thousands years of earlier.

The first sanitation system has been found at the prehistoric Middle East, in south-east of Iran near Zabol in Burnt City (Shahre soukhteh) areas. The earliest covered sewers uncovered by archaeologists are in the regularly planned cities of the Indus Valley Civilization. The first sewers of ancient Rome were built between 800 and 735 B.C. In ancient Rome, the Cloaca Maxima, considered a marvel of engineering, disgorged into the Tiber. In ancient China, sewers existed in various cities such as Linzi. In medieval European cities, small natural waterways used for carrying off wastewater were eventually covered over and functioned as sewers. London River Fleet is such a system (http://en.wikipedia.org/wiki/Sanitary_sewer).

In 16.century many cities had no sewers and sewage run down the streets. This was the source of many of diseases. By the industrial development in 19.century, many sewers were built in Europe and America in order to help control outbreaks of disease such as typhoid and cholera. In 1885, the first urban sewer system was planned in Chicago in United States. The first comprehensive sewer system was built in Hamburg, Germany in the mid-19th century.

All human excreta were excluded from sewers of London until 1815, from those of Boston until 1833 and from those of Paris until 1880 (Punmia & Jain, 1998).

As mentioned above, the first application to prevent diseases and protect human health is collection of sewage and building sewer systems. Initially these systems discharged sewage directly to surface waters without treatment.

The mixture of urban runoff and wastewater was brought by sewer to the nearest watercourse, and dilution of the pollution substances through the flow of the receiving water body was considered satisfactory for controlling pollution. It is interesting to note that until the 1950s, many European receiving water standards were based on dilution (For example, according to the British water quality standards, no treatment was required if 1 part of untreated sewage discharged was diluted by 500 parts of receiving water flow). As a result of building sewers without treatment, many rivers soon became heavily overloaded and gave off an obnoxious stench, which was caused by anoxic decomposition of sewage and garbage in stream water and muds (Novotny, 2003).

Wastewater farming was practiced in Germany in 1550 and in England in 1700.In England, chemical precipitation of wastewater was tried in 1762. The developments in the sewerage works was the result of awakening of the people by a succession of cholera epidemics. Early studies in sewage treatment were made in the United States through the establishment of Lawrance Experimental Station in 1887 by the Massachusets State Board of Health **(**Punmia &.Jain, 1998).

In 19. Century, a number of methods have been used for wastewater treatment. Septic tanks, bar racks, intermittent sand filtration were developed .In addition, chemical precipitation was applied.

In the early 1900s, grit chambers were developed and studies were conducted on disinfection. In 1908 first trickling filter was installed in United States.At lawrance Experiment Station, aeration of wastewater in tanks containing slate was carried out. In 1914 experiments were conducted by Ardern and Lockett that led to development of the activated sludge process that is used widely today. The first activated sludge process application was encountered in a municipal plant for treating sewage at San. Marces, Tex., in 1916. In 1925 contact aerators were developed in United States.

2.2 Biological Nutrient Removal

Phosphorus and nitrogen are referred to nutrients. Nutrients discharges to receiving water bodies can have a significant impact on water quality. Both of them are the reason of eutrophication. There are several reasons for using biological nutrient removal processes. These are environmental, economical and operational benefits. Environmental benefits are the most important as the eutrophication can be prevented by the nutrient removal from wastewaters.

Historically, treatment requirements were determined by the need to protect oxygen resources of the receiving water. This occurs by the removal of organic compounds from wastewater. In the first half of 19th century there were no researches on nutrient removal.

Dating back to the early 1900s, the primary purpose of biological wastewater treatment has been to (1) remove organic constituents and compounds to prevent excessive dissolved oxygen depletion in receiving waters from municipal and industrial point discharges, (2) remove colloidal and suspended solids to avoid accumulation of solids and creation of nuisance conditions in receiving waters and (3) reduce the concentration of pathogenic organisms released to receiving waters (Metcalf & Eddy, 2003).

In more recent years, nitrogen and phosphorus removal processes are used, because they stimulate growth of algae and other photosynthetic aquatic life, which lead to accelerated eutrophication, excessive loss of oxygen resources, and undesirable changes in aquatic populations. Many of countries put nutrient discharge limitations to their regulations.

Shortly, both nitrogen and phosphorus discharges are very important with regard to water quality in receiving water bodies. In this thesis only phosphorus removal performance and factors affecting the performance will be evaluated by conducting a case study.

2.3 Phosphorus Sources

Discharge of wastewater and fertilization of soil are the main reason of phosphorus load to surface waters. Municipal wastewater may contain 4-16 mg/L of phosphorus as P. In municipal wastewater, %50-70 of the phosphorus results from human excreta, %30-50 of the phosphorus from detergents and % 2-20 of the phosphorus from the industrial products, such as toothpastes, fertilizers, and pharmaceuticals. Phosphorus excreted by humans has been estimated at 0.5-2.7 g P/capita/day, with an annual mean of 1.6 g P/capita/day. According to the authors, domestic discharge of phosphates into sewage will fall below 2g/capita/day in developed countries. Contribution of soap and detergents industry is about 0.3 g P/capita/day.

Phosphorus is found in wastewater as phosphates. These can be categorized by physical (dissolved and particulate fractions) and chemical (orthophosphate, condensed phosphate, and organic phosphate fractions) characteristics. Orthophosphates applied to agricultural or residential cultivated land as fertilizers are carried into surface waters with storm runoff. Small amounts of certain condensed phosphates (pyro-, meta-, and other polyphosphates) are added to some water supplies during treatment. Organic phosphates are contributed to sewage by body wastes and food residues (http://www.dnr.state.wi.us/org/ water/wm/ww/ biophos/3 fract.htm).

Wastewater may contain phosphorus forms at different concentrations. “The approximate concentrations of various phosphorus forms in wastewater have been estimated as orthophosphate (5 mg P/), tripolyphosphate (3 mg P/), pyrophosphate (1 mg P/) and organic phosphates (1 mg P/)” (Baetens, 2000). In addition, typical concentrations for various forms of phosphorus in raw wastewater in the United States are shown in table 2.1.

Table 2.1. Chemical Form of Phosphate in U.S. Sewage (Sedlak, 1991).

Phosphate form	**Typical concentration (mg-P/L)**
Orthophosphate	3 - 4
Condensed phosphates	2 - 3
Organic phosphates	1

2.4 History of Biological Phosphorus Removal

In the end of 19th century, because of the difficulties with biological treatment plant designed only organic matter removal, great effort was exerted on treatment technologies based on chemical and physical methods. In this process, chemical precipitation was applied by adding lime, alum and iron salts. Phosphorus is precipitated with these chemicals unintentionally as well as assumed organic matter removal expressed as BOD.

Biological phosphorus removal processes are the most complex processes in the activated sludge processes and for years many of studies were conducted. The earliest investigations on BPR were made by Sawyer (1944), Rudolfs (1947) and in 1955 by Greenburg. Till 1950s control of phosphorus level in lakes and streams was not considered an important pollution control problem. During World War II some experiments on chemical precipitation of phosphorus was carried out but with these studies it is aimed to obtain fertilizer for agriculture. However, the first indication of biological phosphorus removal in a wastewater treatment process was described by Srinath (1959) from India. It is observed that sludge from this treatment plant exhibited excessive (more than needed for cell growth) phosphate uptake when aerated. It was shown that the phosphate uptake was a biological process (inhibition by toxic substances, oxygen requirement), and could be prevented when the initial stage of the plug flow process was properly aerated. Later, in more (plug flow) wastewater treatment plants this so-called enhanced phosphate removal was noticed.

Levin and Shapiro were carried out the first research on biological phosphorus removal process behavior. They observed that activated sludge release phosphorus under anaerobic conditions and take it up under aerobic conditions. It is also concluded that phosphorus is stored in bacteria cell in the form of black granules. They stated that phosphorus uptake exceeded needs for the photosynthesis. They proved that approx. 80% of phosphorus uptake from wastewater under aerobic conditions - they named the observed high phosphorus removal a “luxury uptake”. They also observed in further investigations that uptake and release of phosphorus are reversible processes. These authors however did not explain entire mechanism of the process. Shapiro later proposed to expose return sludge to such conditions prior to return to the aeration basin to strip out phosphorus. That was a predeceasing of the phostrip process (Rybicki, 1998).

At the end of 1960s and early years of 1970s, many of researchers made attempts to find an explanation for the various observations of increased phosphate uptake. Without any microbiological and biochemical base, process boundaries for phosphorus uptake were formulated. At this time it could not be confirmed by experiments that increased phosphorus uptake is based on the chemical reactions.

In the late of 1970s, it is presented that Acinetobacter genus was able to store carbon compounds next to polyphosphate in the form of polyhydroxybutyrate (PHB) during aerated periods.

Fush and Chain found that an anaerobic phase was necessary to produce fatty acids which in turn served as substrate for Acinetobacter in aerated period. The hypothesis at that time said that Acinetobacter needed low fatty acids for growth and uptake of phosphate in the aerated period. The link between anaerobic conditions and bio-P was, however, not made.It is also remarkable that isolated pure cultures did not show any phosphate release in anaerobic phase, while all earlier observations dephosphating activated sludge show this release (Janssen et al.,2002).

The basis for modern multiphase biological rectors for integrated phosphorus and carbon compounds removal were observations made by Barnard (Barnard 1973, 1982,1983) who modified Wuhrmann,s reactor (MoP 1992) constructed in 1950s. Barnard equipped this reactor (known later as the “Bardenpho” reactor) with the inner recirculation system. It means that mixed liquor is directed from final zone of aerobic chamber to anaerobic chamber at the same time the reactor was equipped with another chamber - anaerobic to perform phosphorus release under anaerobic conditions . All further improvements are based on principles described by Bernard (Rybicki, 1998).

UCT, JHB, Bardenpho and Phoredox are some of them. These processes will be mentioned in the following parts.

At the start of 1980s, Rensink stated that PAOs incorporated substrates in their cells in the form of PHB during anaerobic period. The energy needed for this is assured from the hydrolyses of polyphosphate and phosphate is released to wastewater. The relationship between P uptake and P release was in that way established. Two functions were thus attributed to anaerobic phase; production of volatile fatty acids for PAOs and provision of an advantage to PAOs over other heterotphic bacteria which are unable to release phosphate in the anaerobic phase and to incorporate substrate in the form of storage compound.

Several researchers introduced a biochemical model of biological phosphorus removal processes by depending on Rensink’s basic hypothesis. Cameau/Wentzel and Mino are the main models introduced. The major difference between them is that the Mino model incorporates glycogen formation and utilization, whereas Comeau/Wentzel model does not. In the following parts, they will be referred briefly because mechanisms of biological phosphorus removal process must be grasped well to conduct the performance analyses. “An understanding of the steps involved in the biological phosphorus removal mechanism provides a useful insight into the factors that can affect the performance of biological phosphorus removal systems” (EPA, 1987).

In the 1970s and 1980s it is stated that the presence of nitrate in anaerobic zone has an adverse effect on biological phosphorus removal. In this case substrate available for PAOs is utilized for denitrification and the performance of the system decreases. In the 1990s it is founded that nitrate has also positive effect. With an appropriate process configuration and the operation (performance) of the bio-P process, a comparable capacity of phosphate uptake is noted under both anoxic and aerobic conditions. In such conditions active denitrifying utilize the (limited) COD present more efficiently than the aerobic PAOs. The preliminary conditions for limiting the amount of recycling nitrate to the anaerobic phase remains.

2.5 Principles of Biological Phosphorus Removal

Biological phosphorus removal process is one of the most complex process within activated sludge. This situation arises from that the other microbiological processes have effect on biological phosphorus removal. Biological phosphorus removal depends on that some types of bacteria are able to store large amounts of orthophosphate in their cells in the form of insoluble polyphosphate. This means that biological phosphorus removal capacity is concerned with fraction of PAOs in activated sludge process or with the ability to increase this fraction of PAO in sludge. For biological phosphorus removal to occur in wastewater treatment plants, biomass first needs to pass through an oxygen and nitrate free phase, i.e. an anaerobic phase, before entering a phase where an electron acceptor is present, i.e. an anoxic phase where nitrate is present or an aerobic phase where oxygen is present. The oxygen and nitrate free phase can be achieved in a separate reactor, the first section of a plug flow reactor or part of a sequencing batch reactor cycle. Concentration profile of BPR under anaerobic-aerobic conditions is presented in figure below.

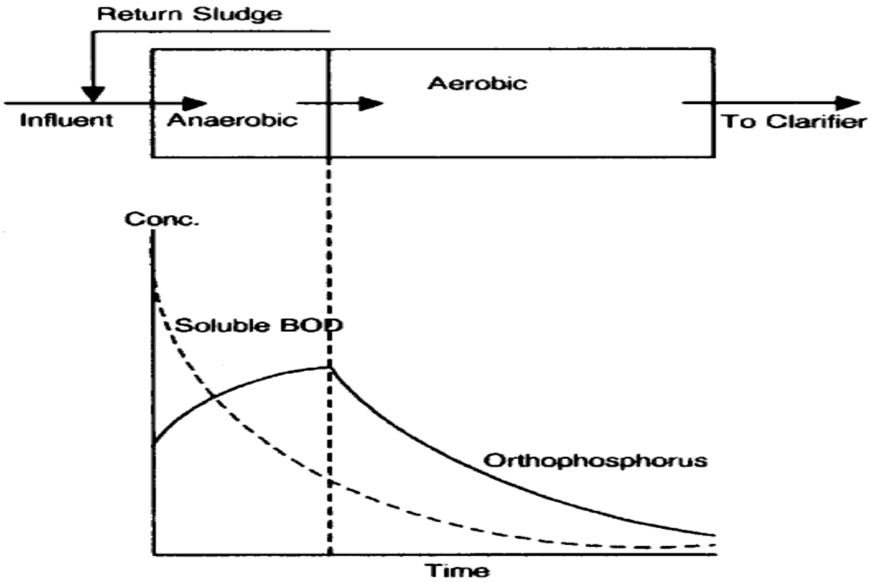


Figure 2.1 Biological phosphorus and BOD removal due to anaerobic-aerobic contacting (EPA, 1987).

Phosphorus removal in biological systems is based on the following observations.

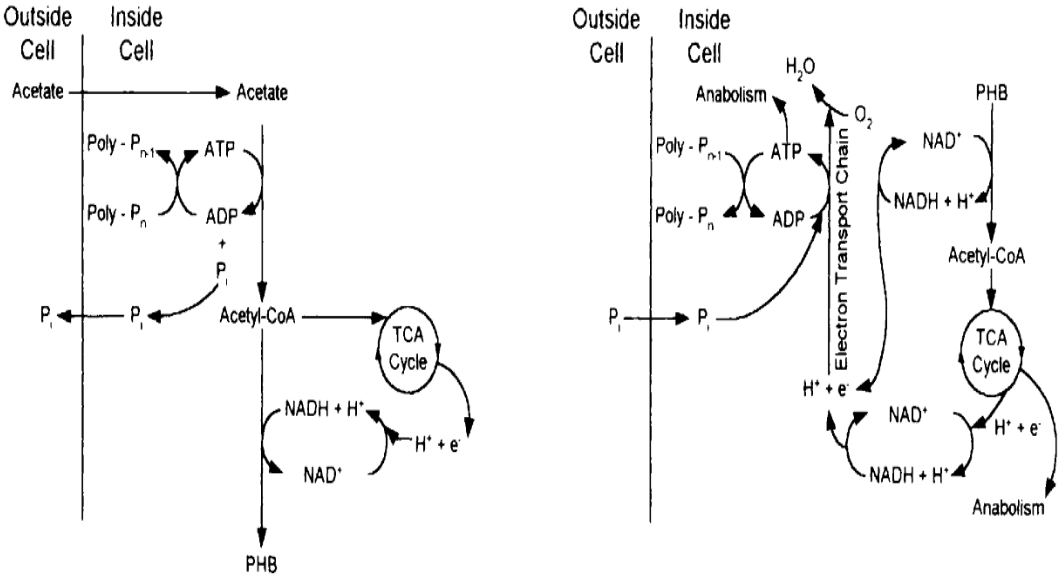
- Numerous bacteria are capable of storing excess amount of polyphosphates in their cells
- Under anaerobic conditions PAOs will assimilate fermentation products e.g., volatile fatty acids into storage products within the cells with the concomitant release of phosphorus from stored polyphosphate.
- Under aerobic conditions energy is produced by the oxidation of storage products and polyphosphate storage within the cell increases (Metcalf & Eddy, 2003).

Two scenarios are submitted to describe the functioning of PAOs. One of them is Comeau-Wentzel model and the other one is Mino model. The difference between the two models is the result of the metabolic diversity among PAOs, and since it is not yet known which model is the more generally applicable, both will be presented.

2.5.1 Comeau- Wentzel Model:

Comeau- Wentzel was the first to describe a mechanistic model attempting to explain these EBPR chemical transformations. The model is thus referred to as Comeau- Wentzel model. Essentially this model suggests under anaerobic feed conditions, stored PolyP is degraded to produce ATP which is thought to provide the energy required to synthesis the energized form of acetate acetyl-coA(AcCoA) and re-establish proton motive force(PMF) consumed by substrate transport. ATP degradation leads to P release. Some of the AcCoA undergoes oxidation via the tricarboxylic acid(TCA) cycle which generates NADH. This provides the reducing power for converting AcCoA to PHB. Under subsequent aerobic famine conditions, the intracellularly stored PHB is oxidized via the TCA cycle which generates PMF used for ATP production which provides PAO cells use for growth and replenishment of intracellular polyP stores (Seviour&Nielsen, 2010).

- Comeau-Wentzel (1986)
- 9n acetate + 9nATP (C4H6O2)4n + 2nCO2 + 9nADP + 9nPi (H2PO4-)



A. Anaerobic

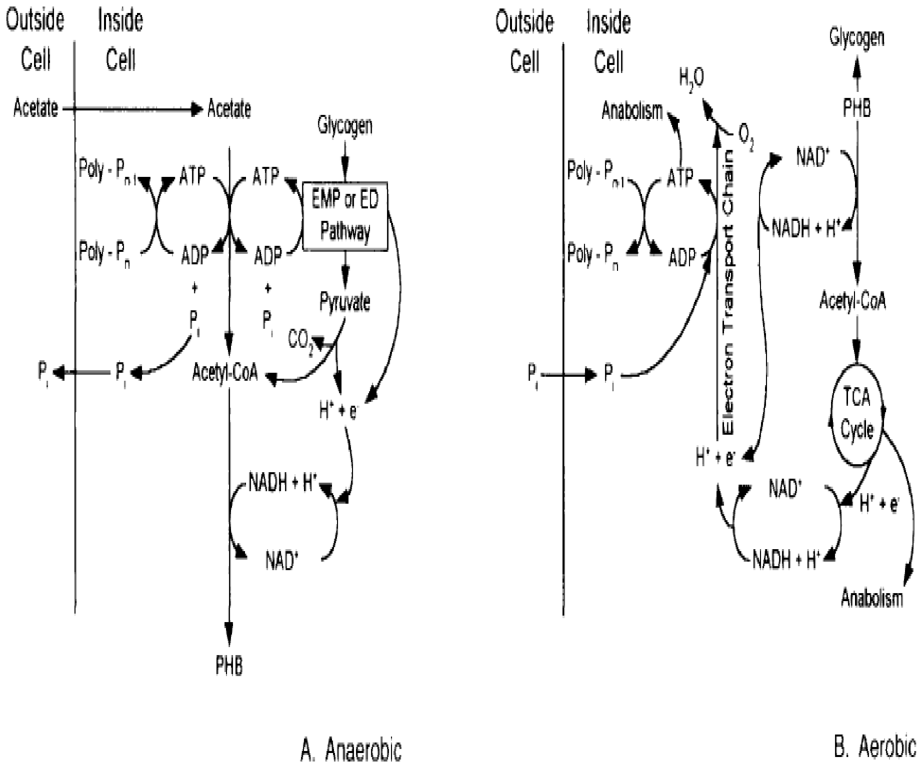
B. Aerobic

Figure 2.2 Schematic diagrams depicting the Comeau- Wentzel model for the uptake and release of inorganic phosphate by PAOs (Grady et al., 1999).

2.5.2 Mino Model

The Mino model, illustrated in Figure 2.6, is very similar to the Comeau-Wentzel model, the major difference being the role of glycogen, a carbohydrate storage polymer. In this case, in the anaerobic zone the reducing power required for synthesis of PHB from acetyl-CoA comes from the metabolism of glucose released from the glycogen. Glucose is oxidized to pyruvate through the Entner-Doudoroff (ED) or Embden-Meyerhof-Parnas (EMP) pathway. Depending in the type of PAO, thereby providing some of the ATP required to convert acetate to acetyl-CoA and some of the reducing power needed for PHB synthesis. Pyruvate, in turn, is oxidatively decarboxylated to acetyl-CoA and carbon dioxide with the electrons released also being used in the synthesis of PHB. Thus, all of the acetate taken up is stored as PHB, as is part of the carbon from the glycogen. In the aerobic zone, PHB is broken down as in the Comeau-Wentzel model to provide for biomass synthesis as well as for phosphate uptake and storage as polyphosphate. In addition, however, PHB is also used to replenish the stored glycogen (Grady, Daigger& Lim,1999).

- Mino (1987)
- The net reaction of convertion of acetate to PHB by glycogen consumption:
- $(C_6H_{10}O_5)_n$ + 6n acetate + 3nATP $(C_4H_6O_2)$ 4n + 3nADP + 3nPi $(H_2PO_4^-)$+ 2nCO_2



A. Anaerobic

B. Aerobic

Figure 2.3 Schematic diagrams depicting the Mino model for the uptake and release of inorganic phosphate by PAOs (Grady et al., 1999).

Up to now, many studies have been done relevant to biological phosphorus removal mechanisms. Funs and Chen examined activated sludge from the Baltimore Back River and the Seneca Falls, New York treatment plants when the plants were exibiting high levels of phosphorus removal. They concluded that the organism asssociated with phosphorus removal belonged to the Acinetobacter genus. They also found that a significant phosphorus release rate could be promoted by the addition of carbon dioxide during the anaerobic phase, which also lowered the pH. This was also observed by Deinema (EPA,1987).

Other investigators also observed Acinetobacter in biological excess phosphorus removal systems. Brodich noted that the removal of phosphorus in a system containing Acinetobacter became significant only after the development of an Aeromonas population. Lotter and Murphy noted an increase of Pseudomonas and Aeromonas in biological phosphorus removal systems. Osborn and Nicholls reported rapid biological phosphorus uptake during nitrate reduction in the absence of DO,indicating that phosphorus uptake may be occurring with denitrifying bacteria. Hascoet also reported phosphorus release in anoxic zones by Acinetobacfer provided that there was a relatively high level of substrate availability.Various investigators have observed a decrease in soluble substrate and an increase in orthophosphate concentrations in the anaerobic zone of anaerobicaerobic sequenced biological phosphorus removal systems. Hong showed a soluble BOD5 (SBOD) concentration decrease from 45 to 15 mgA and an orthophosphorus concentration increase from 6 to 24 mg/l in the anaerobic zone (EPA,1987).

Fukase, using fill-and-draw reactors, observed an acetate utilization to phosphorusrelease molar ratio of 1.0. Arvin reported 0.7, Rabinowitz 0.6, and Wentzel 1.0 from batch studies using sludge from excess biological phosphorus removal systems. Rabinowitz also found that the phosphorus release magnitude and rate were affected by the type of substrate (EPA,1987).

PHB has been found in biologically-removed phosphorus sludges by Timmerman and in Acinetobacter by Nicholls and Osborn. Deinema (42) also observed PHB in a strain of phosphorus-removing Acinetobacter. Senior hypothesized that certain bacteria will accumulate PHB during temporary deprivation of oxygen. Buchan (22) reported Fukase , using fill-and-draw reactors, observed an acetate utilization to phosphorus at PHB increased in bacterial cells while polyphosphate granules decreased in size or disappeared in the anaerobic zone of biological phosphorus removal systems (EPA,1987).

Buchan analyzed the biological species obtained from aerobic zones of various South African activated sludge plants accomplishing biological phosphorus removal. His analysis showed that the intracellular polyphosphate granules contained an excess of 25 percent phosphorus. In the anaerobic zone, the large polyphosphate granules had dispersed into smaller granules and some cells had released virtually all of their accumulated phosphorus (EPA, 1987).

For biological phosphorus removal, wastewater must enter the anaerobic reactor located prior to aerobic reactor. Biomass is recycled to the front of the anaerobic tank from sedimentation tank. These conditions provide advantage to PAOs over other microorganisms and allow them to become dominant in activated sludge.

The anaerobic phase was believed to provide a unique, positive environment for the PAOs, enabling them to reserve the necessary amount of carbon to themselves without having to compete with other microorganisms (Baetens, 2000).

The fact that phosphorus-removing microorganisms can assimilate the fermentation products in the anaerobic phase means that they have a competitive advantage compared to other normally-occurring microorganisms in activated sludge systems. Thus, the anaerobic phase results in a population selection and development of phosphorus-storing microorganisms (Baetens, 2000). More PAOs lead to a better biological phosphorus removal performance.

Under anaerobic conditions, PAOs take up acetate and store it as PHB. Acetate is produced by fermentation of bsCOD. Some colloidal and particulate COD also contribute the fermentation but the amount is often small compared to bsCOD. “It has been assumed that the availability of Short Chain Fatty Acids (SCFAs, also referred to as fermentation products with as main constituent acetate) is a prerequisite for EBPR. In the absence of these components, fermentation of readily biodegradable carbon sources under anaerobic conditions is necessary’’ (Baetens, 2000).

As a result of Poly-P present in cells is splitted up, orthophosphate is released to water. Then phosphorus concentration in anaerobic tank increases. Energy for acetate uptake is provided from breakdown of glycogen and hydrolysis of energy rich internal phosphorus chain called poly-Phosphate (poly-P).

The anaerobic phase needs to be followed by aerobic phase. When biomass enters the aerobic tank PAOs take up phosphorus from liquid phase and store it as Poly-P. During this phase stored PHB is consumed, generating energy for growth of PAOs, for uptake of ortho-phosphate from the liquid phase and generating energy and carbon for replenishment of the glycogen and poly-P pools. Eventually, phosphorus concentration decreases.

However phosphorus can be removed via the excess waste sludge and so phosphorus leaves the system.

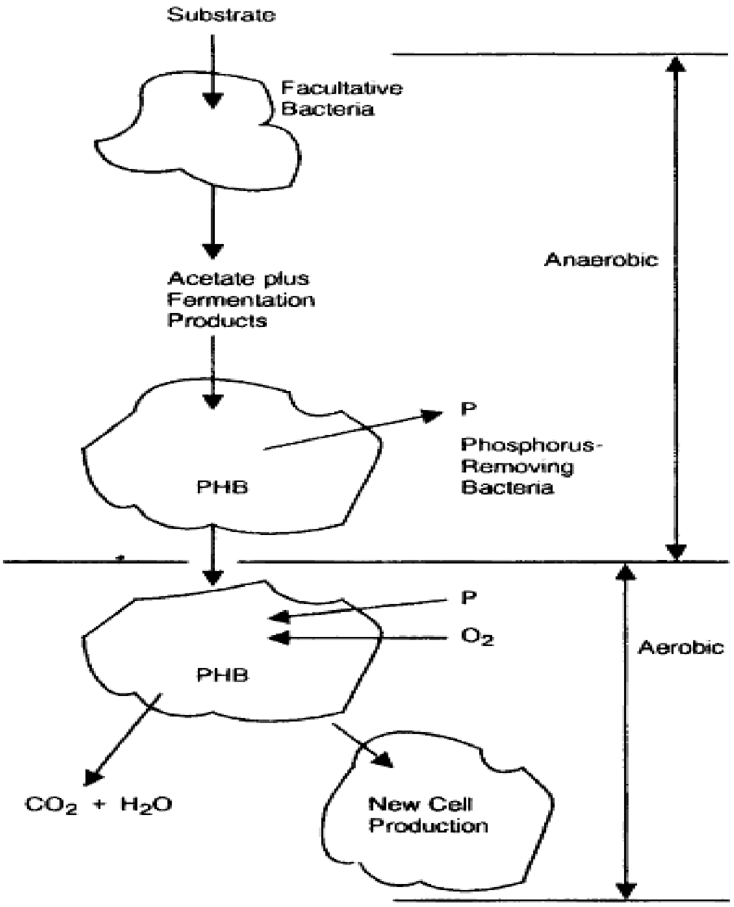


Figure 2.4 Schematic presentation of phosphorus release and uptake (EPA, 1987).

CHAPTER THREE

BPR SYSTEM CONFIGURATIONS

Many of system configurations have been developed for biological phosphorus removal. They have been extensively applied in practice all over the world. The main difference between these systems is the way in which an anaerobic zone is maintained and protected against the introduction of nitrate.

“Besides, the processes can be divided in two main groups: mainstream processes and side-stream processes. Mainstream processes are characterized 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’’ (Baetens, 2000). In this part, these configurations will be discussed.

3.1 Phoredox and A/O configuration:

The phoredox system was proposed by Bernard in 1976. It consist of two reactors in series, first one is anaerobic and the second one is aerobic. The return sludge flow is recirculated from the settler to the anaerobic reactor. There are no other recirculation streams between the reactors. In the anaerobic zone, PAOs release phosphorus, which is subsequently taken up in the aerobic zone. The A/O process shown in Figure is marketed in the United States by Air Products and Chemicals. The A/O system (Timmerman) has the same configuration as the phoredox system, but due to a compartmentalization of the anaerobic zone a plug-flow regime is induced, which promotes the conversion of easily biodegradable material to acetate and increases the phosphorus removal capacity.

A significant problem for A/O process is the introduction of nitrate to anaerobic phase with recycle stream. This results in a reduction of phosphorus removal capacity of system. To reduce this effect, the anaerobic zone is often split into an anoxic chamber for nitrate denitrification and a series of anaerobic zones for phosphorus release. A/O process is not appropriate for the regions with temperate and hot climates since nitrification cannot be completely prevented, even at low sludge ages. “Burke et al., (1990) demonstrated that it is impossible to prevent the establishment of (partial) nitrification in a pilot scale Phoredox system operated at 20 C and at a sludge age of only three days’’ (http://www.wastewaterhandbook.com /documents/phosphorus_removal/512_bioP_configurations.pdf). Furthermore the effect of temperature on the biological phosphorus removal processes will be discussed in the following parts.

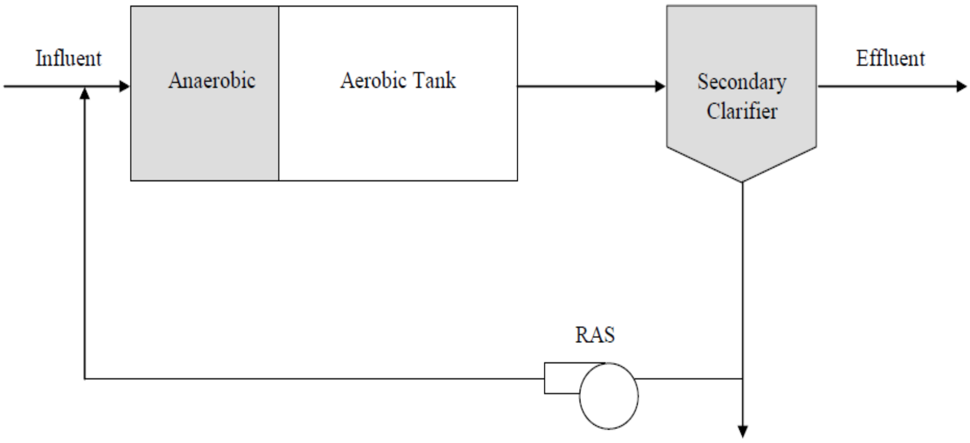


Figure 3.1 A/O process.

3.2 Anaerobic/Anoxic/Oxic (A^2O) Configuration

The anaerobic/anoxic/oxic (A^2O) process consists of an anaerobic zone, an anoxic zone, and an aerobic zone. It is the modification of A/O process. Denitrification occurs in anoxic zone and so introduction of nitrate to anaerobic zone is prevented. The process allows for both nitrogen and phosphorus removal. If the removal of nitrate is not complete in anoxic zone, the nitrate introductions to anaerobic reactor reduce availability of the easily biodegradable material to the PAO and thus reduce the phosphorus removal capacity of the system.

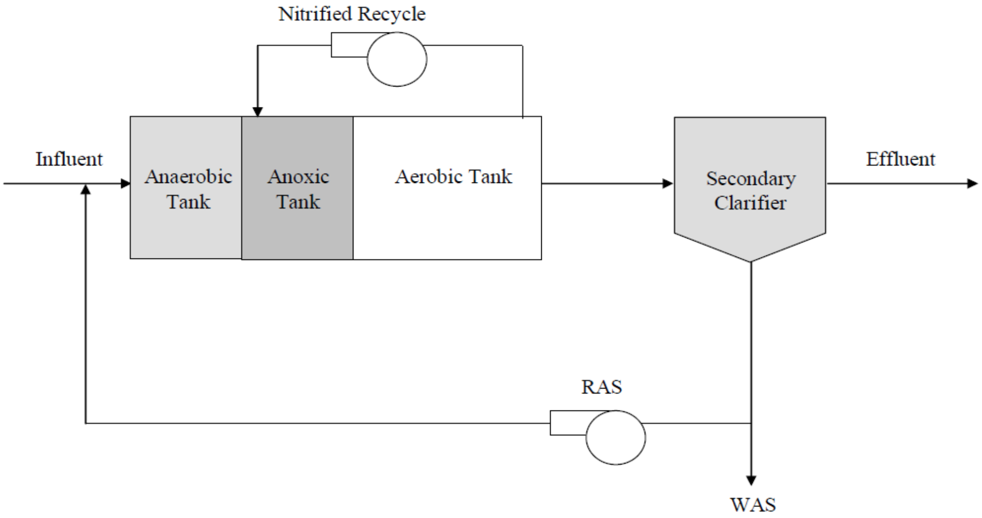


Figure 3.2 A^2O process.

3.3 PhoStrip Process (Sidestream Phosphorus Removal)

Phostrip is a sidestream process and it was first introduced in 1970s before any mainstream BPR processes existed. In this process, a part of sludge from the settler is thrown out of the system and the other part of sludge is kept in sludge thickener and so it is provided that phosphorus presented in biomass is transported to water. Phosphorus free sludge is recycled to activated sludge system. Phosphorus present in supernatant is removed by the lime addition and then recycled to activated sludge system. Sludge enriched with phosphorus is mixed at appropriate rates and used as fertilizer. HRT in sludge thickener is between 8 and 12 hours. Acetic acid or influent is added to stripper tank to supply phosphorus release.

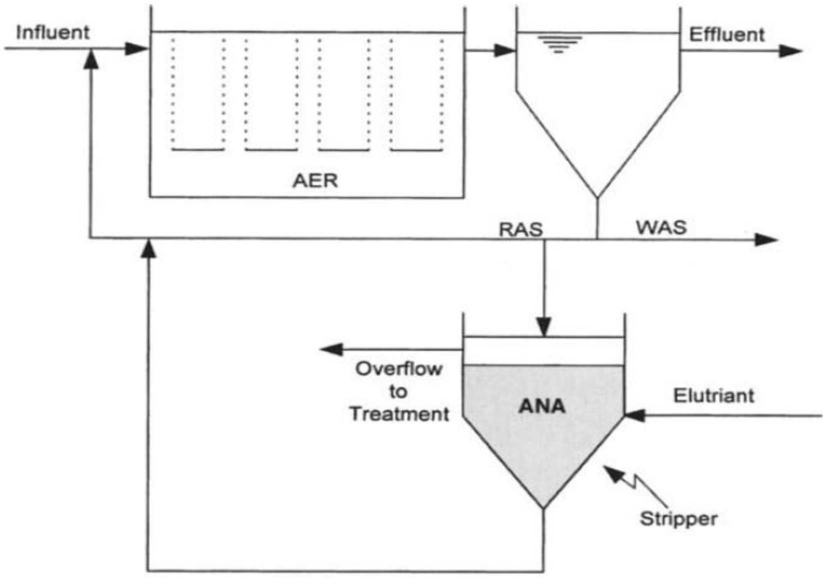


Figure 3.3 Phostrip process.

3.4 UCT Configuration

The University of Cape Town (UCT) process consists of anaerobic, anoxic, and aerobic zones. In the UCT system proposed by Robinowitz and Marais (1980), the introduction of nitrate in the anaerobic zone is avoided because the recycle stream returns nitrates from aerobic zone to anoxic zone. The nitrate-containing sludge is first introduced into a denitrification reactor, after which the nitrate-free sludge/water mixture is partly recycled to the anaerobic tank. This process was developed the adverse effect of nitrate on phosphorus removal performance (http://www. wastewaterhandbook.com/documents/phosphorus_removal/512_bioP_configurations .pdf).

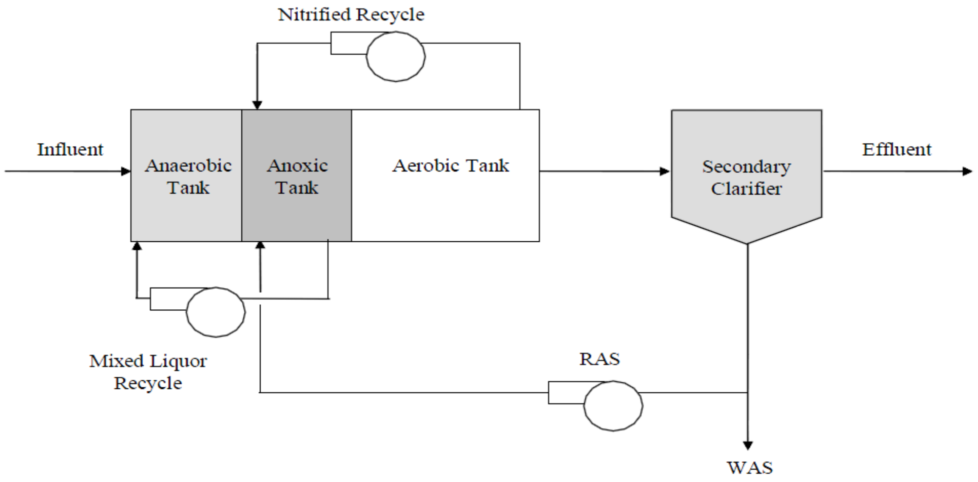


Figure 3.4 University Cape Town process.

3.5 Oxidation Ditch

Oxidation ditches are used for carbon and nitrogen removal for a long time. To allow for phosphorus removal an anaerobic tank is added upstream of oxidation ditch. Notable developments were reported by Pasveer and co-workers in the late 1950s and early 1960s.

The oxidation ditch does not necessarily need to be operated with anoxic zones, although doing so can aid in the partial recovery of alkalinity. As with the A/O process, additional carbon in the form of VFAs is needed only if sufficient rbCOD is not already present in the influent. To obtain very low phosphorus (under 0.1 mg/L), additional carbon is required. The carbon should be added upstream of the secondary clarifier to avoid depleting that nutrient from the biological process. Lower TP concentrations can be achieved by close monitoring and regulation of the anaerobic zone flow and DO levels (EPA, 2008).

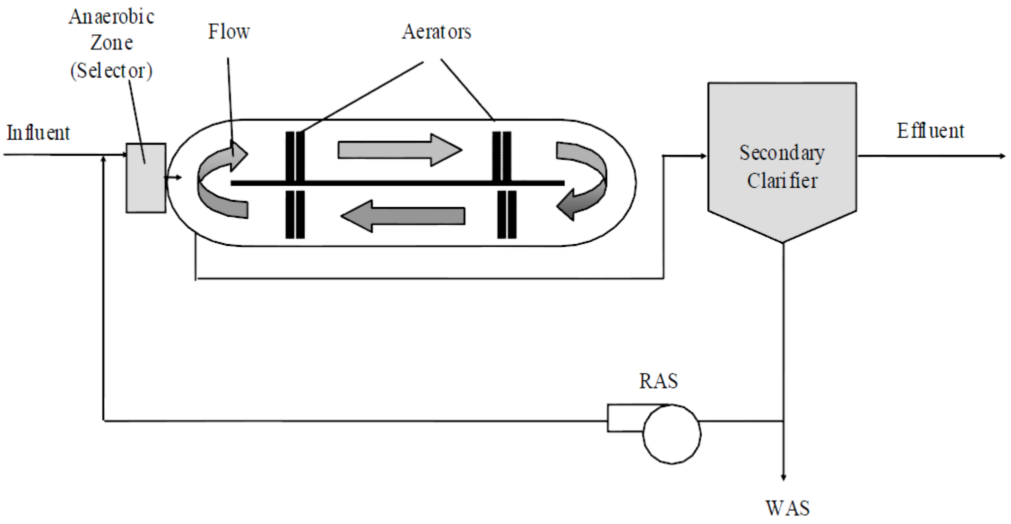


Figure 3.5 Oxidation ditch with anaerobic zone.

3.6 Five-Stage Bardenpho Process

Barnard (1975) first achieved phosphorus removal in a mainstream process later called the BardenphoTM 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 (Baetens, 2000).

To allow phosphorus removal, an anaerobic reactor is located ahead of the four-stage system. The internal recycle from the first aerobic zone to the first anoxic zone remains in place. RAS is returned to the head of anaerobic reactor. Methanol might need to be fed to the second anoxic zone to provide a carbon source for denitrification. In this process, both nitrogen and phosphorus removal are achieved.

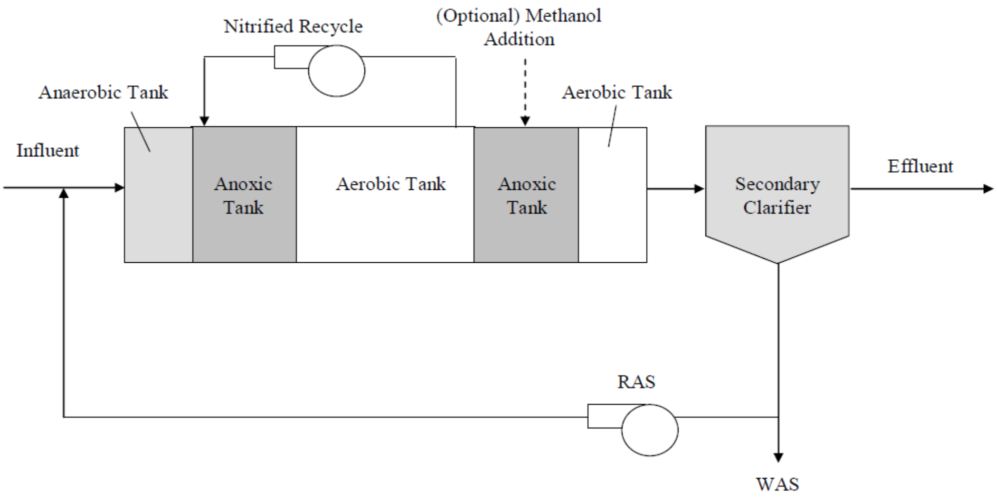


Figure 3.6 Five-Stage bardenpho process.

3.7 VIP Process

The Virginia Initiative process (VIP) is similar to the modified UCT process and is another variation of the Phoredox process. The nitrates from the aerobic zone are returned to the head of the first anoxic zone. The second return is from the end of the second anoxic zone to the head of the anaerobic zone. RAS is returned to the head of the anoxic zone. The VIP process allows for additional denitrification and thus minimizes the introduction of nitrate to the anaerobic zone. The VIP process is operated in a high-rate mode, allowing for small tank volumes, which require less space than other similar processes. As with the other processes, if sufficient VFAs are present, no supplemental carbon sources are required. To achieve low phosphate concentration chemical precipitation can be needed.

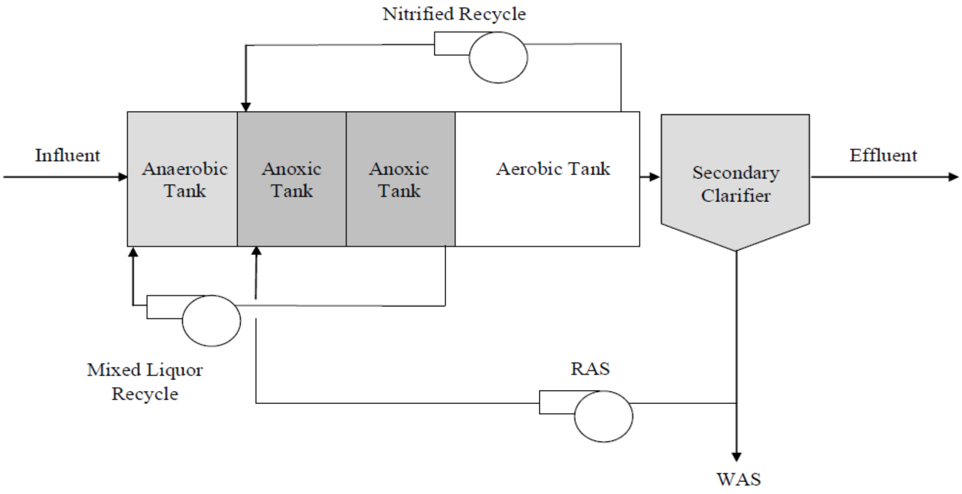


Figure 3.7 VIP process.

3.8 Johannesburg Process

Johennesburg process (Osborn and Nicholls, 1978) comprises of anaerobic, anoxic and aerobic tanks in series. An anoxic tank is located in RAS line to prevent the nitrate introduction to anaerobic tank. Denitrification occurs in this tank but it can be limited by the lack of carbon. This can be overcome by bringing sludge from the end of the anaerobic zone to the RAS-line anoxic zone. If sufficient VFAs are present, no supplemental carbon sources are required. Achieving a very low phosphate concentration requires downstream chemical precipitation.

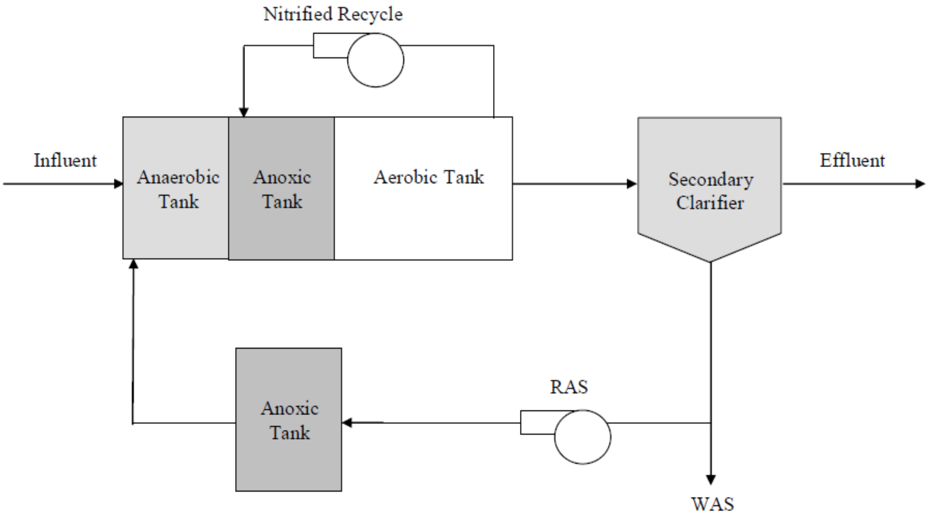


Figure 3.8 Johannesburg process.

3.9 Biodenipho Process

The phased isolation ditch or Biodenipho is a Danish nutrient removal process. An anaerobic tank is placed upstream of the two oxidation ditches which are operated in cyclical manner to promote denitrification and nitrification. In this system, organic carbon is used for both nitrification and biological phosphorus removal. If sufficient carbon is present, no supplemental source is required. The RAS is returned to the anaerobic zone. To achieve very low phosphate concentration chemical precipitation and filtration might be needed.

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 (Baetens, 2000).

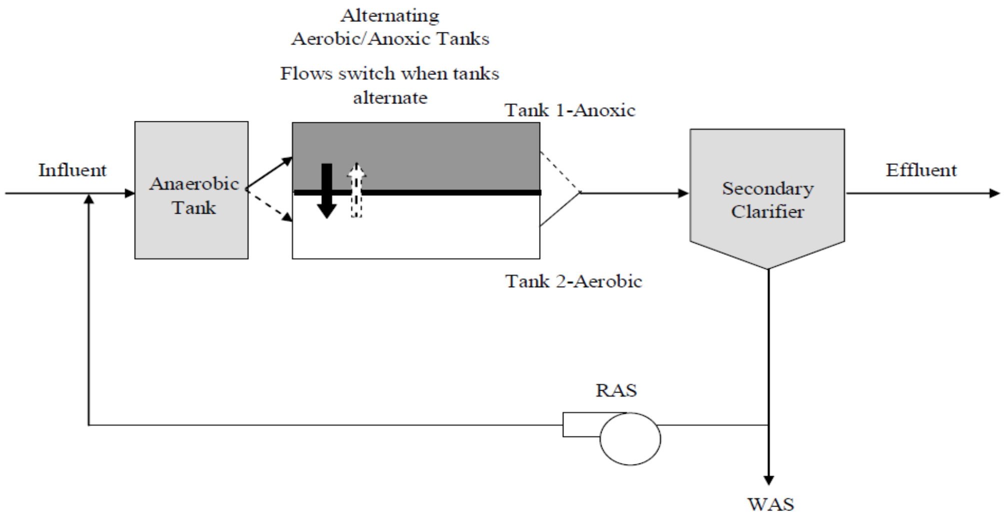


Figure 3.9 Biodenipho process.

3.10 Sequencing Bath 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).

It is based on filling, waiting and drawing of the reactor. If it is required MLSS concentration can be adjusted through the waste sludge. Operation of the system is performed by following the steps below.

- To achieve organic carbon, phosphorus and nitrogen removal, required microorganisms are instilled to the system.

- Aeration is stopped then organic carbon removal and phosphorus release occur by mixing consistently

- By aeration, COD is converted to water and carbon dioxide under aerobic condition. Under this condition nitrification and uptaking of phosphorus occur.

- Under anoxic conditions denitrification occurs and a part of COD in wastewater is utilized as carbon sources for denitrification.

- Soon after waiting and precipitation sample is taken from the upper liquid and COD,NH4-N,NO3-N,PO4-P removal ratios are determined.

- If expected ratios are not obtained, KOI removal and nitrification occurs by aerating again.PO4-P is transported into the sludge.

- Aeration is stopped, denitrification of NO3-N remained from previous stage occurs.

- After waiting and precipitation water of which C, P, N is removed is taken from the top.

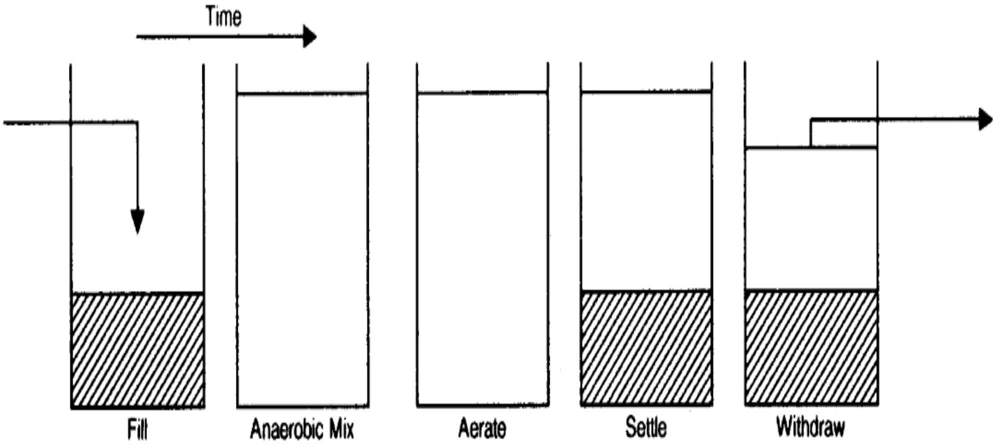


Figure 3.10 Biological phosphorus removal using a sequencing batch reactor.

Table 3.1 SBR Operating Sequence-Biological Phosphorus Removal (EPA, 1987).

Period	Low Loaded	High Loaded
	hr	hr
Fill and Anaerobic Mix	1.8	3.0
Aerate	1.0	0.4
Settle	1.0	0.7
Withdrawn	0.4	0.7
Idle	0.6	0.0

CHAPTER FOUR

FACTORS AFFECTING BPR PROCESS PERFORMANCE

A number of factors affect the biological phosphorus removal system. These should be considered in designing and operating biological phosphorus removal facilities. System performance depends on these factors and it is impossible to obtain a good performance without considering them. In this study, the treatment plant performance analyses will be done by evaluating these factors involves design parameters, environmental factors and wastewater characteristics.

4.1 Solid Retention Time (SRT)

The SRT (otherwise known as the mean cell residence time-(MCRT) or sludge age) is the ratio of the mass of organisms in the reactor to the mass of organisms removed from the system each day. “In effect, it corresponds to the average time the microorganisms remain within the system’’ (Mulkerrinsa, Dobsona& Colleran, 2003).

If the system is to be designed and operated to achieve phosphorus removal, the aerobic SRT must be long enough to allow PAOs to grow. The range of aerobic SRT values required for growth of the PAOs utilized in biological phosphorus removal and anaerobic selector systems is presented in Figure 4.1. As shown in figure, the lower limit on SRT for phosphorus removal is generally higher than that for soluble substrate removal. SRT values longer than it should be, has adverse effect on system performance.

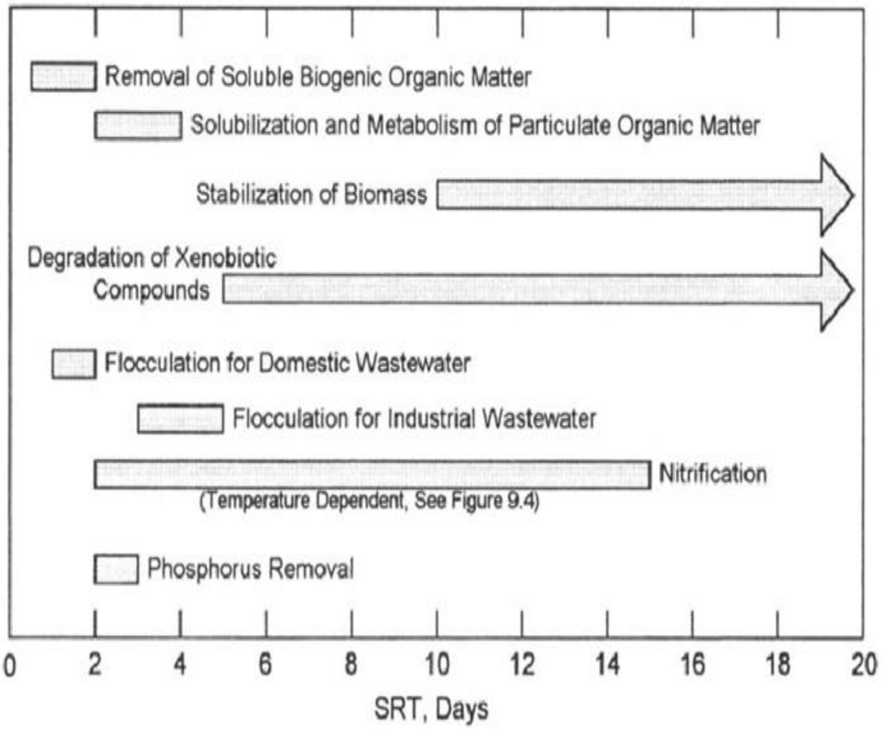


Figure 4.1 Typical SRT ranges for various biochemical conversions in aerobic/anoxic bioreactor systems at 20°C (Grady et al., 1999).

Phosphorus removal can be adversely affected by the use of relatively long anoxic or aerobic SRTS. This may occur for at least three reasons: (1) long SRTs result in reduced solids production so that less phosphorus is removed from the process in the WAS; (2) long aerobic SRTs result in relatively complete oxidation of organic storage products and a reduced rate of phosphorus uptake in the aerobic zone; and (3) decay reactions cause secondary release of phosphorus, i.e., the release of phosphorus without a corresponding uptake and storage of biodegradable organic matter. Thus, SRTs beyond that just required to meet treatment objectives should be avoided for BPR systems (Grady et al., 1999).

An anaerobic SRT of about 1 day for temperatures above 20°C may be choosen. For cold temperatures this value can be increase to 1.5. “ Increases in the anaerobic SRT will allow increased fermentation of biodegradable organic matter in the anaerobic zone, resulting in increased production of VFAs and increased biological phosphorus removal’’(Grady et al., 1999).

If nitrification is an objective, SRT becomes more important.Long SRTs are required to achieve nitrification. The minimum aerobic SRT for nitrification is longer than the minimum for growth of PAOs and this must be taken into as choosing SRT.

If nitrification is not an objective, the aerobic SRT must be short enough.Otherwise nitrate introduction to anaerobic zone with recycle stream reduces the phosphorus removal capacity.Rising of temperature makes it diffucult to preclude the nitrification. Especially temperatures above about 25"C, it may be very difficult to operate at an aerobic SRT sufficiently high to allow PAOs to grow while also excluding nitrifying bacteria.Processes like A/O can be adversely affected due to the nitrate recycle. UCT and VIP processes have advantege over other processes with regard to nitrate recycle.

Many studies have been done to determine the effect of SRT. Barth and Stensel suggested a TBOD removal:TP removal ratio of 33 at an SRT of 25 days and a ratio of 25 at an SRT of 8 days. Fukase found, in an NO system 32 pilot-plant study treating municipal wastewater, that the TBOD removal:TP removal ratio increased from 19 to 26 as SRT was increased from 4.3 to 8.0 days. At the same time, the phosphorus content of the activated sludge decreased from 5.4 to 3.7 percent (EPA, 1987).

In general the EBPR process is not very sensitive to the SRT and it has been shown in practice that good phosphorus removal is possible at SRTs ranging from 3 to 68 days (Reddy, 1998). Wentzel (1989a) showed that, although EBPR is possible at SRTs of less than 3 days, the process is not as stable and the effluent is not clear (Baetens, 2000).

These results indicate that operation at longer SRT values will decrease the efficiency of phosphorus removal per unit of BOD removed. To maximize biological phosphorus removal, systems should not be operated with SRT values in excess of that required for overall treatment needs. Systems that require nitrification and denitrification, such as the Modified Bardenpho system or extended aeration systems promoting sludge stabilization, will require much higher influent TB0D:TP ratios to produce soluble phosphorus concentrations below 1 .O mg/L (EPA,1987).

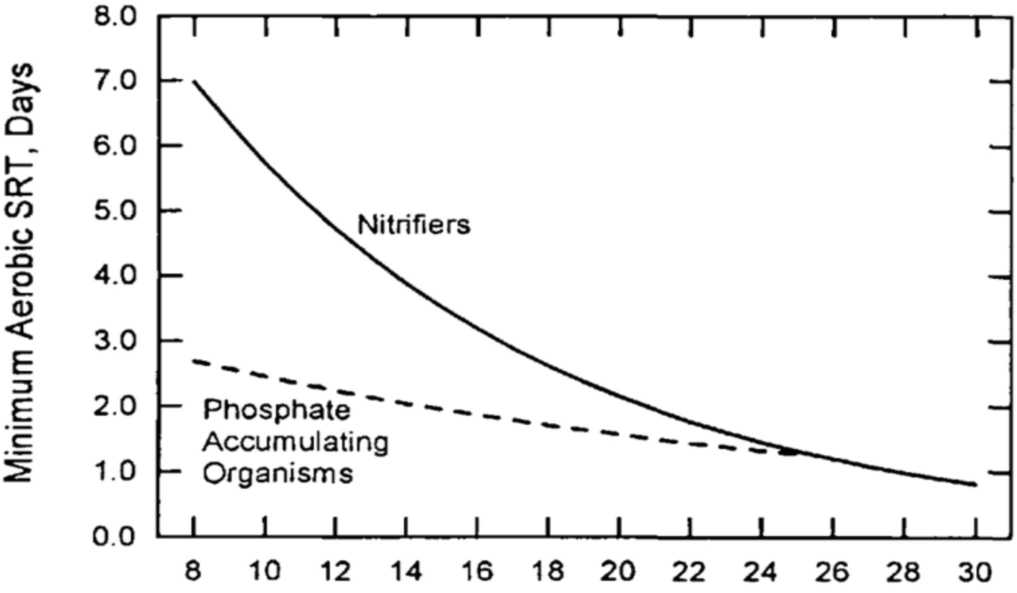


Figure 4.2 Effect of temperature on the minimum aerobic SRT required to grow nitrifiers and PAOs. The nitrifier curve was adapted from Sedlack" and the PAO curve was developed from data presented by Mamais and Jenkins (Grady et al., 1999).

4.2 Wastewater Characteristics

TCOD/TP ratio and available VFA are the key factor to evaluate the performance of biological phosphorus removal system performance. As mentioned in biological phosphorus removal mechanism, acetate is taken up by phosphorus storing bacteria in anaerobic zone and PAOs use carbon products for growth and energy in subsequent aerobic and anoxic zones. The more acetate result in more cell growth and this means that more phosphorus removal.

The rbCOD is primary source of VFA (Volatile Fatty Acids) for PAOs and VFAs are formed through fermentation quickly. Generally raw wastewater especially flows through pressure mains, includes substrates in the form of VFA. In anaerobic tanks uptaking of acetate by PAOs and fermentation occurs simultaneously. The fraction of VFA can be increased by fermentation of the fermentable fraction of COD and fermentation of primary sludge. Wastewater containing high proportion of VFA required smaller anaerobic SRTs. Sufficient fermentable organic matter must be present to generate VFAs for uptake by the PAOs. It has been estimated that a concentration of at least 25 mg/L as COD of readily biodegradable substrate must be available in the anaerobic zone to generate sufficient VFAs to allow adequate biological phosphorus removal. So, the readily biodegradable substrate concentration in the influent wastewater, particularly the VFA concentration, will significantly affect the performance of a biological phosphorus removal system.

Ekama, et al., (1983) reported that wastewater characteristics, i.e., COD concentration, TKN/COD ratio, readily biodegradable COD concentration, maximum specific growth rate of nitrifiers, maximum and minimum temperatures, and P/COD concentration ratio have effect on the design of a biological nutrient removal process. It is also reported that COD concentrations of greater than 60 mg/L is required for sufficient phosphorus removal even with the absence of nitrate. Siebritz, et al., (1983) measured the immediate oxygen uptake of mixed liquor upon addition of a wastewater sample and he concluded that at least 25 mg/L of biodegradable substrate is required for biological phosphorus removal to proceed (Punrattanasin 1997).

Hong et al. have used the soluble BOD Concentration of the influent wastewater as an indication of the amount of substrate readily available for the formation of fermentation products. They have recommended an influent SBOD: soluble phosphorus (SP) ratio of at least 15 to produce an effluent soluble phosphorus concentration below 1.0 mg/l for A/O systems operating at F/M loadings above 0.15 kg TBOD/kg MLVSS/d. Data presented by Tetreault et a/. (47) from the full-scale Largo NO system operation supported this recommendation. At influent SB0D:SP ratios below 12, effluent soluble phosphorus concentrations varied from 0.5 to 4.5 mg/l (EPA,1987).

Gibson and Dold (1993) described the detailed characterization that is needed to accurately predict the performance of BNR processes using equations developed by Marais and co-workers at the University of Cape Town. However, Randall, et al., (1992) suggested that typically characterized influent wastewater could be used as a reasonable predictor for effluent nitrogen and phosphorus concentrations from BNR processes. The organic matter, i.e., BOD5 and COD, to total phosphorus ratio entering the anaerobic zone will determine the effluent phosphorus concentration of the system. They compiled the data from full-scale and pilot-scale studies and develop graphs which suggest that a BOD5:TP ratio of about 20:1 and COD/TP ratio of about 40:1 are needed to achieve effluent phosphorus concentrations of 1 mg/L or less for typical wastewater treatment plants. According to Randall, et al., (1992), Ekama and Marais (1984) reported that 8.6 mg/L COD is required to remove 1 mg/L nitrate while 50 to 59 mg/L COD is needed to remove 1 mg/L phosphorus from municipal wastewater. Experiments at Virginia Tech reported approximately 50 mg/L COD is required per mg/L phosphorus removed. Abu-ghararah and Randall (1991) studied the effect of influent organic compounds on the performance of the UCT process. They concluded that at least 20 mg acetic acid as COD is required to remove 1 mg of phosphorus. All VFAs of two to five carbons increased the removal of phosphorus, however, different VFAs caused different amounts of biological phosphorus removal (BPR). Acetic acid was found to stimulate the largest amount of BPR. In addition, the branched form of the VFAs, e.g., isobutyric and isovaleric, produced more anaerobic phosphorus release and subsequent phosphorus uptake than the nonbrancing form of the same organic acids. Tracy and Flammino (1987) stated that food-to-microorganism ratio (F/M) had a great effect on phosphorus removal. High F/M ratio promoted the rate of phosphorus removal (Punrattanasin, 1997).

To attain lower effluent phosphorus concentration required higher influent TB0D:TP ratios. Figure presents data showing effluent soluble phosphorus concentrations and TB0D: TP ratios. Tetreault et al. have proposed a TB0D: TP ratio of greater than 20-25 to achieve an effluent soluble phosphorus concentration below 1 .O mg/l.

Wastewater may be phosphorus limited or carbon limited. In phosphorus limited wastewater more than sufficient organic matter is available for phosphorus removal. This results in lower effluent phosphorus concentration. In a carbon limited wastewater insufficient organic matter is available to remove all of the phosphorus. Eventually, phosphorus will be present in the process effluent at a concentration determined by the relative concentrations of phosphorus and organic matter in the influent.

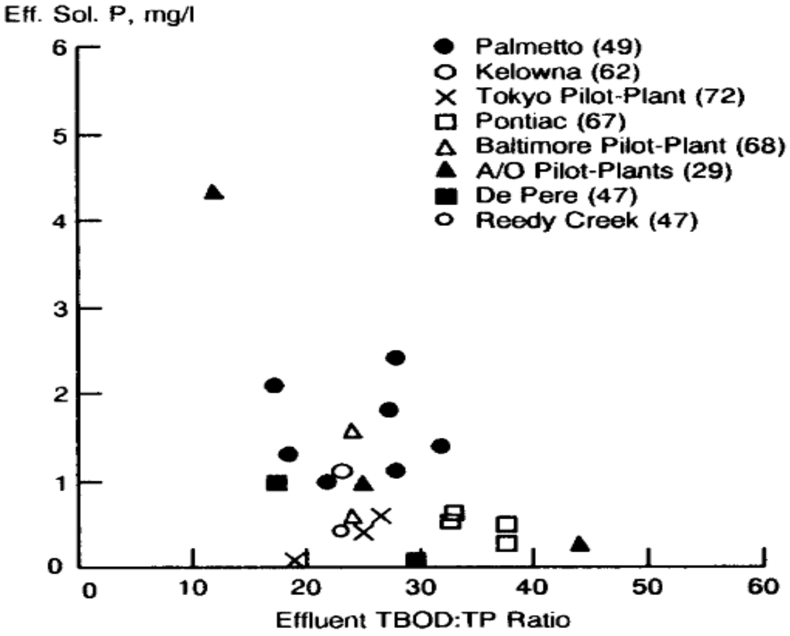


Figure 4.3 Effluent soluble P concentration vs. influent TBOD/TP ratio (EPA, 1987).

Ratio of organic substrate to phosphorus varies according to the process type and nitrate introducing to the anaerobic zone.

Highly efficient BPR processes, such as the A/O''' process operating under nonnitrifying conditions or the VIP process, require only 15-20 mg BOD, (26-34 mg COD) to remove a mg of phosphorus. In these processes, essentially no nitrate-N is recycled to the anaerobic zone, either because it is not generated (for the nonnitrifying A/O''' process) or it is removed (for the VIP process). They are also both high-rate processes, which maximizes phosphorus uptake and waste solids production. A moderately efficient process, such as a nitrifying A/O''' or A'/O''' process, will require 20-25 mg of BOD, (34-43 mg COD) to remove one mg of phosphorus. More organic matter is required for these systems because some will be consumed by non-PAO heterotrophs in the anaerobic zone due to the nitrate-N recycled there in the RAS. The ratio will be even higher for a low efficiency process, such as a five-stage Bardenpho process operating at long SRT, which require more than 25 mg of BOD, (43 mg COD) to remove a mg of phosphorus (Grady et al., 1999).

A BPR process will achieve good performance if it operates under phosphorus limited conditions. This occurs when the organic matter to phosphorus ratio of the influent wastewater is greater than the BOD/TP value for the BPR process being used, i.e., when more organic matter is available per unit of phosphorus than is required by the process to remove the phosphorus. Therefore, appropriate BPR processes can be identified for a particular application by comparing the organic matter to phosphorus ratio for the wastewater to the BOD/TP values for candidate BPR processes and selecting those processes with appropriate removal ratios (Grady et al., 1999). These ratios are presented in table below.

Table 4.1 BOD, and COD to Phosphorus removal ratios for various BPR processes(Grady et al., 1999).

Type of BPR process	$BOD_5/\Delta P$ ratio (mg BOD_5/mg P)	$COD/\Delta P$ ratio (mg COD/mg P)
High efficiency (e.g., A/O Without nitrification, VIP, UCT)	15-20	26-34
Moderate efficiency (e.g., A/O and A^2O with nitrification)	20-25	34-43
Low efficiency (e.g., Bardenpho)	> 25	>43

4.3 Effect of Effluent Total Suspended Solid

One of the important plant performance consideration is effluent suspended solid concentration and phosphorus content of those solids. This is more important for mainstream processes as they produce mixed liquor suspended solids that have higher phosphorus content than phostrip. Phosphorus content of MLSS on a dry solids basis of 2.3-5.8 percent has been reported for phostrip and mainstream process. Phosphorus content of MLSS in BPR processes is higher than conventional systems.

To meet required effluent total phosphorus concentrations, effluent filtration may be needed. To achieve low effluent phosphorus concentrations without filtration, biological phosphorus removal system must produce a well flocculated sludge settles well in sedimentation tanks and a clear effluent that contains low suspended solids.

Figure 4.4 presents the required suspended solid concentration to achieve 1.0 mg/L or less phosphorus concentration with the certain soluble phosphorus concentration and phosphorus content of sludge. If the effluent soluble phosphorus concentration is 0.5 mg/l and the phosphorus content of the MLSS is 5 percent, the effluent TSS concentration has to be 10 mg/l or less to meet the 1.0-mg/l effluent total phosphorus limit. If the solids phosphorus content were 3 or 4 percent, the effluent TSS would have to be equal to or less than 17 or 12.5 mg/l, respectively.

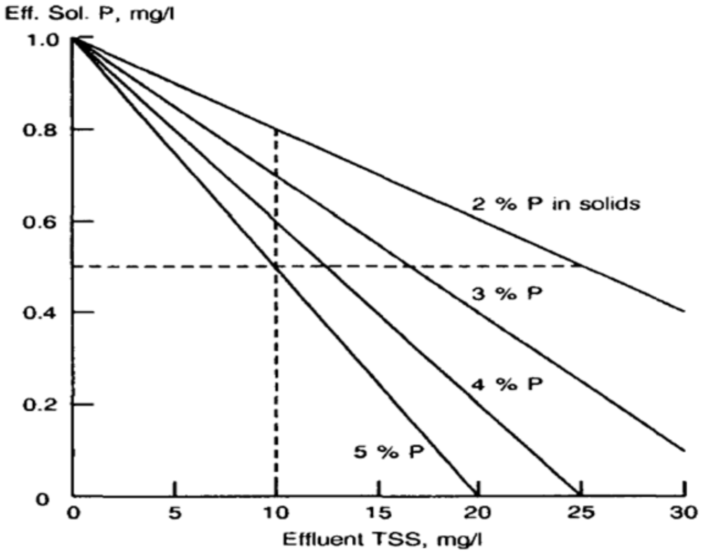


Figure 4.4 Maximum effluent soluble P concentration for effluent total P 1 .O mg/L (EPA, 1987).

In plant studies, 4-8 mg/L effluent SS concentrations have been observed. The effluent suspended solids data shown for Palmetto were after filtration, but effluent TSS concentrations of 4-8 mg/l from the secondary clarifier have been reported .It appears that a conservatively designed secondary clarifier could produce effluent suspended solids concentrations low enough to meet a typical effluent total phosphorus requirement of 1 .O mg/l, provided the soluble phosphorus concentration in the effluent stream does not exceed 0.4-0.6 mg/L (EPA, 1987).

Figure 4.5 illustrates the effect that increasing the phosphorus content of the MLSS can have on the particulate phosphorus concentration in the effluent from a BPR system. It indicates that significant quantities of phosphate can be contributed if effluent TSS concentrations exceed about 10 mg/L (Grady et al., 1999).

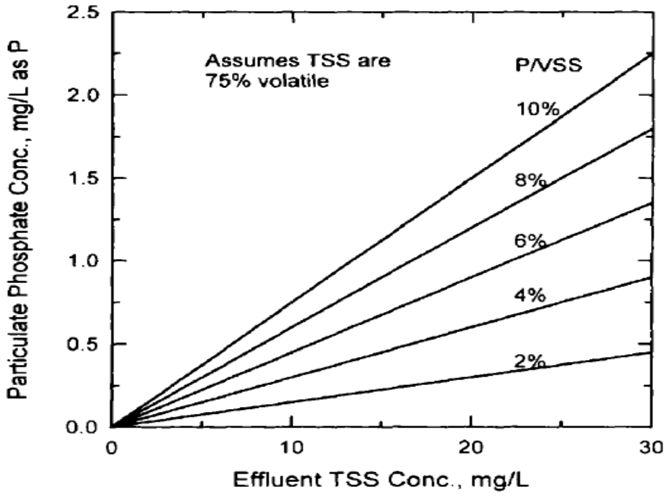


Figure 4.5 Effect of the effluent TSS concentration and the mixed liquor P/VSS ratio on the effluent particulate phos phorus concentration (Grady et al., 1999).

4.4 Effect of Nitrate Nitrogen in Anaerobic Zone

Both nitrate and oxygen input to anaerobic phase via influent and/or recycle streams have adverse effect on the biological phosphorus removal capacity of the system. Nitrate and oxygen are utilized in anaerobic tank. In this case, a part of available substrate is consumed by non PAOs and this reduces the BOD/TP ratio and leads to decrease of performance of the system.

For each mg of nitrate and oxygen, 2 and 4 mg COD is used, respectively. This (readily biodegradable COD) will then not be available for the PAOs. Due to this less phosphate will be removed as polyphosphate (Grady et al., 1999).

1 mg/L nitrate-N is the equivalent of 2.86 mg/L DO, and nitrate does not have a maximum concentration like DO, nitrate has the potential to cause even more disruption to biological phosphorus removal than DO. In a step-feed system, McGrath et al., (2005) determined that 6 mg/L of nitrate nitrogen was the upper limit tolerable for successful EBPR in one particular full-scale operation. If sufficient

rbCOD is available, higher concentrations of return stream nitrate could possibly be tolerated with adequate phosphorus removal (EPA, 2008).

Introduction of nitrate to anaerobic zone leads to growth of normal denitrifying PAOs and a decrease in phosphate release. The figure below illustrates the effect of nitrate and oxygen on system performance.

Figure 4.6 presents the effect of recycling nitrate and oxygen on the COD distribution in a bio-P process. Calculation of Sa fraction in influent after ‘dilution’ with return sludge: consumption is as follows (5000x 50)- (6500 x 1 x 2)- (6500x 4 x 4)/5000 =26.6 mg/L. The reduction amount is then 26.6/50=53.2% (Janssen, et al., 2002).

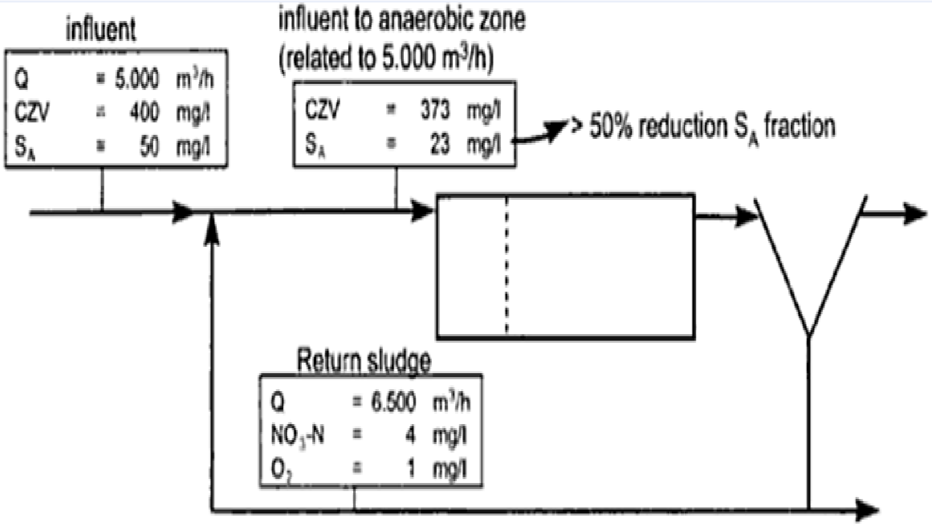


Figure 4.6 Effect of recycle nitrate and dissolved oxygen (Janssen et al.,2002).

Bernard was the first to point out the negatively effect of nitrate on biological phosphorus removal. He observed an increase of redox potential of the reactor and a reduction in the degree of anaerobic stress to induce phosphorus release.

Simpkins and McClaren reported a reduction of total phosphorus removal efficiency from 90 to to 55 percent when the effluent nitrate nitrogen concentration increased from 4.0 mg/l to 6.7 mg/l in a Modified Bardenpho pilot-plant study. During the Palmetto Modified Bardenpho operation, internal recycle pumps were deactivated. Pumps had caused the effluent nitrate nitrogen concentration to increase to about 10 mg/l and the effluent total phosphorus concentration to increase from 2.3 to 7.1 mg/l. This is a good example of stating the effect of nitrate on the system.

Vinconneau et al. also showed that nitrate could significantly affect biological phosphorus removal performance for a lightly loaded A/O system. At similar influent B0D:P ratios and operating F/M loadings, the effluent total phosphorus concentration decreased from 2.0 to 0.9 mg/l as the effluent nitrate nitrogen concentration decreased from 3.4 to 0.6 mg/l (EPA, 1987)

Rabinowitz studied the effect of nitrate nitrogen concentration on phosphorus release in batch tests using activated sludge developed in a UCT system pilot plant. Sodium acetate was used for the substrate source. He found that with excess substrate available, the phosphorus release during anaerobic contacting was inversely proportional to the amount of nitrate nitrogen present. He further found that the denitrification of nitrate in the anaerobic batch tests had the effect of reducing the availability of substrate for phosphorus release. The substrate consumption for denitrification was found to be 3.6 mg COD/mg nitrate nitrogen reduced. This ratio is in close agreement with a ratio of 3.53 developed by McCarty for denitrification using acetate (EPA, 1987)

A substrate consumption ratio determined from an anoxicaerobic pilot-plant system treating domestic wastewater was about 5.0 mg soluble COD/ mg nitrate nitrogen reduced for complete denitrification. The same reference reported on substrate consumption for anoxic-aerobic system denitrification using eleven different industrial wastewater substrate sources. The mean substrate consumption ratio was 5.3 mg COD/mg nitrate nitrogen reduced (EPA, 1987).

A study has been conducted in Delf University of Technology to introduce the effect of nitrate on phosphorus release. In this test an anaerobic-anoxic SBR with a working volume 3.5 L was used and operated in a cycle of 6 hours. A synthetic wastewater containing HAc (400 mg COD/L) and phosphorus (15 mg -P/L) was fed to the rector during the first 10 minutes of anaerobic phase. In the anoxic zone 0.1 L nitrate was pumped into the reactor. Figures below, shows the results of the tests with/without nitrate addition. By looking at the figures negative effect of nitrate can be seen clearly.

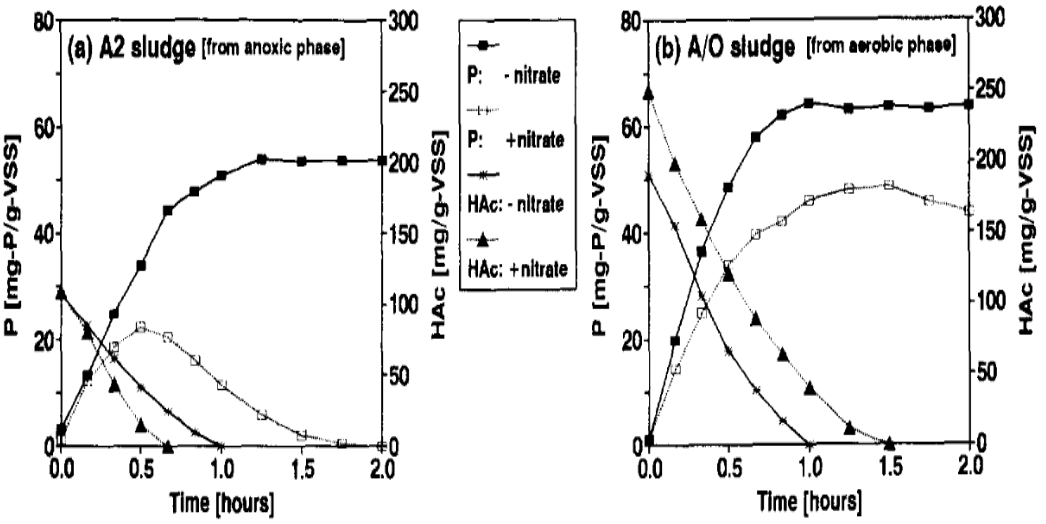


Figure 4.7 Phosphorus and HAc concentrations in batch test with/without nitrate addition using sludge from (a) the A_2 and (b) A/O SBR. The sludge was taken from the SBR at the end of the anoxic or aerobic phase (Kuba, T., Wachmeister, A., Loosdrecht, M.C.M & Heijnen, J.J, 1994).

Stoichiometric and kinetic values obtained from the study are shown below.

Table 4.2 Summery of stoichiometry and kinetics in batch test using A_2 and A/O sludge(Kuba, et.al.,1994).

	with/without nitrate	Hac-consumption rate (mg/mg-VSS.h)	P-release rate (mg-P/ g-VSS.h)	Anoxic p-uptake rate*[1] (mg-P/ g-VSS.h)	P/C ratio*[2] (mol-P/ mol-C)
A_2 sludge (and anoxic phase)	$+NO_3$	192	52	24	0.24
	$-NO_3$	125	62	—	0.45
A_2 sludge (and anaerobic phase)	$+NO_3$	177	35	27	0.24
A/O sludge	$+NO_3$	253	68	10	0.20
	$-NO_3$	236	106	—	0.35

*[1] After HAc was gone. *[2] Rations of the released-phosphorus to the utilized HAc

4.5 Effect of Temperature

Many studies have been done on the effect of temperature. Higher efficiencies were obtained at both low and high temperatures.

BPR efficiency has been reported to improve at higher temperatures (20–37 jC) (McClintock et al., 1993; Converti et al., 1995), while in contrast comparatively better Premoval efficiency has been observed at lower temperatures (5–15 jC) (Viconneau et al., 1985; Florentz et al., 1987). In studies performed by Panswad et al., (2003), the PAOs were found to be lower-range mesophiles or perhaps psychrophiles and predominated only at 20 °C or possibly lower (Mulkerrins, et al., 2003).

Helmer and Kunst (1998) have noted that air temperatures below 0 C in northern hemisphere have effect on plant performance. Okada et al., 1992 reported that rapid decreases in temperature and hydraulic shock loadings affect BPR plant performance adversely resulting in a deterioration of BPR system performance for more than 4 weeks. Brdjanovic et al., (1997) observed that temperature affects the oxygen consumption rate in BPR system. In contrast to incomplete P-uptake at 5-10 °C, complete P-uptake was observed at 20 and 30 °C. Krishna and van Loosdrecht (1999) reported that the accumulation of storage polymers is strongly dependent on temperature, with less PHB formation at higher temperatures. In the same paper, it was shown that, as the temperature increased from 15 to 35 C, the rates of substrate uptake, ammonium consumption, oxygen uptake, CO2 production and PHA formation all increased. Converti et al., (1995) have reported that specific P release is clearly reduced when temperatures are lowered. Marklund and Morling (1994) have reported effluent P concentrations of less than 1.0 mg/l at water temperatures as low as 5 C using a BPR process, with a sharp increase in effluent P to >2.0 mg/l being observed at 4 C.

P-removal can be negatively affected by low temperatures, particularly in a combined BNR system, since low temperatures can lead to higher nitrate concentrations in the return sludge, thereby impacting on BPR. It has been reported that 90% nitrification is possible at temperatures as low as 8 C. However, denitrification becomes the limiting factor in the overall nutrient removal process leading to elevated levels of nitrate in the effluent . Many authors have also reported reduced nitrification at low temperatures (Mulkerrins, et al., 2003).

Peirano et al., reported that wastewater temperature had no significant effect on Phostrip process efficiency during plant-scale testing at Reno-Sparks. Shapiro et al. showed specific phosphorus release rates for activated sludge ranging from 0.63 mg/l-hr/g of volatile suspended solids at 10°C (50°F) to 3.15 at 30°C (86°F). Prior to the Kelowna plant design, bench-scale studies showed that 90 percent biological phosphorus removal was possible over a temperature range from 18°C (64°F) down to 6°C (43OF) (78). The study did exhibit a decreased nitrogen removal efficiency below 10" C (50" F), however (EPA, 1987).

The full-scale NO system operation demonstrated at Pontiac, Michigan, revealed that biological phosphorus removal was not affected by wastewater temperatures as low as 10°C (50°F) (67). Biological phosphorus removal was studied in laboratory batch units over a temperature range of 5-15°C (41- 60°F) by Sell et al. (46). The amount of phosphorus removed at 5°C (41°F) vs. 15°C (60°F) was greater by more than 40 percent. An A/O system operating at a low organic loading rate of 0.032 kg COD/kg MLSS/d produced its lowest effluent soluble phosphorus concentrations of 0.9 mg/L during the coldest operating month when wastewater temperature was 5°C (41 OF). The phosphorus content of the sludge was 4.7 percent compared to a range of 3.5 to 4.9 percent for five other months (EPA, 1987).

Table 4.3 gives an overview of the different effects in decrease of temperature can have on Bio-P efficiency. From this table it can be concluded that net effect of temperature change positively or negatively influence bio-P process and bio-P efficiency (Janssen, et al., 2002).

Table 4.3 Effect of a decrease in process temperature on bio-P process (Janssen, et al., 2002).

Level	Influence	Result	Effect on bio-P
Organism	Lower conversion rates	Reduction in P release and P uptake	-
	Lower decay resulting in higher sludge production (yield)	Storage capacity of poly-P[1] increases.	+
Population	Change in the fraction of PAOs in the sludge	Change in P release and storage kinetics	+/-
	Lower nitrification, less nitrate[2]	More substrate available for PAOs; storage capacity of poly-P[1] increases	+
	Lower fermentation, fewer VFA	Less substrate available for PAOs; storage capacity for poly-P[1] decreases	-
Physical-Chemical	Precipitation	When solubility product is exceeded, the precipitation capacity increases.	+

[1] The storage capacity of polyphosphate is the product of the storage capacity per PAO and the number of PAOs.

[2] This only applies at high sludge loading rates. Because of the current total nitrogen requirements in many cases, the sludge loading is so low that the nitrification is complete at low temperatures too.

4.6 Effect of pH

Two different laboratuary experiments were conducted to determine the effect of pH. Groenestijn and Deinema performed the study of 25 C (77 F) on the maximum specific growth rate. It was observed that maximum specific growth rate was 42 percent higher at a pH of 8.5 compared to that at a pH of 7.0. Below the pH values of 7.0 steady decline in the maximum specific growth rate occurred. Below a pH of 6.0 the organisms did not grow. Between pH values of 6.5- 8.0, the phosphorus content of the culture remained constant at about 6.0 percent. It increased to 7.5 percent at a pH of 6.0.

Tracy and Flamino studied effect of pH on phosphorus uptake rate in aerobic zone. They didn’t observe a significant change between pH 6.5 and pH 7.0. As the pH decreased below 6.5, the phosphorus uptake rate declined steadily. They also reported that all activity was lost at a pH of 5.2. As the pH increased, they claimed that the phosphorus uptake activity was essentially duplicated.

Nagashima stated that efficiency of Bardenpho process increased from 42 to 92 percent as the pH was increased from 5 to 8. Consequently, it can be said that efficiency of biolgical phosphorus removal may decline significantly below a pH of 6.5.

4.7 Effect of Anaerobic Contact Time

The required contact time depends on the amount of readily biodegradable substrate, available and to be formed, maximum storage capacity of PAOs and the amount of phosphorus to be biologically removed (Janssen, et al., 2002).

As a result of investigations at Palmetto and Florida Plants, it is observed that increasing anaerobic contact time from 1.1 to 2.6 hours cause an increase in total phosphorus removal from 59 to 71 percent. In a Bardenpho pilot plant study McLaren and Wood found that effluent soluble phosphorus concentration decreased from 3 to less than 1 mg/l as the anaerobic detention time was increased from 2 to 4 hours. However, after establishing removal at the 4-hour detention time, an effluent soluble phosphorus concentration of less than 1 mg/l was maintained under variable anaerobic detention times. In an A/O pilot plant study, anaerobic tanks mixers were deactivated periodically and this improved the phosphorus removal performance. With the mixers off, improved performance was attributed to a greater SDT. In these cases the longer contact time results in the fermentation of particulates or materials that are more slowly converted to fatty acids. The necessity for and success of longer anaerobic contact times may vary depending on the strength and nature of the wastewater.

4.8 Effect of Dissolved Oxygen Concentration

In BPR systems, the anaerobic zone must be kept devoid of oxygen (0.0–0.2 mg/l oxygen) as the presence of oxidizing substances such as oxygen and nitrate will interf ere with the BPR process.

On the other hand, there is no consensus about the effect of low oxygen concentrations on Bio-P process in aerobic zone. If the dissolved oxygen is too low Ekama et al., claimed that phosphorus removal may be reduced, nitrification may be limited and a poor settling sludge may be developed. If too high, denitrification performance could be limited due to the increase in DO recycled to the first anoxic zone.

Nevertheless, Miyamoto-Mills et al. (38) obtained effluent total phophorus concentrations below 1 mg/l in a Phostrip system pilot-plant study with the aerobic stage operating at DO concentrations of either 2.5 or 0.5 mg/l. It has also been reported that, for successful BPR, a DO concentration of 2.0 mg/l is required, but when nitrification is also necessary a DO of 3.0–4.0 mg/l is essential (Mulkerrins, et al., 2003).

The biological phosphorus removal mechanism suggests that the DO concentration may affect the rate of phosphorus uptake in the aerobic zone, but not the amount of phosphorus removal possible, provided that sufficient aerobic time is available (EPA, 1987).

A lab-scale sequencing batch reactor (SBR) was operated in alternating anaerobic–aerobic mode with a low dissolved oxygen (DO) concentration (0.5 mg/L) during the aerobic period, and was demonstrated to accomplish nitrification, denitrification, and phosphorus removal. Under anaerobic conditions, COD was taken up and converted to polyhydroxyalkanoates (PHAs), accompanied by phosphorus release. In the subsequent aerobic stage, PHA was oxidized and phosphorus was taken up to <0.5 mg/L by the end of the cycle (Zeng, R.J.,Lemaire, R.,Yuan,Z.&Keller,J., 2003)

CHAPTER FIVE
CASE STUDY

5.1 Presentation of Bayındır Wastewater Treatment Plant

BWWTP has been constructed by IZSU within the boundaries of Bayındır Municipality near Tokatbaşı village. It is intended to prevent pollution of the Küçük Menderes Basin by treating the wastewater from Bayındır. The WWTP is designed according to activated sludge process with a capacity of 6912 m^3/d.

5.1.1 Process Description

The Bayındır Wastewater Treatment Plant is a mainstream process consists of a continuous two anaerobic tanks (Bio-P) and two aeration tanks with a circuit character.

The wastewater is collected with gravity sewers and it is connected to the coarse screen channel with a 600 mm diameter pipe. Before wastewater reaches the anaerobic reactor, it passes through a course screen, a fine screen and an aerated grit chamber. From the anaerobic reactor, the activated sludge flows to aeration circuit. Aeration circuit was designed as an extended aeration activated sludge process. Required oxygen is provided from the blowers. If it is necessary $FeCl_3$ can be added to anaerobic reactor for additional chemical P removal and to improve sludge settling characteristics. From the aeration circuit, the activated sludge flows to secondary clarifiers. The return sludge is recycled to the anaerobic reactors (Bio-P tanks).

Waste activated sludge taken from the settling tank is sent to the aeration sludge tank. The secondary sludge collected in sludge tank is aerated and mixed with an aerator for stabilizing. After stabilization, the sludge is sent to centrifuges and dewatered. The internal flow from the sludge treatment is recycled after the screen. A schematic presentation of treatment plant is given in Figure 5.1 and a view from above is given in Figure 5.2.

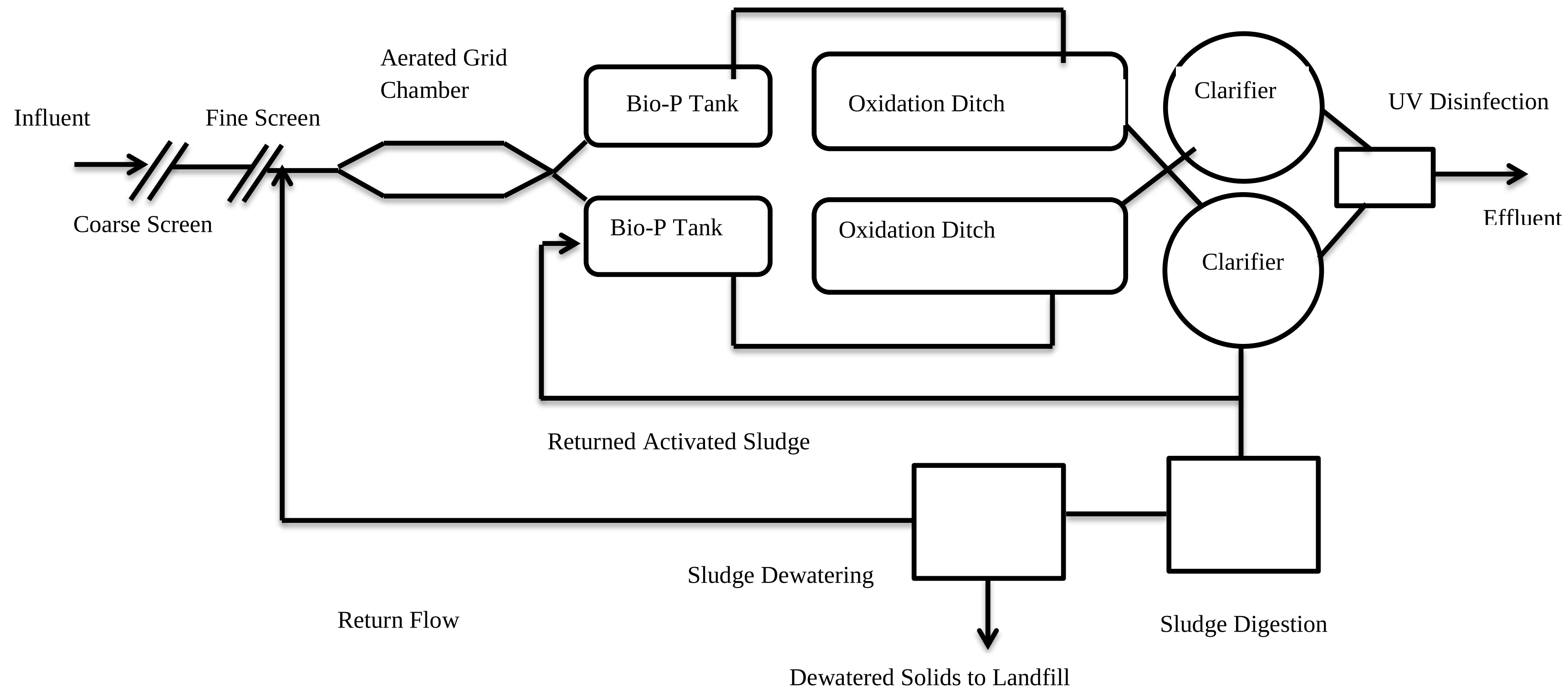


Figure 5.1 Flow diagram of BWTP

5.1.2 Design and Dimensioning

The design parameters of Bayındır Wastewater Treatment Plant and effluent requirements are given in Table 5.1 and 5.2.

Table 5.1 Design parameters of BWWTP.

Parameter	**Unit**	**Value**
Average Flow	m3/d	6912
COD	mg/L	600
BOD5	mg/L	400
Total-P	mg/L	6
SS	mg/L	500
Total N	mg/L	60

Table 5.2 Effluent requirements (Discharge limits).

Parameter	**Unit**	**Value**
COD	mg/L	≤90
BOD5	mg/L	≤ 20
Total-P	mg/L	≤ 2
SS	mg/L	≤ 30
Total N	mg/L	≤ 12

The dimensions and some design aspects of the activated sludge reactors are listed in Table 5.3.

Table 5.3 Features of activated sludge reactors in BWWTP.

Reactor		Unit	Value
Anaerobic Rector	total net volume	m3	510
	number of reactor	_	2
	aerated/non aerated	_	non-aerated
	type of reactor	_	circuit
Aerated Reactor	total net volume	m3	5550
	number of reactor	_	2
	type of reactor	_	circuit

Figure 5.2 A view from Bayındır Wastewater Treatment Plant.

5.2 Conducted Experiments

5.2.1 Determination of Treatment Plant Performance

Initially, information was collected about the operation of wastewater treatment plant and current situation was analyzed. Samples were taken from different parts of plants and a series of tests were carried out. First tests are conducted to determine the treatment plant efficiency under current operation and whether the plant satisfies discharge limits in terms of COD, BOD_5, TSS, Total Nitrogen and Total Phosphorus (TP). The results of analyses were shown below with tables and figures.

5.2.1.2 Obtained Data

5.2.1.2.1 Flowrate. Flow rate is one of the important parameter that determines hydraulic retention time (HRT) and loading rates in treatment plants. When calculating the value of HRT, the recirculation flow rate entering anaerobic reactor must not be forgotten. Especially, anaerobic retention time must be taken into account for design and performance analyses in BPR processes. Formation of fermentation products like VFAs utilized by PAOs requires adequate time.

Generally at BWTP, flow rate variations are within a small range. Significant changes in flow rate occur depending on the infiltration. As shown in Table 5.4, flow rates usually remain in the range of 2500-3000 m^3/d. Peak flow rate is usually 1.3-1.5 times of average hourly flow rate. When the daily flow rate is 2888 m^3/d, peak flow rate and the lowest flow rate was observed as 155 m^3/h between 12.00-13.00 and 82 m^3/h between 06.00- 07.00 respectively.

Table 5.4 Daily flow rates come to BWTP.

Date	Flow rate (m3/d)
01.04.2011	2301
02.04.2011	1963
03.04.2011	2319
04.04.2011	2275
05.04.2011	2315
06.04.2011	2358
07.04.2011	2359
08.04.2011	2365
09.04.2011	2390
10.04.2011	2395
11.04.2011	2423
12.04.2011	2611
13.04.2011	2868
14.04.2011	3505
15.04.2011	2927
16.04.2011	2921
17.04.2011	2937
18.04.2011	3147
19.04.2011	3019
20.04.2011	2870
21.04.2011	2919
22.04.2011	2951
23.04.2011	3025
24.04.2011	2968
25.04.2011	2693
26.04.2011	2863
27.04.2011	3018
28.04.2011	2750
29.04.2011	2845
30.04.2011	2762
01.05.2011	2687
02.05.2011	2717
03.05.2011	2772
04.05.2011	2781
05.05.2011	3099
06.05.2011	2659
07.05.2011	2616
08.05.2011	2567
Average	2709

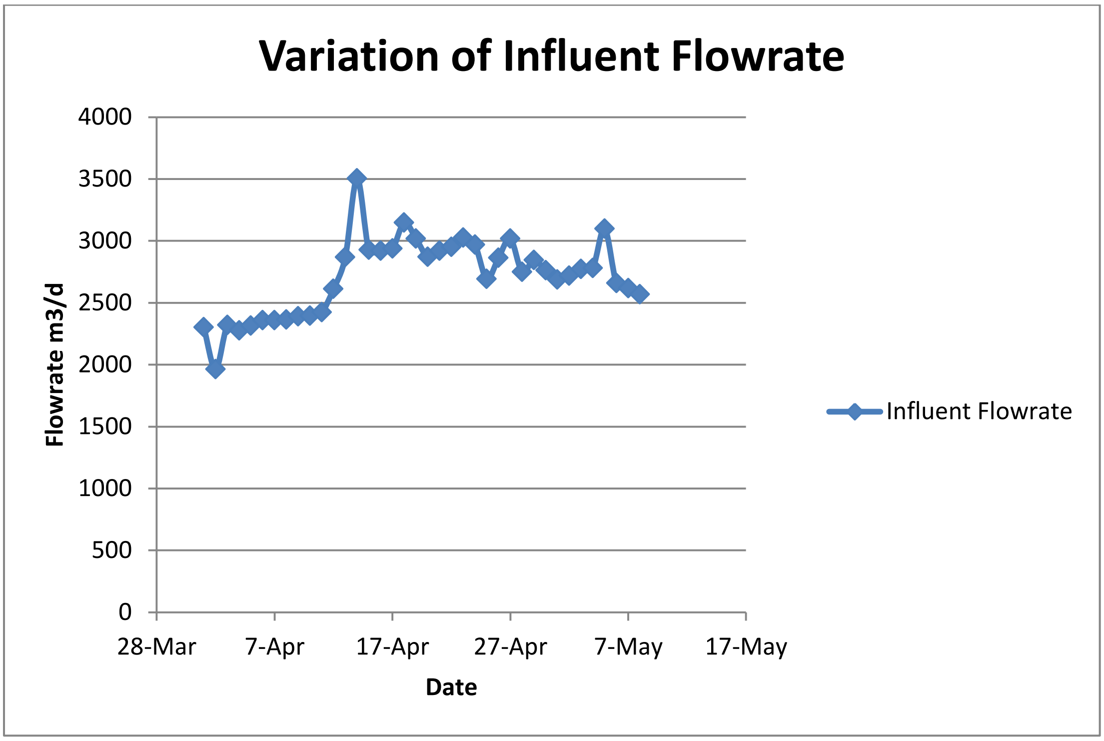


Figure 5.3 Variation of influent flow rate.

5.2.1.2.2 Quality Data. Experiments were conducted from the date 0.1.04.2011 to 13.05.2011 in BWTP laboratory. Obtained results are presented in in two distinct tables below.

As shown in Table 5.5 and 5.6, obtained results are typical domestic wastewater concentrations values and consistent with expected values. However, effluent concentrations satisfy discharge limits except total phosphorus and nitrogen. This situation in treatment plant that have BPR process, indicates a problem.

Table 5.5 Influent BOD$_5$, COD, SS, TOT-N, TOT-P and NH$_4$ -N Concentrations.

PARAMETER DATE	BOD5 (mg/L)	COD (mg/L)	SS (mg/L)	TOT-N (mg/L)	TOT-P (mg/L)	NH4-N (mg/L)
01.04.2011	378	882	371	47,00	6,71	18,40
04.04.2011	587	1676	507	55,30	7,05	15,80
05.04.2011	363	791	289	47,20	5,40	17,90
06.04.2011	238	425	231	37,80	5,60	18,60
07.04.2011	253	470	221	39,20	5,14	17,60
08.04.2011	278	510	250	39,90	5,64	18,20
11.04.2011	403	572	272	43,60	5,95	15,60
12.04.2011	176	310	103	59,30	4,74	19,70
13.04.2011	270	458	258	37,70	5,28	16,70
14.04.2011	263	538	138	38,90	5,74	20,70
15.04.2011	284	532	358	49,60	5,38	19,80
18.04.2011	214	445	212	43,70	5,24	17,70
19.04.2011	211	413	223	43,30	4,69	18,60
20.04.2011	250	446	231	39,30	4,86	15,44
21.04.2011	246	321	142	33,30	5,88	19,30
22.04.2011	241	446	220	37,60	5,05	19,10
25.04.2011	219	416	193	40,30	5,51	25,50
26.04.2011	288	470	231	52,80	6,54	28,40
27.04.2011	249	469	274	39,30	5,44	19,90
28.04.2011	290	690	385	39,90	6,15	17,40
29.04.2011	198	404	167	35,90	4,68	17,00
02.05.2011	248	425	174	38,8	4,99	18,50
03.05.2011	236	431	177	51,2	4,81	18,30
04.05.2011	305	347	333	41,9	7,51	21,00
05.05.2011	289	491	277	35,2	5,78	16,10
06.05.2011	266	569	479	35,7	5,89	16,00
09.05.2011	270	556	255	43,0	5,87	19,10
10.05.2011	210	402	117	36,5	4,85	20,50
11.05.2011	309	517	236	44,9	6,94	20,20
12.05.2011	166	356	134	41,3	4,68	18,80
13.05.2011	120	251	159	27,1	3,47	11,60
AVARAGE	268,2	517	245,7	41,82	5,53	18,62

Table 5.6 Effluent BOD_5 , COD, SS, TN, TP, NH_4-N and NO_3-N Concentrations.

PARAMATER DATE	BOD5 (mg/L)	COD (mg/L)	SS (mg/L)	TOT-N (mg/L)	TOT-P (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)
01.04.2011	4,7	20,40	6,50	12,60	2,59	0,140	7,38
04.04.2011	2,1	19,60	3,93	13,20	2,23	0,097	7,58
05.04.2011	5,9	29,60	1,67	4,80	3,30	0,068	1,69
06.04.2011	3,7	20,90	5,92	4,87	1,43	0,101	2,31
07.04.2011	3,7	28,40	3,80	13,00	1,77	0,089	7,50
08.04.2011	4,0	29,40	6,60	15,60	2,31	0,131	11,60
11.04.2011	4,4	28,60	7,33	16,80	4,60	0,090	10,70
12.04.2011	8,2	31,20	4,70	25,10	4,28	0,080	20,60
13.04.2011	1,8	27,50	7,10	24,70	4,80	0,063	21,30
14.04.2011	1,0	32,50	8,47	22,70	4,45	0,073	20,70
15.04.2011	1,4	24,80	6,53	20,90	3,85	0,062	18,30
18.04.2011	1,6	40,50	7,13	24,20	3,77	0,074	19,00
19.04.2011	0,9	31,70	11,60	24,10	3,62	0,270	19,20
20.04.2011	0,8	29,40	7,20	24,80	3,41	0,062	19,60
21.04.2011	1,1	26,20	4,27	21,10	3,51	0,060	20,10
22.04.2011	1,1	37,00	26,40	26,00	3,82	0,097	19,40
25.04.2011	2,0	35,80	10,80	25,60	3,79	0,173	24,50
26.04.2011	1,6	19,60	3,82	28,00	3,50	0,077	22,80
27.04.2011	5,6	23,60	3,67	27,10	3,71	0,076	24,20
28.04.2011	1,8	25,50	4,93	26,20	3,65	0,077	23,20
29.04.2011	0,9	20,70	4,20	24,80	3,53	0,104	22,00
02.05.2011	1,2	21,30	3,13	23,1	3,70	0,083	20,8
03.05.2011	2,7	24,50	4,07	23,8	3,23	0,083	20,8
04.05.2011	1,4	20,90	3,27	21,9	3,69	0,205	22,7
05.05.2011	5,4	21,80	3,83	22,5	3,23	0,337	21,2
06.05.2011	3,0	19,20	4,20	21,2	3,08	0,154	20,6
09.05.2011	3,9	21,50	4,20	21,5	3,04	0,098	18,7
10.05.2011	1,4	23,80	4,06	20,1	2,82	0,119	18,8
11.05.2011	1,3	22,30	3,47	18,4	2,51	0,164	17,6
12.05.2011	1,9	28,60	8,64	20,0	2,58	0,175	18,6
13.05.2011	1,3	24,90	6,53	20,0	1,91	0,088	17,8
AVARAGE	2,64	26,18	6,19	20,6	3,28	0,115	17,46

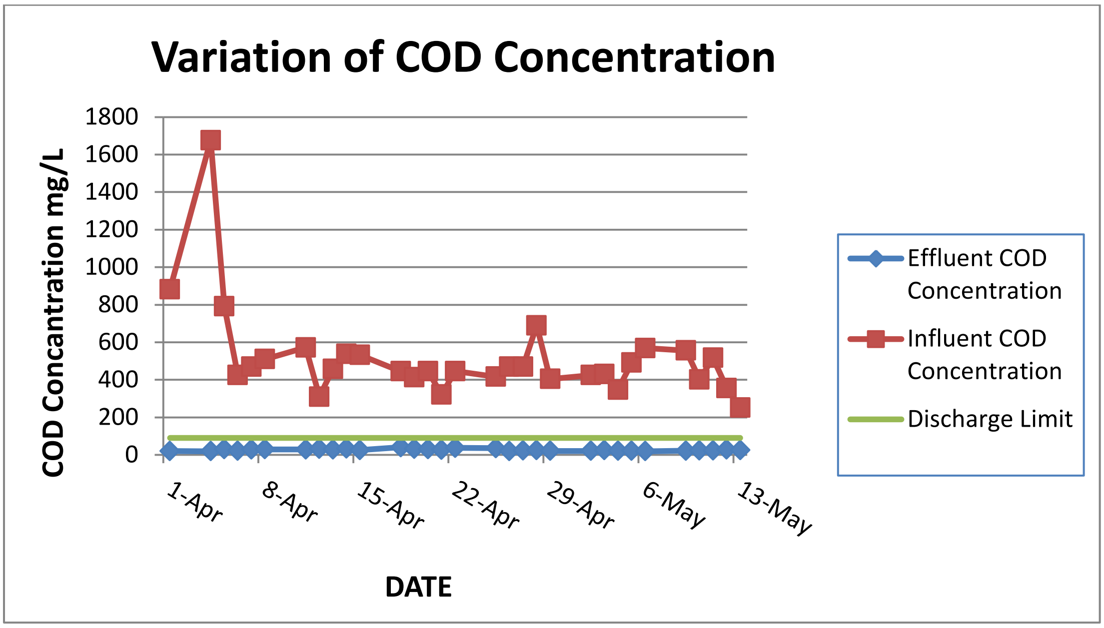


Figure 5.4 Variation of COD concentrations.

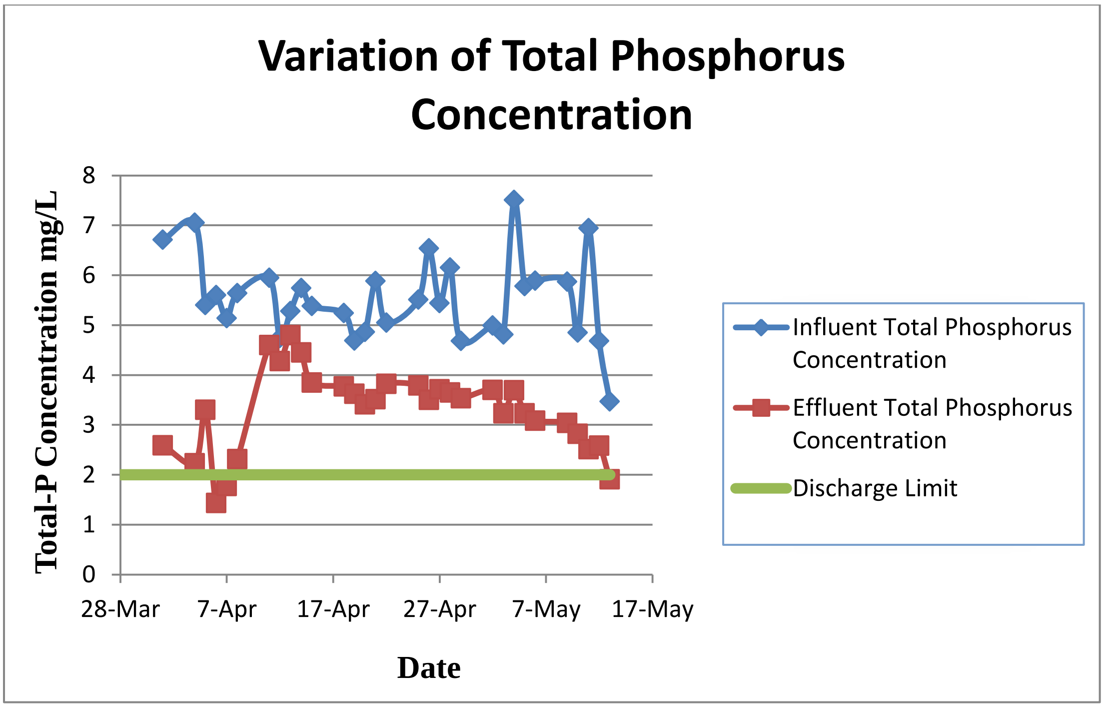


Figure 5.5 Variation of total phosphorus concentrations.

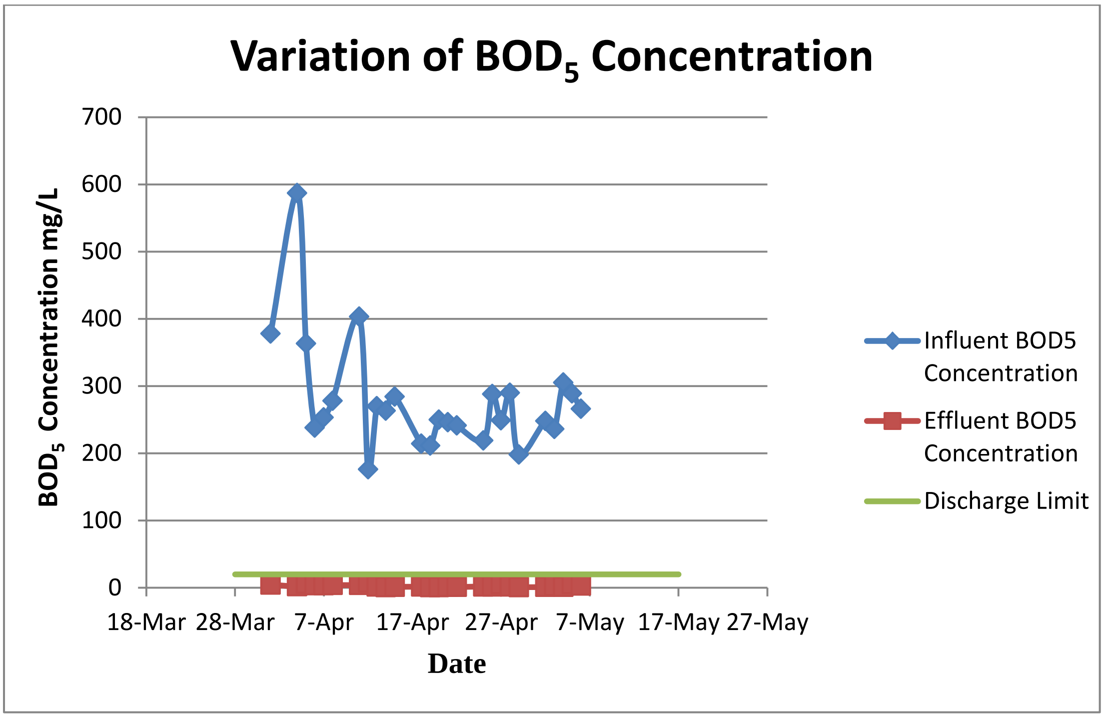


Figure 5.6 Variation of BOD5 concentrations.

Treatment efficiencies were calculated using average concentrations of obtained results and shown in Table below.

Table 5.7 Treatment efficiencies.

Parameter	Treatment Efficiency %
COD	94.9
BOD5	99
TP	40
TN	50

As shown above, the results of analyses put forward that wastewater treatment plant cannot meet the discharge total phosphorus and nitrogen limits. This may result from the operation of the wastewater treatment plant or design. In these thesis, phosphorus removal mechanisms and reasons leading to low phosphorus removal efficiency will be investigated. Obtained results will be compared with the literature values.

CHAPTER SIX

RESULTS AND DISCUSSION

6.1 Evaluation of COD/TP, rbCOD/TP and BOD_5/TP Ratios

As mentioned in the literature review, the most important thing that affects the process performance is wastewater characteristic. According to Randall et al., (1992), a BOD_5/TP ratio of 20:1 and a COD/TP ratio of 40:1 are needed to achieve an effluent total phosphorus concentration of 1 mg/l or less. Actually, this ratio varies according to process configuration and some authors but COD/TP ratio of 40:1 is the most widely accepted rate. In the Table 6.1, COD/TP ratios of influent are presented.

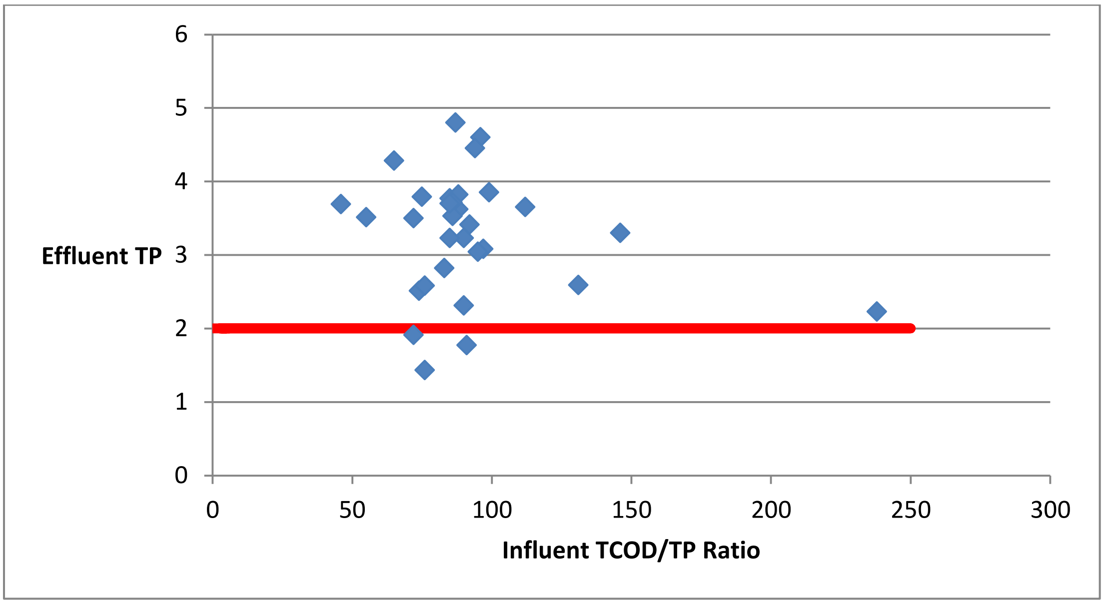


Figure 6.1 Variation of effluent TP depending on TCOD/TP ratio.

Table 6.1 COD, TP, COD/TP, BOD_5/TP ratios.

DATE	**Influent COD (mg/L)**	**Influent TP (mg/L)**	**COD/TP**	**BOD5/TP**
01.04.2011	882	6,71	131	56
04.04.2011	1676	7,05	238	83
05.04.2011	791	5,40	146	67
06.04.2011	425	5,60	76	42
07.04.2011	470	5,14	91	49,
08.04.2011	510	5,64	90	49
11.04.2011	572	5,95	96	67
12.04.2011	310	4,74	65	37
13.04.2011	458	5,28	87	51
14.04.2011	538	5,74	94	45
15.04.2011	532	5,38	99	52
18.04.2011	445	5,24	85	40
19.04.2011	413	4,69	88	44
20.04.2011	446	4,86	92	51,
21.04.2011	321	5,88	55	41
22.04.2011	446	5,05	88	47
25.04.2011	416	5,51	75	39
26.04.2011	470	6,54	72	44
27.04.2011	469	5,44	86	45
28.04.2011	690	6,15	112	47
29.04.2011	404	4,68	86	42
02.05.2011	425	4,99	85	49
03.05.2011	431	4,81	90	49
04.05.2011	347	7,51	46	40
05.05.2011	491	5,78	85	50
06.05.2011	569	5,89	97	45
09.05.2011	556	5,87	95	45
10.05.2011	402	4,85	83	43
11.05.2011	517	6,94	74	44
12.05.2011	356	4,68	76	35
13.05.2011	251	3,47	72	34
Average	**517**	**5.53**	**93**	**47**

An average COD/TP result of 93 was obtained. BOD_5/TP ratio is also above literature value of 20. These are substantially high ratios and an efficient phosphorus removal performance is expected. However, determination of rbCOD concentration of influent will be more appropriate for process performance, because rbCOD is the primary source of volatile fatty acids used by PAOs. The rbCOD can be converted to short-chain VFAs in the anaerobic zone and then used by PAOs. “If data are available about rbCOD, literature shows that good biological phosphorus removal was observed at rbCOD-to-TP ratios of about 15’’ (EPA, 2009). ‘’Finally, if VFAs have been determined, it has been found that a minimum VFA-to-TP ratio of at least 4 is recommended to obtain good biological phosphorus removal’’ (Neethling et al. 2005). In BWTP, rbCOD concentrations were determined on different days for evaluation.

Grab and composite samples were taken from influent and effluent of treatment plant. Readily biodegradable COD (rbCOD) tests were carried out in accordance with the test method described in appendices. Results are shown in Table 6.2.

Table 6.2 Obtained rbCOD/ TP ratios.

Date	**Influent COD (mg/L)**	**Influent rbCOD (mg/L)**	**TP**	**rbCOD/TP**
05.05.2011	535	82.8	5.63	14.70
06.07.2011	496	93.0	6.10	15.24
08.07.2011	423	35.7	4.46	8.0
12.07.2011	417	42.8	5.37	7.97

As shown in Table 6.2 two values are low. Grab samples that have high rbCOD values were taken at 11.00 and 13.00 respectively. The other ones were taken as composite samples. It is normal that composite samples have lower rbCOD concentrations but such a low concentrations are not expected. It may be resulted from that composite samples are not cooled. So these obtained low values are not reliable. Ratio of rbCOD/TP obtained from grab samples cause en exception of good phosphorus removal.

However as shown in Figure 6.1, effluent TP concentration is not decreasing as COD/TP ratio is increasing. This indicates that PAOs are not available in activated sludge.

6.2 Evaluation of Anaerobic Contact Time

Anaerobic HRT can be determined as using equation 6.1;

$$Anaerobic HRT = \frac{Vanaerobic}{Q + Qr} \tag{3.3}$$

Anaerobic HRT: Anaerobic hydraulic retention time

V $_{\textbf{anaerobic}}$: Volume of anaerobic tank

Q $_{\textbf{r}}$: Recycle flow rate

Recycle rate : %60

$$Anaerobic HRT = \frac{510 m^3}{155 m^3 / h + 93 m^3 / h} = 2{,}21 h$$

Anaerobic contact time of 2.21 h is appropriate and sufficient for fermentation and formation of PHB. According to Metcalf-Eddy detention time of 0.25h to 1h are adequate for fermentation of rbCOD. However, very high contact times like 4-5 h may lead to secondary phosphorus release. “Hydraulic retention time of anaerobic reactor for biological P removal is chosen between 0.5h-2h’’(Ministry of Environment and Forest, 2003).

6.3 Evaluation of P Release In Anaerobic Reactor

As shown in Figure 6.2, influent total phosphorus concentration of 4.64 mg/L dropped to 3.63 mg/L after wastewater passed through anaerobic reactor. Vice versa, it is expected to rise in phosphorus concentration. P profiles must be as dashed line. Under anaerobic condition, PAOs take up acetate and store it as PHB. Required energy is provided through breakdown of polyphosphate which results in an increase in phosphate concentration in an anaerobic stage.

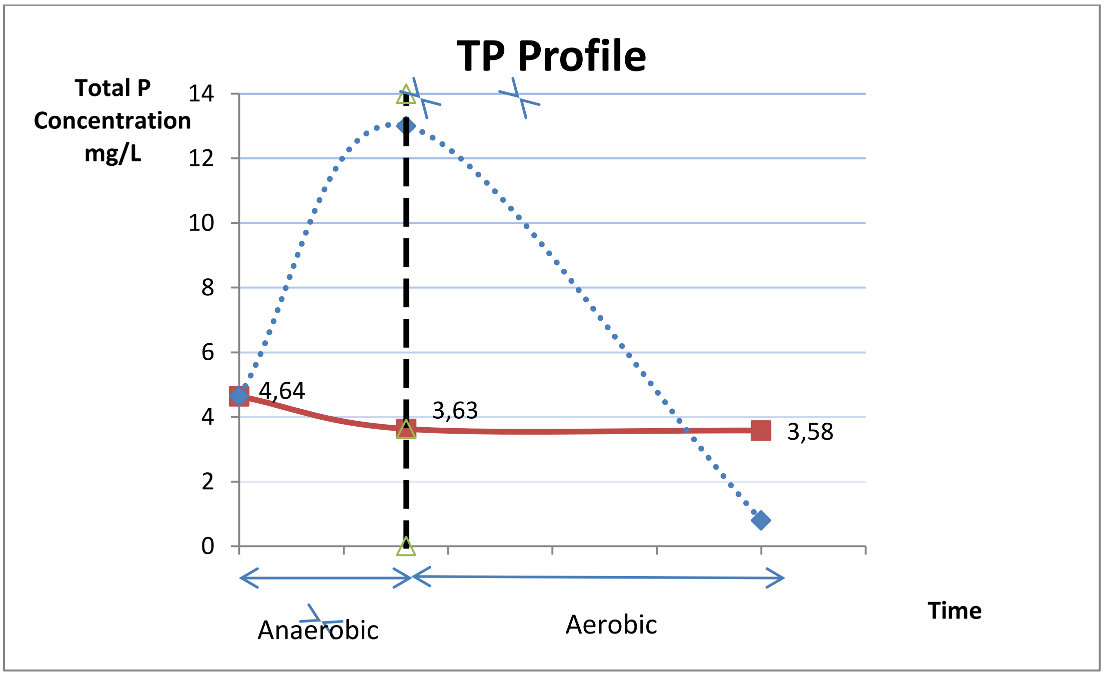


Figure 6.2 Variation of phosphorus concentration through anaerobic and aerobic zone.

Not increasing of phosphorus concentration through “anaerobic tank’’ indicates that anaerobic tank serves as anoxic or aerobic. Under aerobic or anoxic condition release of phosphorus does not occur.

Unlike the autotrophic organisms (e.g., the nitrifiers), which use carbon dioxide (CO_2) in its soluble form HCO (i.e., bicarbonate alkalinity) as their carbon source for growth and have a strict need for oxygen, heterotrophs can grow under the absence of oxygen when other electron acceptors, such as nitrate (NO_3), are present. Hence, PAOs can grow under both anoxic and aerobic conditions, as long as the one and only requirement for their proliferation is met: presence of an anaerobic zone at the head of the secondary treatment units, where no electron acceptor is present, and the secondary influent is introduced (Water Environment Federation, 2006).

6.4 Evaluation of Biochemical Reaction Occurring in Anaerobic Reactor

Grab samples were taken from anaerobic tank in order to determine conditions operated under. After filtration, nitrate concentration was measured. Nitrate and oxygen concentration are presented in Table 6.3.

Table 6.3 Dissolved oxygen and nitrate concentrations.

Date	Dissolved Oxygen (mg/L)	NO3-N (mg/L)
02.05.2011	0.17	2.170
03.05.2011	0.16	0.220
04.05.2011	0.20	0.208
05.05.2011	0.38	0.183
06.05.2011	0.51	0.906
07.05.2011	0.45	-
08.05.2011	0.19	-
09.05.2011	0.33	-
10.05.2011	0.10	-
11.05.2011	0.47	-
12.05.2011	0.38	-

In anaerobic tank, dissolved oxygen values remains between 0.2-0.5 mg/L. Although P release is observed under oxygen levels 0.1 to 0.5 mg/L, this value must be near zero (0). High levels of oxygen can inhibit P release or decrease the release rate.

In BPR systems, the anaerobic zone must be kept devoid of oxygen (0.0–0.2 mg/L oxygen) as the presence of oxidizing substances such as oxygen and nitrate will interfere with the BPR process **(**Mulkerrins et al.,2003).

Table 6.4 DO, pH and ORP values of anaerobic reactor.

Dissolved Oxygen mg/L	pH	ORP (mV)
0.14	7.79	36
0.21	7.58	5
0.46	7.60	45
0.34	7.71	25

In anaerobic reactor, nitrate is used as electron acceptor and result in consumption of rbCOD available for PAOs. Generally nitrate concentration in the bio-P tank remains circa 0.25 mg/L but at the same time high levels of nitrate like 2.1 mg/L was also observed. However, ORP is measured in anaerobic tank to promote results obtained from experiments. “In biological phosphorus release, fermentative bacteria produce fatty acids in an anaerobic tank having an ORP range of -100 to -225 mV’’ (Gerardi,2007). ORP values measured are given in Table 6.4. Measured values are compared with the values in Table 6.5. ORP values indicate that anaerobic tank acts as anoxic.

Table 6.5 Biochemical reactions and ORP values (Gerardi, 2007).

Biochemical Reaction ORP,	mV
Nitrification	+100 to +350
cBOD degradation with free molecular oxygen	+50 to +250
Biological phosphorus removal	+25 to +250
Denitrification	+50 to -50
Sulfide (H2S) formation	-50 to -250
Biological phosphorus release	-100 to -250
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

All of the results obtained from anaerobic tank indicate that nitrate enters the anaerobic reactor with recycle streams.

6.5 Evaluation of the Effect of Recycle Nitrate and DO to Anaerobic Reactor on System Performance

In order to understand nitrate effect on system performance, a mass balance equation was established around anaerobic reactor after determination of recycle flow nitrate and oxygen concentrations. In Table 6.6 DO concentrations measured after aerated grid chamber are given too. Because the flows enters anaerobic reactor after it pass through grid chamber. The oxygen concentration of flow affects the P release. These values are not considered as they are very low.

Table 6.6 Recycle nitrate, dissolved oxygen concentrations.

Date	Nitrate mg/L	Dissolved Oxygen mg/L	DO Downstream of Grid Chamber mg/L
02.07.2011	15.8	2.1	0.18
03.07.2011	16.1	1.9	4.33
04.07.2011	14.8	2.3	0.23
05.07.2011	16.4	3.4	0.25
06.07.2011	16.8	0.9	-
07.07.2011	17.4	1.1	-
08.07.2011	14.9	2.8	-
09.07.2011	16.0	2.6	-
10.07.2011	18.1	1.4	-
11.07.2011	16.2	1.5	-
12.07.2011	15.8	1.9	-
13.07.2011	17.1	2.4	-
Average	**16.28**	**2.025**	**-**

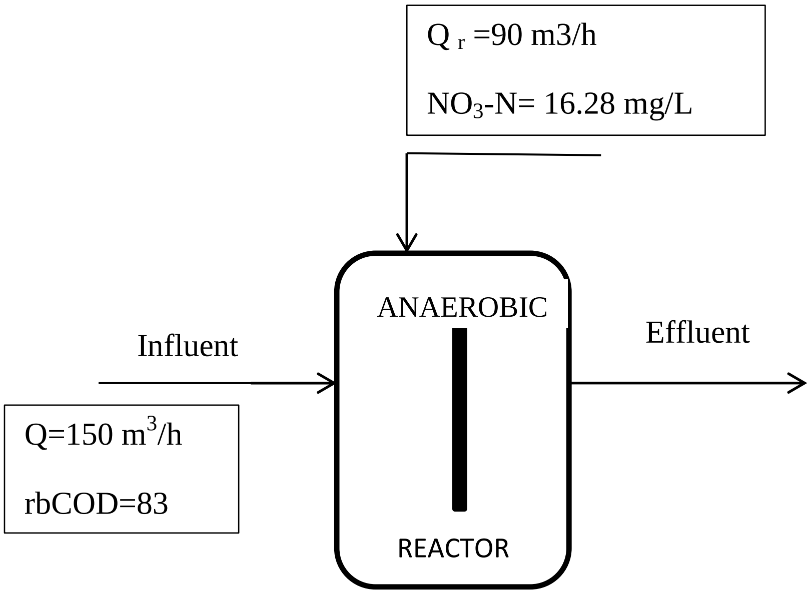


Figure 6.3 Flows enters anaerobic reactor.

Consumed rbCOD by NO_3-N and O_2, available rbCOD for P removal are calculated by using equation 6.2 and 6.3.

-6.6 g rbCOD/ g NO_3-N (Metcalf& Eddy, 2003).

-2.3 g rbCOD used/ g DO added (Metcalf& Eddy, 2003).

Consumed rbCOD= (Q_{RAS} x (NO_3-N) $_{RAS}$ x 6.6) + (Q_{RAS} x O_{2RAS} x 2.3) (6.2)

Available rbCOD for P removal= [Q x C (rbCOD) - Consumed rbCOD]/Q (6.3)

Where;

Q: influent flow rate

Q_{RAS}: recycle flow rate

Consumed rbCOD by NO_{3}-$_{N}$ and O_2;

(90 m3/h x 16.28 mg/L x 6.6) + (90 m3/h x 2 mg/L x 2.3) = 10084 g

rbCOD available for P removal;

[(150 m3/h x 83 mg/L)- 10084 g] /150 m3/h = 15.77 mg/L rbCOD

The reduction amount is then (83-15.77)/83 = % 81

Under these circumstances, an effective P removal is impossible due to the high nitrate input to anaerobic reactor. Theoretically phosphorus concentration that can be removed is calculated as follow;

10 mg rbCOD used/ mg P removed

15.77 mg/L rbCOD/ 10 = 1.57 mg/L P can be removed.

In BWTP, one of the reasons of effluent P concentrations over discharge value is nitrate and oxygen input via recycles streams. Nitrate and oxygen entering the anaerobic reactor result in low P removal efficiency.

As shown in Table 6.6 high nitrate concentrations in recycle stream are evidence of that treatment plant is operated under nitrification but denitrification does not occur in oxidation ditch. However in Table 5.7, N removal efficiency is 50 %. N removal occurs in anaerobic tank with a large probability because this tank acts as anoxic.

As can be seen in Table 5.5 and 5.6, average influent and effluent Total-N concentrations are 41.2 mg/L and 20.6 mg/L respectively. Average NO_3-N concentration in effluent is also 17.46 mg/L.

Table 6.7 Monthly average influent and effluent total- N concentrations.

Date	Inf.TN (mg/L)	Eff.TN (mg/L)	Eff.NO3-N (mg/L)	Inf.COD (mg/L)
July (Average)	35.5	19.1	16.3	405

A mass balance equation can be established for N. It is more appropriate to use values of July. Because, the rain and infiltration into the sewer, NO_3-N concentration of influent may be relatively high. Mass balance equation will be established with the acceptation that influent NO_3-N and NO_2-N concentrations are zero (0).

$C_{NO2N,inf} = 0 \quad C_{NO3N,inf} = 0$ (Accepted)

$$TKN = Norg + NH_3\text{-}N \tag{6.4}$$

$$TN = NO_3\text{-}N + NO_2\text{-}N + TKN \tag{6.5}$$

$C_{NO2N,inf} = 0 \quad C_{NO3N,inf} = 0$ (Accepted) then, TKN= TN

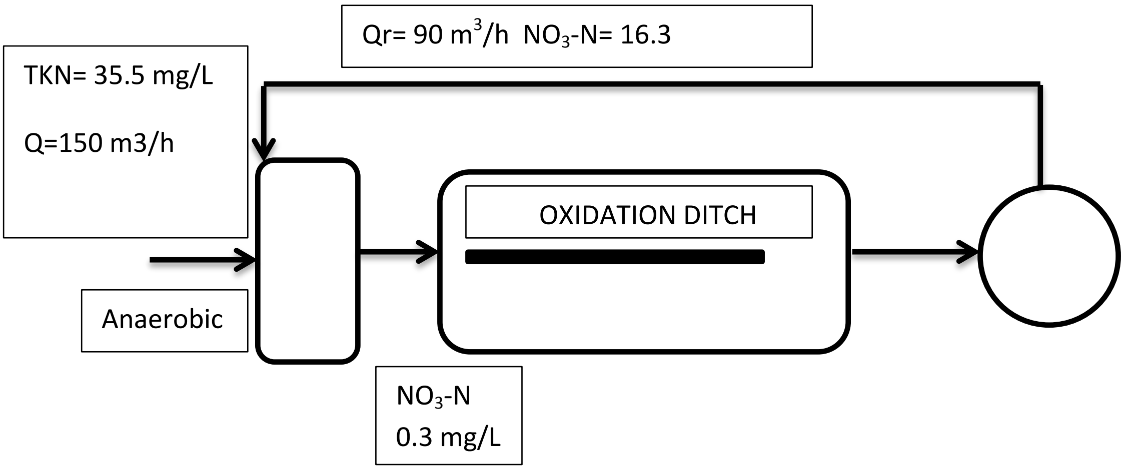


Figure 6.4 Flow diagram and N concentrations.

$X_{orgN,BM}$: concentration of nitrogen taken into the cell

- It is considered to be 0.02-0.025 percent of influent COD concentration. (According to ATV-DVWK-A 131E)

The amount of nitrate (N_R) reduced in anoxic zone is as follow;

N_R=90 m3/h x 16 mg/L- (150+90) m3/h x 0.3 mg/L = 1368 g/h

Total N concentration in effluent is calculated approximately as follow;

Eff. TN = TKN -N_R- $X_{orgN,BM}$

Eff.TN= (150 m3/h x 35.5 mg/L – 1368 g/h)/ 150 m3/h – 405 mg/L x 0.02 =18.28 mg/L.

Total N concentration is found as 18.28 mg/L. The average monthly values are used in here. The obtained result is very close to the value of average monthly effluent TN concentration. This gives an idea how the system is running. Nitrogen removal occurs in anaerobic tank however denitrification cannot occur in oxidation ditch. Now we will discuss the reason of that nitrogen cannot be removed in oxidation ditch.

6.6 Evaluation of Aerobic Reactor

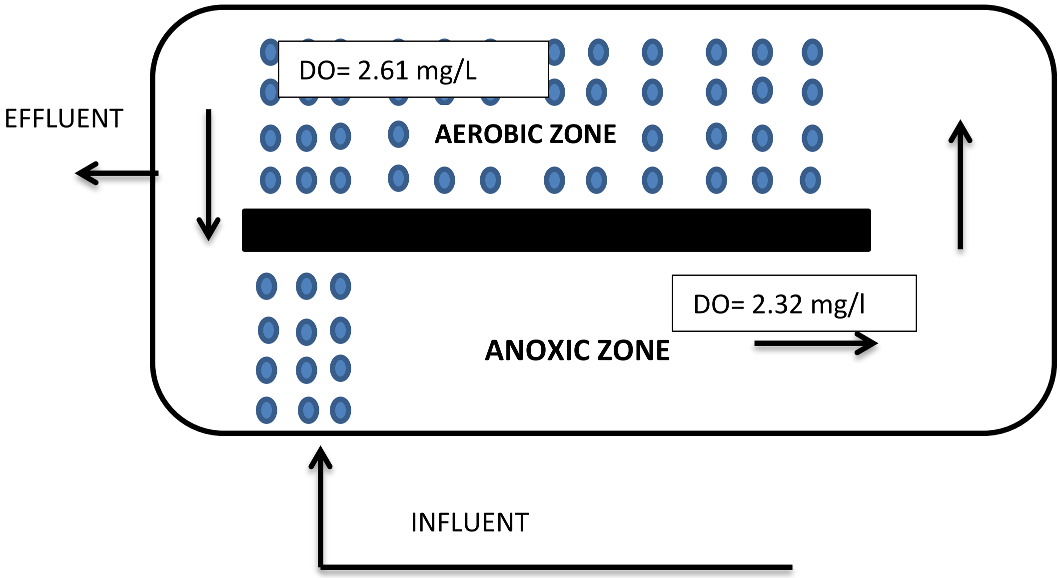


Figure 6.5 Aerobic and anoxic zones of oxidation ditch.

Aerobic reactor in BWTP was designed as oxidation ditch. Oxidation ditches are looped channels that provide continuous circulation of wastewater and biomass. A number of operating methods and designs have been developed to achieve nitrogen removal, all of which work by cycling the flow within the ditch between aerobic and anoxic conditions. In BWTP, oxidation ditch is designed to provide simultaneous nitrification and denitrification. In order to perform denitrification and create an anoxic zone, diffusors have not been put in one side of the oxidation ditch.

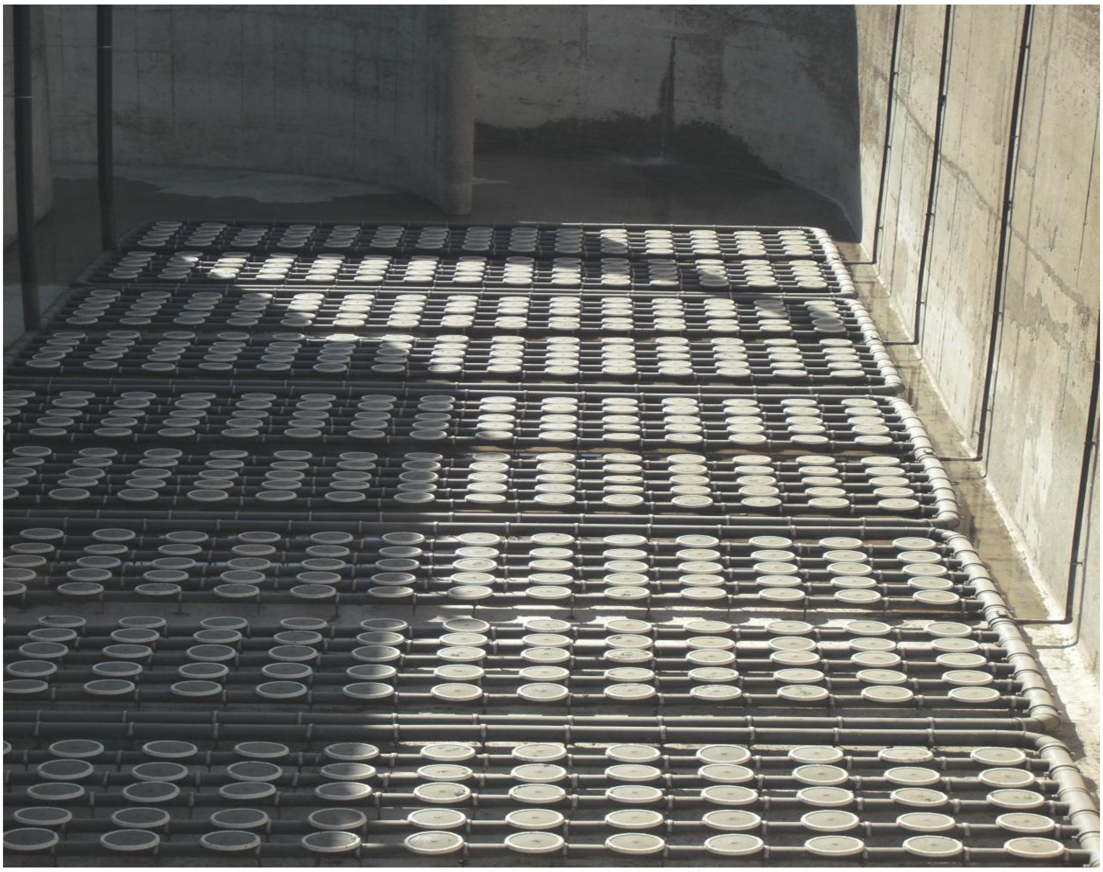


Figure 6.6 View of diffusors placed in the bottom of oxidation ditch.

Oxygen is supplied to oxidation ditch by blowers. Mixers are used to maintain biomass suspension and channel flow.

Table 6.8 Dissolved oxygen concentrations measured in aerobic and anoxic zones.

Aerobic mg/L	Anoxic mg/L
2.05	1.74
2.41	1.74
1.42	1.20
2.48	2.15
1.10	0.75

In BWWTP, process is controlled by oxygen meter. Two oxygen probes are present and mounted to oxidation ditch. One of them measure anoxic zone oxygen concentration the other one measure aerobic zone oxygen concentration. Aerobic and anoxic zone oxygen concentrations measured are given in Table 6.8 .However an ORP measuring device is present but not used for process control. To determine which biological reaction occurs in both anoxic and aerobic zone of oxidation ditch, ORP is measured and compared with Table 6.5. Obtained ORP values are given in Table 6.9.

Table 6.9 Dissolved oxygen, pH and ORP values in aerobic and anoxic zones.

Oxidation Ditch Zones	Dissolved Oxygen (mg/L)	pH	ORP (mV)	Range (mV)
Aerobic Zone	3.29	7.31	230	+50 +250
Anoxic Zone	2.63	7.37	211	-50 +50

As shown in Table 6.9 ORP values indicate that nitrification and cBOD degradation occurs in both zones. Anoxic conditions cannot be provided for denitrification. However, pH values are appropriate for P removal. As mentioned in literature at pH values below 6.5, P removal may decline significantly.

Average of the oxygen values measured in anoxic and aerobic zones are determined and transmitted to PLC control system. For instance, when the oxygen concentrations are 1.0 mg/L in anoxic and 2.0 mg/L in aerobic zone, then the average value will be 1.5 mg/L. Blower is activated below the average oxygen concentrations of 2 mg/L and blower is off above 3 mg/L. Oxygen set points have been adjusted as 2.0 and 3.0 mg/L. Creating an anoxic zone is impossible within oxidation ditch operated in such a range of oxygen levels. At the same time diffuse aeration creates disadvantages for simultaneous nitrification and denitrification system. This aeration method has high oxygen transfer efficiency. It complicates depletion of oxygen within flocks and creation of anoxic zone. “Point source aerators allow for much higher rate of denitrification in aeration basin, a fact that will not be reflected in any of the current models for BNR plants” (Randall et al., 1992).

Oxidation ditch system is a type of extended aeration and operated with long HRT and SRT. At the same time this is a low-loaded system that has low F/M value. “With such a low loaded system, the oxygen uptake rate can be estimated at about 7 mg/L-hr or only 0.1 mg/L-min.’’ (Randall et al., 1992).

The length of anoxic zone in oxidation ditch is 56 m. If the valve is off and air is not transferred to the diffusors located at anoxic side of ditch as a loop, this length will be 79 m. Channel velocity was determined as 0.35 m/s. The travel time through anoxic zone and the amount of oxygen depletion for both distances can be calculated as follow;

T: Travel Time

X: Length of anoxic zone

V: Channel velocity

C_1: Depletion of DO concentrations through 79 m

$C_{2:}$ Depletion of DO concentrations through 56 m

$$T_1 = \frac{X}{V} = \frac{56m}{0.35m/s} = 160s = 2.66\,\text{min}.$$

$$T_2 = \frac{X}{V} = \frac{79m}{0.35m/s} = 225.7s = 3.76\,\text{min}.$$

C_1= 2.66 min x 0.1 mg/L- min= 0.266 mg/L

C_2= 3.76 min x 0.1 mg/L-min= 0.37 mg/L

Thus, in 3.76 minutes the DO depletion would only be about 0.4 mg/L, and it is necessary to operate the system at a low DO concentration to assure condition for denitrification. However, obtained oxygen values shown in Table 6.8 confirm this. The optimum pH for denitrification is 6.5 to 8.0, and the optimum DO concentration is 0.0 mg/l. As DO levels increase from 0.0 to 0.3 mg/l, the denitrification rate goes down. If DO is greater than or equal to 0.3 mg/l, denitrification is completely inhibited. It is impossible to remove nitrogen in oxidation ditch by keep the oxygen values in the range of 2 -3 mg/L in aerobic zone.

There are not sufficient studies conducted about the effect of aerobic DO concentration on P uptake. As a result, oxygen levels in BWTP should be reduced for denitrification. Due to the high SRT and temperature, it is not possible to prevent nitrification under low oxygen levels. However, the nitrification capacity can be reduced. As for the removal of P, studies are present that high efficiencies are obtained at low oxygen levels , but the prevailing opinion is that at least 2 mg / L DO should be provided for efficient P uptake.

“The influent rbCOD concentration has a significant effect on the denitrification rate in the anoxic zone’’ (Metcalf & Eddy, 2003). Denitrification process uses carbon as energy sources. PAOs use rbCOD so that denitrification rate goes down in oxidation ditch. At the same time, this must be considered for design purposes.

6.7 Evaluation of SRT

One of the factors affecting the bio-P removal process is SRT. SRT is obtained by dividing biomass present in the system to biomass wasted per day. It can be formulated as follow;

$$SRT = \frac{V.X}{Qw.Xw} \tag{6.6}$$

The BWTP has an oxidation ditch that has aerobic retention time varying between 36-50 h. These extended aeration systems are designed due to longer SRTs. Oxidation ditches are usually operated at solids retention times (SRTs) of 25-30 days. At the same time this result in less sludge production. The amount of wasted sludge from BWTP is given in Table 6.10 with dates.

Table 6.10 Amount of waste sludge from BWTP.

Date	Solid Percent of Waste Sludge %	Mass of waste Sludge (kg/d)	Mass of dry solid (kg/d)
02.04.2011	23	14560	3348
09.04.2011	23	15520	3569
13.04.2011	27	15320	4136
23.04.2011	26	15610	4058
29.04.2011	23	15760	3624
08.05.2011	25	16430	4107

As shown in Table 6.10, excess sludge is not wasted daily. However in May, the sludge was wasted once. To calculate a SRT value, the amount of daily wasted sludge is required to be known. We assume that wasted total sludge in April and May is wasted daily. Daily wasted sludge is obtained dividing total sludge by number of days in month. SRT values will be as follow;

$$SRT_{APRIL} = \frac{5550m^3 \times 4023g/m^3}{624.5kg/d} = 35.75\,d$$

$$SRT_{MAY} = \frac{5550m^3 \times 3297g/m^3}{136.9kg/d} = 133.6\,d$$

High SRTs result in lower sludge yields and have adverse effect on biological phosphorus removal system. It decreases the P removal capacity of the system as it is operated under endogenous respiration that leads to P release. The basic principles of bio-P are sludge growth and remove the P with the excess sludge. Sludge must be wasted on a daily basis at SRT values lower than 30 d.

The concentration of phosphorus in the sludge typically increases as the SRT increases, although the impact is very small over the SRT range of 4 to 30 days. Efficient phosphorus uptake typically requires a minimum SRT of 3 to 4 days depending on temperature. Higher SRTs will not increase phosphorus uptake; given there is sufficient VFAs available. If SRT becomes too great, however, effluent quality can degrade. This can be due to release of phosphorus as biomass degrades (EPA, 2009).

Two adverse effects on phosphorus removal efficiency are associated with lightly loaded and long SRT processes. First, because the final amount of phosphorus removed is proportional to the amount of biological phosphorus-storing bacteria wasted, the phosphorus storing biomass production is lower so that less phosphorus can be removed. Second at long SRTs biological phosphorus are in a more extended endogenous phase, which will deplete more of their intracellular storage products. If the intracellular glycogen is depleted, less efficient acetate uptake and PHB storage will occur in the anaerobic contact zone, thus making the overall BPR process less efficient (Metcalf & Eddy, 2003).

P is taken into the cell and the only way of removing P from the system is wasting excess sludge. It is concluded that one of the reasons of not removing P biologically at BWTP is that sludge is not wasted daily.

In previous parts, it was indicated that anaerobic conditions could not be provided for enrichment of PAOs. Anoxic and aerobic conditions are present in BWTP. This means that PAOs are not present in activated sludge. Phosphorus removed in treatment plants results from that phosphorus is used by heterotrophic organisms for cell synthesis. Effluent phosphorus concentration can be calculated approximately by using kinetic equations according to SRT calculated above.

Recycle nitrate concentration: 16 mg/L

NO_x = (Qx16 mg/L+ 0.6Qx16 mg/L)/ Q= 25.6 mg/L

bCOD= 1.6x BOD= 1.6x281 mg/L= 449 mg/L

Assume $S_0 = S_0 - S$

$$Px,bio = \frac{Q(Y)(S_0 - S)}{[1+(k_d)SRT]} + \frac{Q(Y_n)(NO_x)}{[1+(k_{dn})SRT} \qquad (6.7)$$

$$Px,bio = \frac{(2702m^3/d)(0.4g/g)(449g/m^3)}{[1+(0.08g/g.d)(35d)]} + \frac{(2702m^3/d)(0.12g/g)(25.6g/m^3)}{[1+(0.08g/g.d)(35d)]}$$

Px,bio= 129889 g/d

P utilized for biomass growth:

P used = (0.015 g P/ g biomass) (129889 g/d) =1948 g/d

In g/ m^3= (1948 g/d)/ (2702 m^3/d) = 0.72 g/m^3

For the month April, average 2.2 mg/L P removal was achieved. In previous parts it was claimed that PAOs were not present in activated sludge. Calculations above were made according to Metcalf &Eddy to determine the amount of phosphorus used for cell synthesis and obtained value is very low. However according to ATV-DVWK-A 131E phosphorus utilized for cell growth is accepted as 0.005 of COD.

P utilized for biomass growth= 556 mg/Lx 0.005= 2.78 mg/L.

The amount of phosphorus used for cell synthesis is calculated according to IWA. The main difference from Metcalf &Eddy is kinetic coefficients.

$$X = \frac{QxYx(S_0 - S)SRT}{(1+k_d xSRT)} \qquad (6.8)$$

X: Total biomass in the system (g VSS)

Y: Biomass yield (g VSS/ g COD)

T: 16 °C

k_d= 0.08 x $1.072^{(16-15)}$= 0.085 d^{-1}

Assume bCOD= 0.82 x COD

Active heterotrophic bacteria;

$$X = \frac{2702m^3 x0.67x455mg / Lx35d}{1000(1 + 0.085x35d)} = 7252 \text{ kg bacteria-COD}$$

Inert amount heterotrophic bacteria;

Inert fraction=0.1

X= 7252 x 0.085 x 35 x 0.1=2157 kg bacteria-COD

Elimination P load by active fraction;

7252 kg x 0.03/35= 6.216 kg P/d

Elimination of P load by inert fraction;

2157 kg x 0.01/ 35= 0.61 kg P/d

Total heterotrophic elimination;

0.61+6.216=6.826 kg P/d

Decrease in P-concentration by heterotrophs;

6.826/ (2702 m^3/d) x1000 = 2.52 mg/L

Active autotrophic bacteria;

Total N= 35.5 mg/L

$$X = \frac{2702m3x0.24x35.5mg/Lx35d}{1000(1+0.05x35d)x(1.09^{(16-15)})} = 277 \text{ kg bacteria COD}$$

Inert amount of nitrifies;

X=277 x 0.05 x 1.09 $^{(16-15)}$ x 35 x 0.1=52 kg bacteria-COD

Total autotrophic elimination;

(277kg x 0.03/35)+ (52 kg x 0.1/ 35) = 0.386 kg

Decrease in P-concentration by autotrophic;

0.386 kg/ (2702 m^3/d) x 1000= 0.142 mg/L

Total P elimination;

0.142 mg/L+ 2.52 mg/L =2.66 mg/L

The reason of the difference between results is that kinetic coefficients and the amount of P utilized for the growth of a per gram of biomass are different in two calculations.

Consequently, 2.66 mg/L is greater value than obtained in practice. This means that it can be possible to achieve 33% percent of P removal without bio-P process.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Biological phosphorus removal (BPR) is a very complex process that many factors have effect on the process. In this thesis, parameters that affect BPR process such as influent COD/TP and BOD/TP ratio, rbCOD, SRT, pH, anaerobic contact time, DO concentration in anaerobic and aerobic zone, recycle NO_3-N and O_2 are determined and their effects on process performance are discussed.

This study was conducted in Bayındır Wastewater Treatment Plant. The wastewater treatment plant under operation was preferred instead of laboratory. Laboratory studies are conducted for practical aims, but sometimes unexpected results are encountered in practice. The conditions are changing continuously, so that results obtained from studies conducted in wastewater treatment plants under operation provides more significant information about process.

Firstly, to determine the wastewater treatment plant performance under current operation, samples were taken from influent and effluent and then analyzed. It was found that in contrast to COD and BOD_5 removal with high efficiencies, nutrients could not be removed efficiently. 50% N removal and 40% P removal were achieved in treatment plant. This means that effluent concentrations of nutrients cannot satisfy discharge limits.

The most important parameter affecting system performance is influent COD/TP and BOD_5/TP ratios. These ratios must be 40:1 and 20:1 respectively in order to achieve good phosphorus removal. Obtained results are above these ratios. Readily biodegradable COD (rbCOD) concentration was also analyzed in influent wastewater, because system performance depends on rbCOD fraction of wastewater.

High rbCOD values such as 93 and 83 mg/L were obtained from grab samples. RbCOD/TP ratios are also about 15. Results from grab samples appropriate for good P removal. After these ratios were determined, it is investigated that whether effluent P concentration decreases depending on the increasing of COD/TP ratio. Decreasing of P concentration is not observed in effluent. It indicates that PAOs are not present in activated sludge. At the same time, in following parts to promote this claim, P release test is conducted. It is expected that P concentration increases through anaerobic reactor. Vice versa, decreasing of P concentration was observed. This also indicates absence of PAOs in activated sludge.

By the way, average anaerobic contact time was calculated as 2.21 h. This time is enough for fermentation and assimilation of fermentation products by PAOs.

All studies conducted so far indicate that environmental conditions are not appropriate for the growth of PAOs. PAOs need anaerobic and aerobic environment for growth. Dissolved oxygen, ORP and NO_3-N were measured in anaerobic reactor to determine conditions which anaerobic reactor was operated under. Dissolved oxygen concentrations are found to be near zero (0). Only dissolved oxygen data are not enough to define the reactor as anaerobic. The reactor may be anoxic with these oxygen concentrations. Average nitrate concentration and ORP are measured as 0.7 mg/L and 27.75 mV respectively. ORP and nitrate measurements indicate the anoxic conditions in anaerobic reactor.

The only way for nitrate entrance to anaerobic reactor is return sludge stream. Average recycle NO_3-N and DO concentrations were measured as 16.28 and 2.025 mg/L respectively. These values are very high but they are not enough by themselves for determination of the impact on system performance. In order to assure effect of nitrate and dissolved oxygen, a mass balance equation is established around anaerobic rector by using return sludge ratio of 60%. It is concluded that electron acceptors like O_2 and NO_3-N enters anaerobic reactor cause %81 reduction of rbCOD available for PAOs. It is found that only 1.57 mg/L P can be removed by PAOs. These results were calculated by assumption that rbCOD concentration was

83 mg/L. If composite samples values were used in order to calculate P removal, lower removal values would be obtained.

Aeration basin was evaluated in terms of system performance. Oxygen concentration in oxidation ditch is appropriate for P uptake but this oxidation ditch was designed for the purpose of simultaneous nitrification and denitrification. Oxygen concentration is not reduced enough in anoxic zone of oxidation ditch. Oxygen concentrations, ORP and pH values are measured in anoxic and aerobic zone. The difference between oxygen concentrations in both zones is only 0.3 mg/L and obtained ORP values are in the range of nitrification. Denitrification does not occur in oxidation ditch. Anoxic zone length is determined as 59 m. This length can be up to 79 m by closing air valves. Both of the lengths are not enough for the reduction of oxygen concentration to zero (0) for denitrification. However, diffuse aeration, low loading and oxygen set point of 2-3 mg/L in oxidation ditch have adverse effect on denitrification.

SRT was considered to determine process performance. One of the reasons of low performance is that excess sludge is not wasted daily in BWTP. Phosphorus is taken up by PAOs and removed from the system by only waste sludge. Too long SRTs and operation in endogenous respiration phase can reduce phosphorus removal capacity in BWTP.

Consequently, COD/TP and readily biodegradable fraction of wastewater (rbCOD concentration) are very important parameters for high P removal performance. However, these parameters are not enough alone. For efficient P removal appropriate environmental conditions must be created and system must be operated with appropriate SRTs. This study introduced that although high COD/TP ratios, SRT, recycle NO_3-N and dissolved oxygen can inhibit P removal. NO_3-N and DO prevent to create anaerobic and aerobic environment for the growth of PAOs.

7.2 Recommendations

1. The basic principle of bio-P is sludge growth and removing the P with the excess sludge. An optimum SRT must be chosen and excess sludge must be wasted on a daily basis.

2. COD/TP ratio and rbCOD concentration should be determined and used for evaluation of process performance.

3. Recycle NO_3-N and dissolved oxygen concentration should be checked every day.

4. ORP must be used for process control in anaerobic, aerobic and anoxic zones.

5. Mechanical aeration must be preferred instead of diffuse aeration.

6. The system is low-loaded and aerobic zone of oxidation ditch must be operated with low oxygen concentrations such as 0.5-1 mg/L to create anoxic conditions.

7. In order to increase travel time of activated sludge through anoxic zone, shallower oxidation ditches must be constructed with same volume. For design purposes low-loading must be taken into account.

8. An anoxic reactor may be constructed on return sludge flow line or return sludge must be taken into anoxic zone of oxidation ditch.

9. Transition structure may be constructed between oxidation ditches. So, oxidation ditches can be operated in series and mixed liquor can be transferred from one oxidation ditch to another. High nutrient removal ratios can be obtained by operating as phase isolation ditch.

10. A part of raw wastewater can be fed into anoxic zone of oxidation ditch for safe denitrification.

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APPENDICES

Appendix A. Abbreviations

A/O	Anaerobic/Oxic
A^2/O	Anaerobic/Anoxic/Oxic
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
rbCOD	Readily Biodegradable Chemical Oxygen Demand
PAO	Phosphate Accumulating Organism
ORP	Oxidation Reduction Potential
TP	Total Phosphorus
BWTP	Bayindir Wastewater Treatment Plant
BPR	Biological Phosphorus Removal
SRT	Solid Retention Time
EPA	Environment Protection Agency
PHB	Poly-β-hydroxybutyrate
bsCOD	Biodegradable Soluble Chemical Oxygen Demand
EBPR	Enhanced Biological Phosphorus Removal
VFA	Volatile Fatty Acids
DO	Dissolved Oxygen
RAS	Return Activated Sludge
WAS	Waste Activated Sludge
TBOD	Total Biological Oxygen Demand
MLVSS	Mixed Liquid Volatile Suspended Solids
TKN	Total Kjeldahl Nitrogen

MLSS	Mixed Liquid Suspended Solids
TSS	Total Suspended Solids
PHA	Polyhyroxyalkanoic Acid
SDT	Solid Detention Time
TN	Total Nitrogen
UCT	University of Cape Town
VIP	Virginia Initiative Plant
ED	Entner-Doudoroff pathway
EMP	Embden-Meyerhoff-Parnas pathway
TCA	Tricarboxylic Acid Cycle
NAD	Nicotinamide Adenine Dinucleotide
NADH	Reduced Nicotinamide Adenine Dinucleotide
poly-P	Polyphosphate
OUR	Oxygen Uptake Rate
ATP	Adenosine Triphosphate
F/M	Food to Microorganism ratio
bCOD	Biodegradable Chemical Oxygen Demand

Appendix B. Symbols

N_R	Nitrate reduced in anoxic zone
$X_{orgN,BM}$	Concentration of organic nitrogen embedded in the biomass
V	Volume of Reactor
X	Biomass Concentration
Q_w	Waste Sludge Flowrate
X_w	Waste Activated Sludge MLSS Concentration
k_d	Endogenous Decay Coefficient
Y	Heterotrophic Synthesis Yield
T	Temperature
S_0	Influent BOD or bsCOD Concentration
S	Effluent BOD or bsCOD Concentration
Px, bio	Net waste activated sludge produced each day
Q	Flowrate
Y_n	Synthesis Yield For Nitrifying Organisms
k_{dn}	Endogenous Decay Coefficient For Nitrifying Organisms

Appendix C. Test Methods

For scientific studies, it is very important to conduct experiments accurately. Otherwise incorrect results are obtained and this may affect the accuracy of the result of study negatively. The routine analyses are conducted in the laboratory of BWWTP. Also, BWWTP was monitored for operational purposes. Concentrations of parameters in all experiments were checked using HACH LANGE cuvette tests. Experiments were conducted according to Hach-Lange test procedure by using thermo reactor and spectrophotometer. For high and low concentrations, cuvettes that have different measuring ranges were used. Cuvette tests and their measuring ranges are presented below.

Table 1 Cuvette tests and measuring ranges

Test	Parameter	Measuring Range
LCK 314	**COD**	**15-150 mg/L**
LCK 114	**COD**	**150-1000 mg/L**
LCK 338	**TN**	**20-100 mg/L**
LCK 238	**TN**	**5-40 mg/L**
LCK 350	**TP**	**2-20 mg/L**
LCK 348	**TP**	**0.5-5 mg/L**
LCK 339	**NO3-N**	**0.23-13.5 mg/L**
LCK 304	**NH4-N**	**0.015-2 mg/L**
LCK 303	**NH4-N**	**2-47 mg/L**

BOD_5 tests were conducted using BOD_5 test incubator and results were read at the end of five days period. However, SS tests were performed using filter with a pore diameter of 0.45 µm. After filtration, drying was applied at least one hour at 103-105 C. Results were obtained by weighing.

Floc/Filtration Method

In order to determine rbCOD concentration of influent, floc/filtration method was used. Also it can be determined by oxygen uptake rate (OUR) method. Floc/filtration method was preferred due to its simplicity although it may not give exact results as the determination by respirometry.

The test procedure is based on assumption that suspended solids and colloidal material can be captured effectively and removed by flocculation with zinc hydroxide precipitate to leave only truly dissolved organic material after filtration. The steps in the method for each sample are as follows: (1) 1 ml of a 100 g/L $ZnSO_4$ solution is added to 100 mL of sample with vigorous mixing for 1 minute. (2) the pH is raised to about 10.5 using 6 M NaOH, with 5 to 10 minutes of gentle mixing for floc formation. (3) the sample is settled for 10 to 20 min and supernatant withdrawn and filtered using a 0.45 µm membrane filter and (4) the filtrate is analyzed for COD concentration. The difference in the COD concentration between wastewater and avtivated-sludge treated sample is rbCOD (Metcalf & Eddy, 2003).

Table 2 COD values of samples after floc/filtration

COD of influent sample after floc-filtration	COD of effluent sample after floc-filtration	The difference between samples (rbCOD)
113 mg/L	30.2	82.8
118 mg/L	25.2	93
56.2	20.5	35.7
61.6	18.8	42.8

Appendix D. Correspondences

From Birkan AKYOL to Jae K. (Jim) Park, Tuesday, July 12, 2011

Hello dear sir, I am sorry to bother you. I need your help. I am a graduate student in environmental technology program at 9 Eylul University in Turkey. I am studying on biological phosphorus removal and I am investigating the performance of Bayındır WTP. It is a sewage treatment plant. As we know, the performance of treatment plant is affected by wastewater characteristics strongly. I took a spot sample from the influent at 14:00 pm and I determined COD and rbCOD concentration 542 mg/L, 83 mg/L with floc-filtration method using spectrophotometer. However I took a composite sample from influent and I obtained rbCOD concentration 38 mg/L, 42.5 mg/L respectively. These samples have about 450 mg/L COD concentration. I did not expect such a low concentrations of rbCOD. How the samples must be taken to evaluate the performance of treatment plant. Spot or composite? Is it possible that 38 and 42 mg/L rbCOD concentrations can be obtained in response to 450 mg/l COD concentration? If you help me, I will be very glad. Thanks in advance.

Yours sincerely...

From Jae K. (Jim) Park to Birkan AKYOL, July 12, 2011

If the composite sample is not preserved well, the result may not be reliable. If the COD/P is > 40 and COD/TKN is < 0.08, BPR is feasible. The readily biodegradable soluble COD can be obtained for most municipal wastewater if GW infiltration is low.

Best wishes,

From Birkan AKYOL to Paul Janssen, July 14, 2011

Hello dear Sir**,**

I am graduate student at environmental engineering program in Turkey. I benefit from the book called biological phosphorus removal. You are one of the author of this book. I need your help. I am studying on biological phosphorus removal in BWTP which consists of an anaerobic reactor and an oxidation ditch. It is a sewage treatment plant. I am searching the reason of the low treatment efficiency of phosphorus I try to determine rbCOD concentrations with floc-filtration method. As we know, the performance of treatment plant is affected by wastewater characteristics significantly. I took a grab sample from the influent at 14:00 pm and I determined COD and rbCOD concentration 542 mg/L, 83 mg/L with floc-filtration method using spectrophotometer. However I took a composite sample from influent and I obtained rbCOD concentration 38 mg/L, 42.5 mg/L respectively. These samples have about 450 mg/L COD concentration. I did not expect such a low concentrations of rbCOD. How must the samples be taken to evaluate the performance of treatment plant? Grab or composite? Is it possible that 38 and 42 mg/L rbCOD concentrations can be obtained despite 450 mg/l COD concentration? If you help me, I will be very glad. Thanks in advance.

Yours sincerely...

From Paul Janssen to Birkan AKYOL, July 14, 2011

Dear Birkan Akyol

Possibilities which I see:

Disappearance of a part of the rbCOD during storage of composite sample(not cooled perhaps? Evaporation of volitale acids?). Sufficient cooling should solve this problem.

Variation in waste water composition during day/night time. A peak of approx. 20% rb COD enters the sewage plant at 11.00 while other periods the rbCOD approx. < 10%. Taking a profile of several grab samples during a representative day (and compare this with the composite sample of the same day) may clear this. Is there a special industry which discharges a certain type of waste water during the morning? By the way what do you mean exactly with floc filtration (filtration over a ‘paper filter)?

Did you check the other possibilities fora lower efficiency?
Return of P by sludge treatment processes
Low oxygen concentration in ditch?
Release in clarifier?
Nitrate in anaerobic tank
Best regards,

Correspondence with Paul Janssen, July 14, 2011

Note: Italic texts belong to Paul Janssen.

See additional answers in blue below

(this is my last day before holiday, (3weeks)

Starting in August 10th again.

I’ve cc ‘ed a colleague of my Asli Akoz, She is working on her pH thesis (sludge digestion / dewatering) in our company at this moment. Maybe she can communicate some questions with colleagues of mine the next weeks.

OK 0,45 um filter paper is correct. Is the coagulation really necessary?

COD/TP ratio is always over 40. *(In principal BOD5/TP ratio of 15-20 should be enough for a good bio-P removal.* This cause an exception of effluent P concentration is under 2 mg/L. I don't think this data will be sufficient alone. I want to establish amass balance equation around anaerobic reactor. So I need to know rbCOD concentrations. 1 mg/L nitrate causes 6.6 mg/L rbCOD consumption theoretically and to remove 1 mg phosphorus 10 mg rbCOD is required. are they true? *1 mg O2 requires 2 mg rbCOD; 1 mg NO3-N requires 4 mg rbCOD; and yes 1 mg P removed by bio-P requires 10 mg rbCOD.*

See page 29 of IWA book

Recycle nitrate concentration is very high. It is about 16 mg/L. Nitrification occurs but denitrification cannot be provided. *This may cause the problem for your system. The question is: is your anaerobic tank anaerobic or anoxic? You can check this with grab samples and checking on the presence of nitrate concentration (after direct filtration)or measurement of the Redox potential.* When oxygen concentration is 2.5 mg/L in aerobic zone, 1.5 mg/L oxygen concentration is monitored in anoxic side of oxidation ditch. I think it results from low-loading and diffuse aeration with blower. *Yes ,a lower set point of O2 will help increase the anoxic zone in the ditch. The questions of the blower can be controlled in such way that less oxygen supplied. Switch of and on can be a possibility (depending on the type of diffusors)* Excess sludge is not wasted daily. *The basic principle of bio-P is sludge growth and removes the P with the excess sludge. Try to convince the operators to waste on a daily basis. (Removing every day 1/25 part of the activated sludge volume means an operation at an average sludge age of 25 days.* Qr/Q value is%30. *(Ok that means that sludge return flow is relatively low. So maybe the influence of the high nitrate concentration (see earlier) is not so high.* Unfortunately in Turkey wastewater treatment plants are not operated accurately. Engineers don't have adequate information and they don't search. I will evaluate other factors that have effect on process performance respectively after searching the wastewater characteristic.

In my thesis I am trying to determine mistakes related to design and operation of treatment plant. If you have suggestions, article and share with me, I will be very glad.

I understand you have the IWA book Biological Phosphorus Removal (2002), ISBN 1 84339 012 4

See chapter 7 / 7.3 Best regards...

From Birkan AKYOL to Clifford W. Randall, July 12, 2011

Hello dear Sir**,**

I am graduate student at environmental engineering program in Turkey. I benefit from the book called biological phosphorus removal. You are one of the authors of this book. I need your help. I am studying on biological phosphorus removal in BWTP which consists of an anaerobic reactor and an oxidation ditch. It is a sewage treatment plant. I am searching the reason of the low treatment efficiency of phosphorus I try to determine rbCOD concentrations with floc-filtration method. As we know, the performance of treatment plant is affected by wastewater characteristics significantly. I took a grab sample from the influent at 14:00 pm and I determined COD and rbCOD concentration 542 mg/L, 83 mg/L with floc-filtration method using spectrophotometer. However I took a composite sample from influent and I obtained rbCOD concentration 38 mg/L, 42.5 mg/L respectively. These samples have about 450 mg/L COD concentration. I did not expect such a low concentrations of rbCOD. How must the samples be taken to evaluate the performance of treatment plant? Grab or composite? Is it possible that 38 and 42 mg/L rbCOD concentrations can be obtained despite 450 mg/l COD concentration? If you help me, I will be very glad. Thanks in advance.

Yours sincerely...

From Clifford W. Randall to Birkan AKYOL, September 22, 2011

Dear Birkan,

I apologize to you for not replying to this message in July. I was traveling a lot during July, and frequently did not have access to the internet. Also, I developed a medical problem that month. Somehow your email was overlooked.

You should always use a composite sample to determine influent concentrations. It is quite possible to have wide variations in the rbCOD from day to day and from season to season. The changes can be from day to day if you have a large industry on the system that discharges readily biodegradable COD in large amounts periodically, or if they operate only 8 hours per day, or if they do not operate on weekends, for examples. You also can get large differences following rain events, etc. You need to look at week day differences, and determine the average rbCOD over at least a two week period. Also, the rbCOD will vary with the amount of fermentation that occurs in the collection system, so the amount can be very high in the summer time and quite low during cold weather, as another example.

I hope you have been able to resolve your problem without my input.

C. Randall

From Birkan AKYOL to Clifford W. Randall, September 27, 2011

Dear Mr. Randall

I am so glad because of the reply from a very valuable scientist like you. I benefited from "design and retrofit of wastewater treatment plants for biological nutrient removal" through my thesis. I have not encountered any other source that helps me so much. Thanks.

I studied my thesis in BWTP. I tried to find the reason of low P treatment efficiency. It is a sewage treatment plant. Treatment plant consists of an anaerobic reactor and an oxidation ditch. Anaerobic tank is placed prior to oxidation ditch. Recycle ratio is 60% and return sludge is directed to anaerobic tank. Anaerobic tank acts as an anoxic because of the high recycle nitrate concentration of about 16 mg/L. I measured ORP and nitrate concentrations. ORP value is between 0-50 mV. Oxidation ditch was designed for simultaneous nitrification and denitrification. Oxygen set point is 2-3 mg/l in ditch. It is a low-loaded system that about 0.3-0.4 mg/L oxygen drop is observed through "anoxic" zone of the ditch. However excess sludge is not wasted on daily basis. SRT is too long.

In Turkey engineers that design and operate treatment plants, have not detail information about BPR. They apply chemical treatment to satisfy discharge limits in BPR plants. Have you any recommendation for good removal efficiency? Is this process appropriate for BPR? Thank you very much for your help.

From Clifford W. Randall to Birkan AKYOL, September 28, 2011

Dear Mr. Birkan,

I have successfully used the configuration of your plant to obtain very low phosphorus and nitrogen concentrations simultaneously. The problem is that the oxygen set point in your ditch is too high, which reduces the amount of denitrification you obtain in the ditch thereby resulting in too much nitrate recycle to the anaerobic zone, making it anoxic zone. You need to get most of your denitrification in the ditch, not in the anaerobic tank. For this system you must decrease the DO set point in the ditch to less than 1.0 mg/L so that denitrification can take place in it. I don't know how many aerators or what type of aerators you have in your ditch. If you have brush aerators, perhaps three, you should turn one of them off so that you can get near depletion of DO in one section of the ditch, i.e.as close to zero as it will get before it is aerated by the next brush aerator. I converted a ditch with three equally spaced brush aerators by completely removing one of the aerators, the one immediately downstream from where the influent wastewater entered the ditch, and this stimulated a lot of denitrification, plus some BPR, in the ditch. For your system, this would reduce the amounts of nitrates cycling back to the anaerobic zone, and decrease the ORP to minus 100 to minus 200, and stimulate BPR. Further, you need to decrease the SRT to less than 20 days, or until you have to waste some sludge every day. I did not have primary sedimentation for the ditch I converted, and I assume that you don't either. Using an SRT of 15 days, based on the MLSS in the anaerobic zone and ditch, but not that in the secondary settling basins, we obtained an effluent TP concentration of < 0.25 mg/L, and effluent TN concentrations of less than 5 mg/L, annual averages, throughout 20 years of operation.

I hope the above is helpful to you.

From Birkan AKYOL to Clifford W. Randall, September 28, 2011

Dear Mr. Randall

Thank you very much for your help. I would like to express my gratitude to you. Blowers are used for aeration in treatment plant. Diffusors are placed on the base of the ditch. I think this aeration method is disadvantaging.

Best Regards...

From Clifford W. Randall to Birkan AKYOL, September 29, 2011

Dear Birkan,

You are right. Do you have a section of aerators you can turn off?

From Birkan AKYOL to Clifford W. Randall, September 30, 2011

Dear Mr. Randall

Air valves are present on the pipe that transfer air to diffusor loops. These valves can be turned off. However, frequency of blower can be adjusted to reduce air flow rate. These precautions have positive effect. Nevertheless, oxygen concentration drops with difficulty. The depths of ditches are about 6 m. Shallower oxidation ditches with the same volume must be constructed. This can result in increasing flow time under anoxic conditions in oxidation ditch. Mechanical aeration must be preferred instead of diffuse aeration that oxygen transfer efficiency and dissolved oxygen concentrations within flocks are higher at diffuse aeration. This may complicated to create denitrification conditions. Am I wrong? I sent you photographs from oxidation ditches of BWTP in enclosed. Thanks again.

Appendix E. All of the test results conducted in BWTP between 01.04.2011-17.05.2011

BAYINDIR ATIKSU ARITMA TESİSİ LABORATUVAR SONUÇLARI (NİSAN 2011)

TARİH	GİRİŞ VE ÇIKIŞ ANALİZ SONUÇLARI													B NOLU HAVALANDIRMA ANALİZ SONUÇLARI						GİRİŞ LOI	ÇIKIŞ LOI	DEBİ
	Giriş BOI5	Çıkış BOI5	Giriş KOI	Çıkış KOI	Giriş AKM	Çıkış AKM	Giriş TOP-N	Çıkış TOP-N	Giriş TOP-P	Çıkış TOP-P	Giriş NH4-N	Çıkış NH4-N	Çıkış NO3-N	ÇKM	MLSS	SVI	MLVSS	MLVSS	F/M			
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ml/l)	(mg/l)	(ml/g)	(mg/l)	(% Org)		%	%	(m3/gün)
01.04.2011	378	4,7	882	20,40	371	6,50	47,00	12,60	6,71	2,59	18,40	0,140	7,38	320	4310	74,25	3330	77,26	0,047	95,00	73,20	2301
02.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	1963
03.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2319
04.04.2011	587	2,1	1676	19,60	507	3,93	55,30	13,20	7,05	2,23	15,80	0,097	7,58	285	3680	77,45	2850	77,45	0,084	92,05	99,98	2275
05.04.2011	363	5,9	791	29,60	289	1,67	47,20	4,80	5,40	3,30	17,90	0,068	1,69	340	3780	89,95	2940	77,78	0,051	97,52	99,97	2315
06.04.2011	238	3,7	425	20,90	231	5,92	37,80	4,87	5,60	1,43	18,60	0,101	2,31	290	4110	70,56	3020	73,48	0,033	88,31	70,13	2358
07.04.2011	253	3,7	470	28,40	221	3,80	39,20	13,00	5,14	1,77	17,60	0,089	7,50	280	4150	67,47	3070	73,98	0,035	85,52	73,68	2359
08.04.2011	278	4,0	510	29,40	250	6,60	39,90	15,60	5,64	2,31	18,20	0,131	11,60	310	4130	75,06	3050	73,85	0,039	83,60	62,63	2365
09.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2390
10.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2395
11.04.2011	403	4,4	572	28,60	272	7,33	43,60	16,80	5,95	4,60	15,60	0,090	10,70	275	3450	79,71	2523	73,13	0,070	91,18	96,36	2423
12.04.2011	176	8,2	310	31,20	103	4,70	59,30	25,10	4,74	4,28	19,70	0,080	20,60	270	3670	73,57	2690	73,30	0,031	85,71	74,65	2611
13.04.2011	270	1,8	458	27,50	258	7,10	37,70	24,70	5,28	4,80	16,70	0,063	21,30	250	3440	72,67	2530	73,55	0,055	72,82	76,70	2868
14.04.2011	263	1,0	538	32,50	138	8,47	38,90	22,70	5,74	4,45	20,70	0,073	20,70	270	3690	73,17	2710	73,44	0,061	77,29	76,38	3505
15.04.2011	284	1,4	532	24,80	358	6,53	49,60	20,90	5,38	3,85	19,80	0,062	18,30	275	4090	67,24	2950	72,13	0,051	60,34	69,39	2927
16.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2921
17.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2937
18.04.2011	214	1,6	445	40,50	212	7,13	43,70	24,20	5,24	3,77	17,70	0,074	19,00	275	4360	63,07	3120	71,56	0,039	81,13	71,96	3147
19.04.2011	211	0,9	413	31,70	223	11,60	43,30	24,10	4,69	3,62	18,60	0,270	19,20	315	4760	66,18	3460	72,69	0,033	73,54	72,41	3019
20.04.2011	250	0,8	446	29,40	231	7,20	39,30	24,80	4,86	3,41	15,44	0,062	19,60	295	3890	75,84	2800	71,98	0,046	78,79	77,78	2870
21.04.2011	246	1,1	321	26,20	142	4,27	33,30	21,10	5,88	3,51	19,30	0,060	20,10	290	3890	74,55	2900	74,55	0,045	91,55	99,97	2919
22.04.2011	241	1,1	446	37,00	220	26,40	37,60	26,00	5,05	3,82	19,10	0,097	19,40	305	4080	74,75	2880	70,59	0,044	84,42	58,71	2951
23.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	3025
24.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2968
25.04.2011	219	2,0	416	35,80	193	10,80	40,30	25,60	5,51	3,79	25,50	0,173	24,50	290	3720	77,96	2631	70,73	0,040	81,87	68,74	2693
26.04.2011	288	1,6	470	19,60	231	3,82	52,80	28,00	6,54	3,50	28,40	0,077	22,80	450	4740	94,94	3500	73,84	0,042	86,49	95,24	2863
27.04.2011	249	5,6	469	23,60	274	3,67	39,30	27,10	5,44	3,71	19,90	0,076	24,20	290	4020	72,14	2920	72,64	0,046	76,28	92,73	3018
28.04.2011	290	1,8	690	25,50	385	4,93	39,90	26,20	6,15	3,65	17,40	0,077	23,20	310	4160	74,52	3040	73,08	0,047	75,97	86,49	2750
29.04.2011	198	0,9	404	20,70	167	4,20	35,90	24,80	4,68	3,53	17,00	0,104	22,00	315	4370	72,08	3160	72,31	0,032	89,22	88,89	2845
30.04.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2762
Ortalama	**281**	**2,8**	**556,4**	**27,8**	**251**	**7,0**	**42,90**	**20,29**	**5,6**	**3,4**	**18,921**	**0,098**	**16,4**	**300**	**4023**	**74,62**	**2956**	**73,49**	**0,046380**	**83,27**	**80,29**	**2702,07**
Toplam	**5899,00**	**58,30**	**11684,00**	**582,90**	**5276,00**	**146,57**	**900,90**	**426,17**	**116,67**	**71,92**	**397,34**	**2,06**	**343,66**	**6300,00**	**84490,00**	**1567,12**	**62075,15**	**1543,32**	**0,97**	**1748,60**	**1685,99**	**81062**

TARİH	GERİ DEVİR					GÜNLÜK ELEKTRİK TÜKETİM MİKTARLARI						PH		Sıcaklık		İlet.	İlet.	Tuz.	Tuz.	H.Hav.	
	θc	G.D AKM	DS	Fazla çam.debisi	LOI	ELK.TÜK	Özgül enerji Sarfiyatı	En.Sarfiyatı/ Giderilen	POLİ TÜK.	ÇIKAN ÇAMUR	KM	Giriş	Çıkış	Giriş	Çıkış	Giriş	Çıkış	Giriş	Çıkış	Ç.O	
	(gün)	(mg/l)		(m3/gün)	%	kWh/gün	kwh/m3	kg KOI/kwh	kg/gün	kg/gün	%			°C	°C	µs/cm	µs/cm	$^{0}/_{00}$	$^{0}/_{00}$	mg/l	HAV. HACMİ
01.04.2011	29	8690	0,918		74,80	2055,51	0,89	0,96				7,22	7,99	16,5	19,6	954	941			1,97	5550
02.04.2011	****	****	****	200	****	2007,90	1,02	****	19	14560	23	****	****	****	****	****	****	****	****	2,43	5550
03.04.2011	****	****	****	****	****	1701,54	0,73	****	****	****	****	****	****	****	****	****	****	****	****	0,26	5550
04.04.2011	18	7890	0,840		75,03	1854,72	0,82	2,03				7,19	7,86	14,8	19,0	908	875			0,39	5550
05.04.2011	32	8250	0,852		75,27	1831,95	0,79	0,96				7,47	7,93	13,8	19,0	907	858			2,20	5550
06.04.2011	43	9990	1,204		73,21	1734,66	0,74	0,55				7,68	7,93	13,2	18,5	903	831			2,59	5550
07.04.2011	45	11180	1,156		72,81	1670,49	0,71	0,62				7,53	7,82	15,5	19,2	1027	857			1,86	5550
08.04.2011	40	10280	1,118		72,76	2243,88	0,95	0,51				7,52	8,02	14,9	20,0	929	893			2,10	5550
09.04.2011	****	****	****	180	****	1649,79	0,69	****	14	15520	23,00	****	****	****	****	****	****	****	****	1,51	5550
10.04.2011	****	****	****	****	****	1573,20	0,66	****	****	****	****	****	****	****	****	****	****	****	****	2,02	5550
11.04.2011	30	8370	1,000		75,51	1558,71	0,64	0,84				7,51	7,72	14,9	19,9	958	908	0,46	0,44	2,16	5550
12.04.2011	79	9650	0,960		73,06	2115,54	0,81	0,34				7,62	7,56	12,9	15,8	917	879	0,45	0,43	1,70	5550
13.04.2011	12	4830	0,558	190	73,08	1740,87	0,61	0,71	16	15320	27,00	7,55	7,47	12,1	15,9	1048	886	0,52	0,43	2,23	5550
14.04.2011	45	7130	0,774		73,77	1829,88	0,52	0,97				7,45	7,51	15,4	16,2	933	911	0,46	0,45	2,32	5550
15.04.2011	22	8220	0,858		71,29	1949,94	0,67	0,76				7,90	7,27	13,0	16,6	869	843	0,43	0,41	2,03	5550
16.04.2011	****	****	****	****	****	1792,62	0,61	****	****	****	****	****	****	****	****	****	****	****	****	2,43	5550
17.04.2011	****	****	****	****	****	1730,52	0,59	****	****	****	****	****	****	****	****	****	****	****	****	1,70	5550
18.04.2011	38	8260	0,872		72,03	1958,22	0,62	0,65				7,45	7,58	15,8	16,8	911	860	0,45	0,42	3,13	5550
19.04.2011	41	9740	1,042		71,87	1962,36	0,65	0,59				7,55	7,59	14,9	15,9	875	845	0,43	0,41	2,48	5550
20.04.2011	34	7260	0,754		72,45	1925,10	0,67	0,62				7,57	7,47	13,9	15,5	923	831	0,45	0,41	2,38	5550
21.04.2011	54	7610	0,848		72,14	1943,73	0,67	0,44				7,60	7,56	15,0	16,1	949	851	0,46	0,42	1,63	5550
22.04.2011	40	8860	0,918		69,75	2529,54	0,86	0,48				7,65	7,58	12,9	14,9	949	860	0,47	0,42	2,68	5550
23.04.2011	****	****	****	180	****	1784,34	0,59	****	17	15610	26,00	****	****	****	****	****	****	****	****	****	5550
24.04.2011	****	****	****	****	****	1852,65	0,62	****	****	****	****	****	****	****	****	****	****	****	****	2,57	5550
25.04.2011	42	8310	0,896		70,64	1929,24	0,72	0,53				7,62	7,46	13,5	16,7	960	904	0,47	0,44	2,79	5550
26.04.2011	40	9230	0,740		72,16	1987,20	0,69	0,65				7,58	7,58	14,5	16,5	971	867	0,48	0,43	2,84	5550
27.04.2011	27	8710	0,940		70,95	2020,32	0,67	0,67				7,51	7,58	17,5	18,3	1076	880	0,53	0,43	3,21	5550
28.04.2011	22	8420	0,900		70,78	2070,00	0,75	0,88				7,47	7,63	15,9	16,9	886	907	0,44	0,44	3,05	5550
29.04.2011	12	7900	0,832	200	71,01	2506,77	0,88	0,44	18	15760	23,00	7,52	7,61	17,3	17,8	942	887	0,46	0,44	2,80	5550
30.04.2011	****	****	****	****	****	1941,66	0,70	****	****	****	****	****	****	****	****	****	****	****	****	1,80	5550
Ortalama	**22,08161**	**8513**	**0,9038**	**190**	**72,59**	**1915,10**	**0,72**	**0,72**	**17**	**15354**	**24,4**	**7,53**	**7,65**	**14,7**	**17,4**	**942,6**	**875,0**	**0,5**	**0,4**	**2,18**	
Toplam	**743,41**	**178780,00**	**18,98**	**950,00**	**1524,37**	**57452,850**	**21,54**	**15,21**	**84**	**76770**	**122,00**	**158,16**	**160,72**	**308,20**	**365,10**	**19795,0**	**18374,0**	**6,96**	**6,42**	**63,26**	

BAYINDIR ATIKSU ARITMA TESİSİ LABORATUVAR SONUÇLARI (MAYIS 2010)

TARİH	GİRİŞ VE ÇIKIŞ ANALİZ SONUÇLARI													B NOLU HAVALANDIRMA ANALİZ SONUÇLARI						GİRİŞ LOI	ÇIKIŞ LOI	DEBİ
	Giriş BOI5	Çıkış BOI5	Giriş KOI	Çıkış KOI	Giriş AKM	Çıkış AKM	Giriş TOP-N	Çıkış TOP-N	Giriş TOP-P	Çıkış TOP-P	Giriş NH4-N	Çıkış NH4-N	Çıkış NO3-N	ÇKM	MLSS	SVI	MLVSS	MLVSS	F/M			
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ml/l)	(mg/l)	(ml/g)	(mg/l)	(% Org)		%	%	(m3/gün)
01.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2687
02.05.2011	248	1,2	425	21,30	174	3,13	38,8	23,1	4,99	3,70	18,500	0,083	20,8	280	3820	73,30	2780	72,77	0,044	87,93	97,87	2717
03.05.2011	236	2,7	431	24,50	177	4,07	51,2	23,8	4,81	3,23	18,300	0,083	20,8	280	3930	71,25	2850	72,52	0,041	94,34	88,52	2772
04.05.2011	305	1,4	347	20,90	333	3,27	41,9	21,9	7,51	3,69	21,000	0,205	22,7	250	3460	72,25	2520	72,83	0,061	82,50	95,92	2781
05.05.2011	289	5,4	491	21,80	277	3,83	35,2	22,5	5,78	3,23	16,100	0,337	21,2	250	3530	70,82	2550	72,24	0,063	80,72	99,97	3099
06.05.2011	266	3,0	569	19,20	479	4,20	35,7	21,2	5,89	3,08	16,000	0,154	20,6	240	3330	72,07	2370	71,17	0,054	66,87	90,48	2659
07.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2616
08.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2567
09.05.2011			556	21,50	255	4,20	43,0	21,5	5,87	3,04	19,100	0,098	18,7	240	2690	89,22	1945	72,30	0,000	82,35	92,06	
10.05.2011			402	23,80	117	4,06	36,5	20,1	4,85	2,82	20,500	0,119	18,8	220	3000	73,33	2180	72,67	0,000	90,60	89,23	
11.05.2011			517	22,30	236	3,47	44,9	18,4	6,94	2,51	20,200	0,164	17,6	220	2940	74,83	2150	73,13	0,000	90,30	98,08	
12.05.2011			356	28,60	134	8,64	41,3	20,0	4,68	2,58	18,800	0,175	18,6	255	3120	81,73	2270	72,76	0,000	92,54	78,70	
13.05.2011			251	24,90	159	6,53	27,1	20,0	3,47	1,91	11,600	0,088	17,8	230	3150	73,02	2300	73,02	0,000	75,85	64,29	
14.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	
15.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	
16.05.2011																						
17.05.2011																						
18.05.2011																						
19.05.2011																						
20.05.2011																						
21.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	
22.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	
23.05.2011																						
24.05.2011																						
25.05.2011																						
26.05.2011																						
27.05.2011																						
28.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	
29.05.2011	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	
30.05.2011																						
31.05.2011																						
Ortalama	**269**	**2,7**	**434,5**	**22,9**	**234**	**4,5**	**39,6**	**21,3**	**5,5**	**3,0**	**18,010**	**0,151**	**19,8**	**247**	**3297**	**75,18**	**2392**	**72,54**	**0,03**	**84,40**	**89,51**	**2737**
Toplam	1344,00	13,70	4345,00	228,80	2341,00	45,40	395,60	212,50	54,79	29,79	180,10	1,51	197,60	2465,00	32970,00	751,82	23915,04	725,41	0,26	844,00	895,12	**21898**

TARİH	GERİ DEVİR					GÜNLÜK ELEKTRİK TÜKETİM MİKTARLARI						PH		Sıcaklık		İlet.	İlet.	Tuz.	Tuz.	H.Hav.	
	Θc	G.D AKM	DS	Fazla çam.debisi	LOI	ELK.TÜK	Özgül enerji Sarfiyatı	En.Sarfiyatı/ Giderilen KOI	POLİ TÜK.	ÇIKAN ÇAMUR	KM	Giriş	Çıkış	Giriş	Çıkış	Giriş	Çıkış	Giriş	Çıkış	Ç.O	
	(gün)	(mg/l)		(m3/gün)	%	kWh/gün	kwh/m3	kg KOI/kwh	kg/gün	kg/gün	%			°C	°C	µs/cm	µs/cm	$^0/_{00}$	$^0/_{00}$	mg/l	HAV. HACMİ
01.05.2011	****	****	****	0	****	1838,16	0,68	****	****	****	****	****	****	****	****	****	****	****	****	1,90	5550
02.05.2011	46	8450	0,888	0	71,12	1974,78	0,73	0,56				7,50	7,43	17,6	18,8	955	875	0,47	0,43	2,33	5550
03.05.2011	46	7230	0,772	0	71,37	2442,60	0,88	0,46				7,54	7,48	17,5	18,9	927	878	0,46	0,43	2,83	5550
04.05.2011	8	6400	0,744	230	71,09	1709,82	0,61	0,53	19	16430	25	7,42	7,44	19,9	20,3	1029	886	0,51	0,43	2,44	5550
05.05.2011	23	6700	0,764	0	70,60	1869,21	0,60	0,78				7,63	7,14	19,1	20,4	927	915	0,46	0,45	2,74	5550
06.05.2011	15	6690	0,732	0	69,96	1682,91	0,63	0,87				7,81	7,18	18,5	20,1	839	870	0,41	0,43	2,25	5550
07.05.2011	****	****	****	0	****	1682,91	0,64	****	****	****	****	****	****	****	****	****	****	****	****	2,48	5550
08.05.2011	****	****	****	0	****	1616,67	0,63	****	****	****	****	****	****	****	****	****	****	****	****	2,61	5550
09.05.2011		7390	0,784	0	69,82							7,73	7,18	16,1	19,3	942	865	0,46	0,42		5550
10.05.2011		5400	0,588	0	70,74							7,61	7,22	17,1	19,8	966	872	0,48	0,43		5550
11.05.2011		5320	0,576	0	71,05							7,58	7,24	16,5	20,0	968	868	0,47	0,43		5550
12.05.2011		6240	0,672	0	70,51							7,56	7,16	17,0	19,8	923	864	0,45	0,42		5550
13.05.2011		7450	0,769	0	69,80							7,65	7,20	15,1	19,1	710	817	0,35	0,40		5550
14.05.2011	****	****	****	0	****			****	****	****	****	****	****	****	****	****	****	****	****	****	5550
15.05.2011	****	****	****	0	****			****	****	****	****	****	****	****	****	****	****	****	****	****	5550
16.05.2011				0																	5550
17.05.2011				0																	5550
18.05.2011				0																	5550
19.05.2011				0																	5550
20.05.2011				0																	5550
21.05.2011	****	****	****	0	****			****	****	****	****	****	****	****	****	****	****	****	****	****	5550
22.05.2011	****	****	****	0	****			****	****	****	****	****	****	****	****	****	****	****	****	****	5550
23.05.2011				0																	5550
24.05.2011				0																	5550
25.05.2011				0																	5550
26.05.2011				0																	5550
27.05.2011				0																	5550
28.05.2011	****	****	****	0	****			****	****	****	****	****	****	****	****	****	****	****	****	****	5550
29.05.2011	****	****	****	0	****			****	****	****	****	****	****	****	****	****	****	****	****	****	5550
30.05.2011				0																	5550
31.05.2011				0																	5550
Ortalama	**27**	**6727**	**0,7289**	**7**	**70,61**	**1852,13**			**19**	**16430**	**25,0**	**7,60**	**7,27**	**17,4**	**19,7**	**919**	**871**	**0,45**	**0,43**	**2,45**	
Toplam	136,99	67270,00	7,29	230,00	706,06	**14817,06**			**19**	**16430**	25,00	76,03	72,67	174,40	196,50	9186	8710	4,52	4,27	19,58	