DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

# EFFECTS OF FILTER RATIO AND OPERATION MODE ON THE EFFICIENCY OF ANAEROBIC FILTER TREATING MOLASSES WASTEWATER

by
Ezgi ÖZGÜNERGE

October, 2008
İZMİR

# EFFECTS OF FILTER RATIO AND OPERATION MODE ON THE EFFICIENCY OF ANAEROBIC FILTER TREATING MOLASSES WASTEWATER

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

**by**
**Ezgi ÖZGÜNERGE**

**October, 2008**
**İZMİR**

**M.Sc THESIS EXAMINATION RESULT FORM**

We have read the thesis entitled **"EFFECTS OF FILTER RATIO AND OPERATION MODE ON THE EFFICIENCY OF ANAEROBIC FILTER TREATING MOLASSES WASTEWATER"** completed by **EZGİ ÖZGÜNERGE** under supervision of **ASSIST. PROF. DR. SEVGİ TOKGÖZ GÜNEŞ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. SEVGİ TOKGÖZ GÜNEŞ

Supervisor

Prof. Dr. Delia Sponza

(Jury Member)

Prof. Dr. Rengin ELTEM

(Jury Member)

Prof.Dr. Cahit HELVACI
Director
Graduate School of Natural and Applied Sciences

**ACKNOWLEDGEMENTS**

I would like to thank Assist. Prof. Dr. Sevgi TOKGÖZ GÜNEŞ, the advisor of the thesis, for her effort, intelligent, sincere and help during my thesis.

I would like to thank Prof. Dr. Aysen MÜEZZİNOĞLU for her moral motivation, intelligence and interest.

I also thank to MSc. Melik KARA, Miss. Bilge DEMİRTAŞ and Mr. Özgür AYKAN for their valuable help in first step of laboratory studies for my thesis.

I am also thankfull to Dr. Duyuşen GÜVEN, Dr. Hasan SARPTAŞ, Miss. Yıldız ERÇELEBİ, MSc. Rukiye ÖZTEKİN, MSc. Serpil ÖZMIHÇI, MSc. Gülden GÖK, MSc. Oğuzhan GÖK, MSc. Hakan ÇELEBİ, MSc. Melayib BİLGİN, Mr. Sertaç SATIRLI, MSc. Baran EMİROĞLU, MSc. Ersan KUZYAKA, Miss. Deniz KARADAŞ and Tech. Yılmaz SAĞER for their great help and friendship.

I especially would like to thanks to MSc. Diclehan SIR for her valuable help and supports for preparation of the thesis.

I am grateful to my engaged Mr. Gökay FALAY for his love, patience, moral motivation, encouragement and help.

Finally, I specially thank to my parents, Atilla ÖZGÜNERGE and Aysun ÖZGÜNERGE, and my brother Mert ÖZGÜNERGE for their love, moral support, patience, encouragement and help during my education. I would like to dedicate the thesis to my family.

Ezgi ÖZGÜNERGE

İzmir, 2008

# EFFECTS OF FILTER RATIO AND OPERATION MODE ON THE EFFICIENCY OF ANAEROBIC FILTER TREATING MOLASSES WASTEWATER

## ABSTRACT

In this thesis, treatability studies were realized by using an upflow anaerobic filter model reactor that is accepted as one of the most economical systems in the world. Hydraulic retention time, filter material ratio, organic loading rate, temperature and operation mode, which are design and performance parameters, were evaluated at four upflow anaerobic filter reactors having different filter material ratios in the study.

During the study anaerobic filter reactors were fed with the synthetic wastewater containing molasses. Experimental studies were examined at different organic loading rates varied between 0.5 and 2.0 kg COD/$m^3$day for hydraulic retention time (HRT) of 2 days at temperature range of $37 \pm 1$°C. Four anaerobic filter reactors called as UAF 100, UAF 75, UAF 50 and UAF 25 according to filter material ratio were operated at continuous and semi-continuous operation mode.

Chemical oxygen demand (COD), total solid (TS) and total volatile solid (TVS) analyses were done for evaluate the performance of upflow anaerobic filter reactors during the study. When the results of this analysis were compared, COD, TS and TVS removal efficiencies were affected by continuous operation mode and filter material ratio in anaerobic filters. Depending on operation mode, the highest COD, TS and TVS removal efficiencies were achieved at continuous mode than the semi-continuous mode.

Increasing organic loading rates were increasingly affected the reactor performances from UAF 100 to UAF 25 in both operation conditions. The highest COD (85%-80%), TS (76%-70%) and TVS (71%-66%) removal efficiencies were achieved in fully packed UAF 100 at 0.5 kg $COD/m^3$.day and the lowest COD (46%-40%), TS (41%-31%) and TVS (34%-27%) removal efficiencies were achieved in least packed UAF 25 at 2.0 kg $COD/m^3$.day of organic loading rate in both operation modes.

The reduction of filter material at a ratio of 50% was resulted the decrease of the COD removal efficiencies of 15%, 70% of COD removal efficiency, that is the acceptable value for anaerobic treatment as a preliminary treatment. This is also reduced the investment cost and the makes the anaerobic treatment attractive.

**Keywords**: anaerobic filter, upflow reactor, filter material ratio, organic loading rate, operation mode

**FİLTRE MALZEMESİ ORANI VE İŞLETİM MODUNUN MELASLI ATIKSU ARITAN ANAEROBİK FİLTRENİN VERİMİ ÜZERİNDEKİ ETKİSİ**

# ÖZ


Bu tez kapsamında, dünyadaki en ekonomik sistemlerden biri olarak kabul edilen yukarı akışlı anaerobik filtre modelinde arıtılabilirlik çalışmaları gerçekleştirilmiştir. Çalışmada, tasarım ve performans parametrelerinden olan hidrolik alıkonma süresi, filtre malzemesi oranı, organik yükleme oranı, sıcaklık ve işletim türü, farklı filtre malzemesi oranına sahip dört yukarı akışlı anaerobik filtre reaktörde değerlendirilmiştir.

İşletim boyunca, anaerobik filtre reaktörler melas içeren sentetik atıksuyla beslenerek deneysel çalışmalar 37 ± 1°C sıcaklık aralığında, 2 günlük alıkonma süresi için 0.5 ile 2.0 kg COD/$m^3$.gün arasında değişen organik yükleme değerlerinde gerçekleştirildi. Filtre malzemesi doluluk oranına göre UAF 100, UAF 75, UAF 50 ve UAF 25 olarak adlandırılan dört reaktör, sürekli ve yarı sürekli olarak işletildi.

Organik yük değeri, işletim boyunca 0.5 ile 2.0 kg COD/$m^3$.gün arasında değiştirildi. İki günlük alıkonma süresinde, her iki işletim modu için sırasıyla 0.5 kg COD/$m^3$.gün, 1.0 kg COD/$m^3$.gün ve 2.0 kg COD/$m^3$.gün organik yükleme değerleri uygulandı.

Yukarı akışlı anaerobik filtre reaktörlerin arıtım verimlerini değerlendirebilmek için işletim boyunca kimyasal oksijen ihtiyacı (KOİ), toplam katı (TK) ve toplam uçucu katı (TUK) analizleri yapıldı. Bu analizlerden elde edilen sonuçlar karşılaştırıldığında; anaerobik filtrelerde, filtre malzemesi oranının ve sürekli işletme türünün KOI, TK ve TUK giderim verimi üzerinde etkili olduğu görülmüştür. Sonuçlar işletme moduna göre değerlendirildiğinde, en yüksek COD, TS ve TVS giderim verimlerinin sürekli işletim modunda elde dildiği görülmüştür.

Her iki işletim modu için, organik yükün artması reaktör performansını UAF 100'den UAF 25'e doğru azalacak şekilde etkilemiştir. En yüksek COD (85%-80%), TS (76%-70%) ve TVS (71%-66%) giderme verimleri tam dolu olan UAF 100 reaktöründe 0.5 kg COD/$m^3$.gün oganik yükleme değerinde, en düşük COD (46%-40%), TS (41%-31%) ve TVS (34%-27%) giderme verimleri ise, en az dolu olan UAF 25 reaktöründe 2.0 kg COD/$m^3$.gün organik yükleme değerinde elde edilmiştir.

Filtre malzemesinin 50% oranında azaltılması, 70% COD giderme veriminin 15% oranında azalmasıyla sonuçlanmıştır. Bu değer, anaerobik arıtmanın bir ön arıtma olarak kullanılabilmesi için kabul edilebilir bir değerdir. Bu durum anaerobik arıtmanın ilk yatırım maliyetini azaltmakta ve anaerobik arıtmayı daha cazip hale getirmektedir.

**Anahtar sözcükler**: anaerobik filtre, yukarı akışlı reaktör, filtre malzemesi oranı, organik yük, işletim türü

**CONTENTS**

# CHAPTER ONE
# INTRODUCTION

## 1.1 General

Generally, treatment technologies can be classified as aerobic and anaerobic systems. Anaerobic treatment processes have some advantages over aerobic processes. The main advantages of anaerobic treatment in comparison with aerobic treatment are; the lower energy requirement with the production of biogas and the much lower production of excess sludge. These advantages have led researchers to investigate ways of minimizing the limitations of anaerobic treatment.

For a long time anaerobic treatment was thought feasible only for the digestion of concentrated wastes at long retention times. Around 1960's also anaerobic treatment of wastewater was attempted and special reactor types for wastewater treatment were developed (Lettinga, 1981).

The high rate anaerobic reactors such as Anaerobic Filter (AF), Upflow Anaerobic Sludge Blanket (UASB), etc. are capable of treating dilute wastewater such as sewage and high strength wastewater from various industries (Lettinga, 1981). For strong organic wastewaters, anaerobic treatment systems become increasingly preferable over the aerobic methods since anaerobic processes are bioenergy producers (Eroğlu *et al*., 1991).

Because of the high industrialization rate and increase of energy costs, anaerobic treatment systems, which are accepted as the most economical alternatives in the world, should be used in our country as well. As it is the case for all technological applications, sufficient knowledge is needed in the application of anaerobic technologies.

Consequently, model studies aimed to determine the technological basis of anaerobic systems will help enrichment of the present knowledge and they will help minimizing the problems in construction and operation stages.

## 1.2 Aims of the Thesis

Molasses wastewater is a high strength wastewater that can be hardly treated. To treat this wastewater, generally aerobic and / or anaerobic biological processes are used.

One of the most suitable treatment methods for molasses wastewater is high-rate anaerobic biological systems. Anaerobic reactors are used mainly for color removal, organic material and total solids reduction.

This study was planned to investigate the behavior of pilot scale upflow anaerobic filter (UAF) system for organic substances (COD) and total solid removal from molasses containing synthetic wastewater treatment under different organic loading rates and filter material ratio.

The aims of this thesis are as follows:

- To investigate the filter material ratio effect on anaerobic treatment efficiency in an upflow anaerobic filter (UAF),
- To determine the organic substances (COD), total solid and total volatile solid removal efficiency of UAF reactor by using molasses containing synthetic wastewater,
- To understand the effect of operation mode on anaerobic treatment efficiency in an UAF,
- To evaluate the effect of organic loading rates on anaerobic treatment efficiency in an UAF.

# CHAPTER TWO
# LITERATURE SURVEY

## 2.1 Anaerobic Treatment

Anaerobic treatment can be defined as degradation of organic materials by anaerobic microorganisms by conversion to methane and some inorganic products in the absence of molecular oxygen for providing the stabilization. Anaerobic processes provide odor, pathogens and mass reduction. This process is shown in equation 2.1.

$$\text{Organic material} + H_2O \xrightarrow{\text{Anaerobic organisms}} CH_4 + CO_2 + NH_3 + H_2S + \text{new cells} \qquad (2.1)$$

Anaerobic treatment of wastes results in conversion of biodegradable organic material into biogas (20-30 % $CO_2$, 60-79 % $CH_4$, 1-2 % $H_2S$ and other gasses) and water. Plant residues, treatment plant biosolids, agricultural wastes, manures and effluents from several industries can be treated using anaerobic treatment (Demirer, 2001).

As such in aerobic systems, the bacteria in anaerobic systems require a source of elemental oxygen to survive. In an anaerobic reactor, gaseous oxygen is prevented from entering the system. The oxygen source for the anaerobic microorganisms can be the organic material itself or alternatively may be supplied by inorganic oxides from within the input material (www.en.wikipedia.org).

When the oxygen source in an anaerobic system is derived from the organic material itself, the 'intermediate' products are primarily alcohols, aldehydes, organic acids and carbon dioxide. In the presence of methanogens, the intermediates are converted to the 'final' products of methane, carbon dioxide with trace levels of hydrogen sulfide (Lettinga, 1981). In an anaerobic system, the majority of the chemical energy contained within the starting material is released by methanogenic bacteria as methane.

Populations of anaerobic microorganisms typically take a long time to establish themselves to be very effective. It is therefore common method to introduce anaerobic microorganisms from materials with existing populations (Alicbusan, 1973). This process is called 'inoculation' and typically takes place with the addition of sewage sludge.

During inoculation period, facultative anaerobes utilized the organic material present in the substrate and created anaerobic conditions for anaerobic bacteria. Biofilm development was appeared by gas production and visual observation in change of color. Initially biogas production was low because of acclimatization and adaptation of the bacteria on support materials. After the establishment of all the group of bacteria biogas production increased, and as the organic material present in the substrate reduced biogas production increased gradually (Acharya *et. al*., 2007).

### *2.1.1 Stages of Process*

The main steps in anaerobic processes are; hydrolysis, acidogenesis, acetogenesis and methanogenesis. These stages are shown in Figure 2.1.

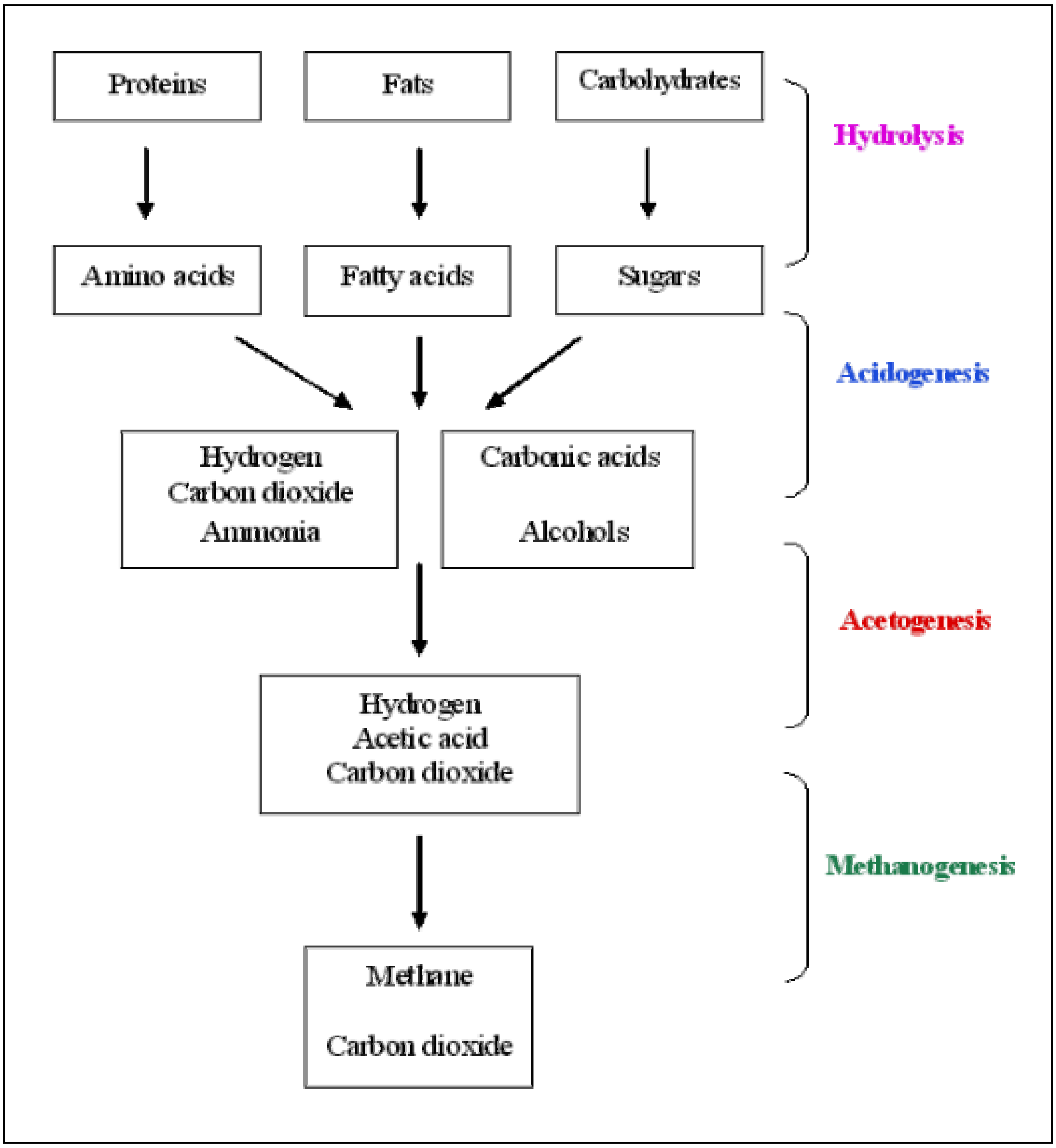


Figure 2.1 Process stages of anaerobic treatment

*2.1.1.1 Hydrolysis*

In most cases, biomass is made up of large organic polymers. These polymers must first be broken down into their smaller constituent parts to access the energy potential of the material. These constituent parts or monomers such as sugars are readily available by other bacteria. The process of breaking these polymers and dissolving the smaller molecules into solution is called hydrolysis (Sleat & Mah, 1987). Therefore, hydrolysis is the necessary first step in anaerobic treatment. Through hydrolysis, the complex organic molecules are broken down into simple sugars, amino acids and fatty acids. Hydrolysis of biodegradable material is carried on by facultative bacteria.

In hydrolysis stage;

**1)** Carbohydrates are broken down to simple sugars,
**2)** Proteins are broken down to amino acids,
**3)** Lipids are broken down to long chain fatty acids.

Hydrolysis of lipids is the limiting step. Chemical oxygen demand (COD) reduction does not occur in this step.

*2.1.1.2 Acidogenesis*

The second stage of anaerobic processes is acidogenesis that is a biological reaction where simple monomers are converted into volatile fatty acids by fermentative bacteria.

In this phase, complex molecules (carbohydrates, lipids, proteins) are depolymerized into soluble compounds by hydrolytic enzymes (cellulases, hemicellulases, amylases, lipases and proteases). The hydrolyzed compounds are fermented into volatile fatty acids (acetate, propionate, butyrate, and lactate), neutral compounds (ethanol, methanol), ammonia, hydrogen and carbon dioxide (Dinopolou *et al.,* 1987).

In this step, volatile fatty acids (VFAs) are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products.

*2.1.1.3 Acetogenesis*

The third stage of anaerobic treatment is acetogenesis where volatile fatty acids are converted into acetic acid, carbon dioxide and hydrogen.

Acetate is produced by anaerobic bacteria from a variety of energy and carbon sources. The different bacterial species, which is called acetogens, are capable of acetogenesis.

In this stage, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen (Martin, 2007).

*2.1.1.4 Methanogenesis*

The important stage of anaerobic digestion is the biological process of methanogenesis. In this stage, acetates are converted into methane, carbon dioxide and water by methanogenic bacteria. The components that make up the majority of the biogas emitted from the system. Methanogenesis stage is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8.0 (Martin, 2007). The remaining, non-digestable material, which the microbes cannot feed upon, along with any dead bacterial remains, constitutes the digestate. Methane formation from acetate is known to be the rate-limiting step in methanogenic phase.

Methanogenic bacteria, which are called methanogens, are obligate anaerobes. There are two groups of these organisms in reactors.

**1) $H_2$-oxidizing methanogens:** This group reduces $CO_2$ using $H_2$ as the electron donor and forming methane.

**2) Acetoclastic methanogens:** This group cleaves acetic acid into methane and $CO_2$.

### *2.1.2 Importance of Balance between Acid Formers and Methanogens*

- Formation of acetic acid and hydrogen gas ($H_2$) by anaerobic oxidation is inhibited by high partial pressures of $H_2$. Methanogens cannot use organic acids other than acetic acid.

- $H_2$-utilizing methanogens must remove $H_2$ as fast as it is produced to allow anaerobic oxidation to proceed.

- If acid forming bacteria grow faster than $H_2$-utilizing methanogens, then pressure of $H_2$ will build up, anaerobic oxidation will stop and digestion will be incomplete.

Protein and carbohydrate degrading bacteria grow rapidly, and these kinds of substrates are rapidly fermented with a retention time of less than a day (Rozzi, 1994). If the substrate is easily hydrolysed, the last degradation step is often rate limiting since methanogens grow more slowly than the acidogens upstream in the degradation chain. The acid consuming methanogenic species are more inhibited by a decrease in pH than are the acid producing species (Anderson & Yang, 1991). This causes further acid accumulation and eventually leads to process failure.

The resistance to a pH change in the reactor depends on the buffering capacity, which is mainly comprised of the bicarbonate/carbon dioxide buffer (Rozzi, 1994). If other ions are present, they also contribute to the alkalinity. For example, when proteins are degraded, ammonium is released forming ammonium bicarbonate, which results in additional buffering of the reactor (Murto *et al*., 2004). However, the anaerobic degradation process may be inhibited by high amounts of ammonia. The toxicity is related to temperature and the pH dependent concentration of free ammonia (Murto *et al*., 2004).

Chemical oxygen demand (COD) reduction which performed by facultative bacteria are little in fermentation process. Hydrogen production from fermentation process are small, majority of hydrogen arises from oxidation of VFAs and long chain fatty acids to acetic acid.

### *2.1.3 Advantages of Anaerobic Treatment*

There are many reasons to consider anaerobic treatment, including:

- **Lower electrical requirements:** Because an anaerobic system does not require oxygen, the high electric requirements of surface aerators or blowers are avoided.
- **Higher organic loading rate:** Anaerobic systems are capable of providing high treatment efficiencies at BOD concentrations ranging from 1,000 mg/L to 20,000 mg/L. Organic loading rates of 3.2 to 32 kg COD/$m^3$.day may be achieved which compares with 0.5 to 3.2 kg COD/$m^3$.day for aerobic processes (Metcalf & Eddy, 2003).
- **Small reactor volume:** Application of higher loading rate requires smaller reactor volume.
- **Energy production:** A byproduct of anaerobic degradation of pollutants is the production of a methane-rich biogas that can be used to supplement or replace natural gas for fueling plant boilers, engine generators, and other energy systems.
- **Good process stability:** The anaerobic process is very stable under varying hydraulic and organic loadings and other conditions that may cause upsets in other types of biological systems.
- **Lower nutrient requirements:** Anaerobic systems require a fraction of the nitrogen and phosphorus than an aerobic system does.
- **Lower operating costs:** Because anaerobic systems require less nutrients and electrical input and generate less sludge than aerobic systems, they have inherently lower operating costs.

- **Low sludge yield:** Anaerobic systems typically produce a small fraction of the sludge generated by aerobic systems (http://www.etsenvironmental.com).

### *2.1.4 Disadvantages of Anaerobic Treatment*

Disadvantages of anaerobic treatment are;

- **Long start-up time:** Because of lower biomass synthesis rate, it requires longer start-up time to attain a biomass concentration. The major concerns with anaerobic processes are their longer start-up time generally it takes months.
- **Long recovery time:** If an anaerobic system subjected to disturbances due to either biomass washout, toxic substances or shock loading, it may take longer time for the system to return to normal operating condition.
- **Specific nutrients/trace metal requirements:** Anaerobic microorganisms especially methanogens have specific nutrients (e.g. Fe, Ni and Co) requirement for optimum growth.
- **More susceptible to changes in environmental conditions:** Anaerobic microorganisms especially methanogens are prone to changes in conditions such as temperature, pH, redox potential, etc.
- **Treatment of sulfate rich wastewater:** The presence of sulfate not only reduces the methane yield but also inhibits the methanogens due to sulfide production.
- **Need for alkalinity addition:** Alkalinity concentrations of 2000 to 3000 mg/L as $CaCO_3$ may be needed in anaerobic processes to maintain an acceptable pH with the high gas phase $CO_2$ concentration. If this amount of alkalinity is not available in the influent wastewater or cannot be produced by the degradation of proteins and amino acid, a significant cost may be incurred to provide alkalinity (Metcalf & Eddy, 2003).

- **Effluent need for further treatment:** Effluent may be required further treatment with an aerobic treatment process to meet discharge standards.
- **Treatment of high protein & nitrogen containing wastewater:** The anaerobic degradation of proteins produces amines, which are no longer, is degraded anaerobically. Similarly, nitrogen remains unchanged during anaerobic treatment.
- **Need heating:** Anaerobic processes may need heating to achieve adequate reaction rates (http://www.anaerobic-digestion.com).

### *2.1.5 Environmental Conditions for Anaerobic Treatment*

Anaerobic treatment is a stable process when properly operated. However, parameters such as process configuration, temperature, biomass immobilization, pH, nutrient supplementation and substrate complexity must be carefully observed in order to make possible successful anaerobic treatment (Azbar *et al*., 2001).

Anaerobic microorganisms are very sensitive to environmental effects. Because of that, optimum environmental conditions must be provided for obtains high methane gas volume, microorganism population and treatment efficiency. These environmental conditions are nutrients, pH, temperature, alkalinity, toxicity, C/N/P ratio and total volatile acids. Optimum values of these conditions are given in Table 2.1.

Table 2.1 Optimum environmental conditions for anaerobic microorganisms (Tokgöz, 1998; Kara, 2007)

| **Parameter** | **Optimum Environmental Conditions** |
|---|---|
| Wastewater composition | It should contain C, N, P and trace elements and not contain inhibitory and oxidizing elements |
| Temperature (°C) | 30 – 38°C (mesophilic)<br>50 – 60°C (thermophilic) |
| COD : N : P | 500-3000 : 5-10 : 1-5 |
| pH | 6.5 - 7.6 |
| Alkalinity | 1000 - 4000 (2000) mg $CaCO_3$/L |
| Total Volatile Acid (TVA) | <1000 -1500 mg acetic acid/L |
| TVA / Alkalinity | < 0.1 |
| Oxygen | none |
| Toxic materials | none |

*2.1.5.1 Nutrients*

Anaerobic microorganisms are needed to nutrients for the new cell development. Therefore, wastewater should contain a sufficient amount of nutrients. Anaerobic microorganisms generally require nutrients such as sulfur, iron, calcium, magnesium, sodium, potassium, cobalt, nickel, nitrogen and phosphorus. Nutrient demand is depend on content of the organic matters to be treated in the reactor (Kara, 2007).

Domestic wastewater generally contains sufficient quantities of nitrogen and phosphorus. As a result, generally there is no need for nutrient addition to the domestic wastewater for anaerobic treatment. But for anaerobic treatment of industrial wastewater, additional nitrogen and / or phosphorus should be added into the system (Tokgöz, 1998).

During the start-up, the wastewater may not need any nutrient addition. Sometimes additional nutrients can be required during operational period. Necessary phosphorus and nitrogen are added as potassium dihydrogen phosphate ($KH_2PO_4$) and urea ($Co\ (NH_2))_2$, respectively (Boller & Eugster, 1992).

*2.1.5.2 Temperature*

Different species of bacteria can survive at different temperature ranges. Ones living optimally at temperatures between 30-38°C are called mesophiles or mesophilic bacteria. Some of the bacteria can survive at temperatures between 50-60°C these are called thermophiles or thermophilic bacteria (www.face-online.org.uk).

Methane producing bacteria are more resistant to heat and can therefore operate at thermophilic temperatures, a property that is unique to bacterial families. To increase the growth rates of the slow growing methane bacteria, most anaerobic processes operate at elevated temperatures in the mesophilic (30 - 38°C) or termophilic (50 - 60°C) ranges (Kobayashi *et al*., 1983).

In anaerobic processes, operation in mesophilic temperatures is generally preferred for efficient treatment because of its lower energy requirement.

*2.1.5.3 C / N Ratio*

Carbon is used by the microorganisms to provide energy requirement. The most important nutrients for microorganisms are nitrogen and phosphorus. Nitrogen is required for growing and reproducing of bacteria. Phosphorus need for bacterial growth is about 1/7 - 1/5 of nitrogen required and it is necessary for ATP, RNA, and DNA synthesis (Toprak, 1990). For an infinite biological reduction, COD: N: P ratio should be 100:2 - 10:0.5 - 1, respectively (Boller & Eugster, 1992).

*2.1.5.4 pH*

A successful pH range for anaerobic treatment is 6.5 - 7.6, but efficient treatment occurs at a pH near neutrality. Methane bacteria are very sensitive so they do not live at low pH. Low pH may be remedied by dilution or by the addition of lime.

Low and high pH values make inhibitory effect on the system. When pH values fall under six the system is called “dead” and the treatment efficiency reduces. In addition, the pH values reach nine methane formation decreases. If the system waits in low pH values more than three days, it is generally impossible for the system to return steady state conditions (Tokgöz, 1998).

If necessary optimum conditions are not provided in the system, acidogenic bacteria may produce volatile acids more than methanogenic bacteria produced. In this kind of a situation, pH falls down to unsuitable values for anaerobic treatment. Consequently, methane production is decreased and will be completely ended at a certain pH value (Tokgöz, 1998).

However, under the highest organic loading rate (OLR), the pH decreased rapidly and the conversion of substrate to biogas was reduced due to the inhibition of methanogenic bacteria, caused by pH decrease (Stadlbauer *et. al*., 1994).

*2.1.5.5 Alkalinity*

In the anaerobic treatment, buffering capacity is commonly measured as alkalinity and as a dominant buffering system bicarbonate alkalinity is used. Protection of a sufficient alkalinity in the system is significant in protecting the operation against low pH value (Tokgöz, 1998).

If bicarbonate alkalinity value in the system falls under 500 mg/L and approximately 38% of the gas produced is carbon dioxide, pH of the system falls under six and finally all the systems stay under the toxic effect.

*2.1.5.6 Total Volatile Acids*

In the anaerobic treatment, acetic, propionic and butyric acids are produced as intermediate products. Inhibitory organic volatile acids concentration depends on the pH of the system. If the system pH is controlled at a constant range, volatile acids concentration is tolerated at a certain value. When volatile acids concentration is higher than 3500 mg/L, this situation makes inhibitory effect on the system (Tokgöz, 1998).

*2.1.5.7 Toxic Materials*

Like aerobic treatment processes, toxic materials make inhibition effects on anaerobic treatment processes. Many materials show toxic characteristics in high concentrations but at low concentrations they are increased the microbial growth.

Common toxic substances are the soluble salts of copper, zinc, nickel, mercury, and chromium. On the other hand, salts of sodium, potassium, calcium, and magnesium may be stimulatory or toxic in action. In addition, dissolved heavy metals at very low concentrations (0.1 – 10 mg/L) have toxic effects on anaerobic treatment. Inhibitory concentrations of toxic materials for anaerobic processes are given in Table 2.2.

Table 2.2 Inhibitory concentration of toxic materials for anaerobic process (Tokgöz, 1998; Filibeli, Büyükkamacı, Ayol, 2000; Öztürk, 2005; Kara, 2007)

| **Material** | **Harmful Concentration (mg/L)** |
|---|---|
| $NH_4^+$ , $NH_3$ | 1500-2000* |
| Dissolved $H_2S$, $HS^-$, $S^{-2}$ | 100-150 |
| Sodium ($Na^{+1}$) | 3.500-5.500 |
| Potassium ($K^{+1}$) | 2.500-4.500 |
| Calcium ($Ca^{+2}$) | 2.500-4.500 |
| $CN^-$ | 0,5-1 |
| Magnesium ($Mg^{+2}$) | 1.000-1.500 |
| $SO_3^{-2}$ | $200^+$ |
| Copper ($Cu^{+2}$) | 100 |
| Chrome ($Cr^{+3}$) | $200^+$ |
| ($Cr^{+6}$) | $3^+$ |
| Nickel ($Ni^{+2}$) | 200-500 |
| $Zn^{+2}$ | $1^+$ |
| Sulfate ($SO_4^{-2}$) | 5.000 |
| Sodium chloride and general salts (NaCl) | 40.000 |
| Nitrate (determined as N) | 0.05 |
| Manganese ($Mn^{+2}$) | >1.500 |

*(* harmful especially at pH>7.5; + dissolved)*

## 2.2 Molasses Wastewater

### *2.2.1 Characteristics and Environmental Effects of Molasses Wastewater*

Molasses, a waste product of the sugar industry, is a cheap raw material used in fermentation industries for the commercial production of yeast and ethanol. Wastewater generated from these industries is dark brown in color due to melanoidin. Melanoidin is a brown polymer that is generated during the manufacture of raw sugar. It is hardly decomposed by the usual biological treatments such as aerobic and anaerobic treatment systems (Pena *et al*., 2003). This colored polymer is a major pollutant when it is discharged into a water resource system. It prevents the penetration of sunlight that affects the photosynthetic activity of marine plants. This will therefore create an anaerobic condition thereby killing most of the aerobic marine animals (Bernardo *et al*., 1997).

Wastewater from molasses processing industries presents a large amount of colored substances that give brown color and high organic load to the effluents (Pena *et al*., 2003). In addition, molasses contains approximately 1.000.000 mg/L of chemical oxygen demand (COD), because of that; it was caused production of strong wastewater. Therefore, anaerobic treatment processes must be used to treat molasses wastewaters.

### *2.2.2 Treatment Methods of Molasses Wastewater*

Molasses wastewaters are high strength wastewaters, which are difficult to degrade because of melanoidin that is hardly decolorized by the usual biological treatments such as aerobic and anaerobic treatment systems. Currently, treatment processes such as chemical precipitation, chemical adsorption or carbon adsorption are used for removal of melanoidins from treated wastewater. However, these processes still have disadvantages due to high operation cost, high consumption of chemical agents, fluctuation of the color removal efficiency and high volume of solid waste produced (Sirianuntapiboon *et al*., 2004).

The complexity of the organic and inorganic structure of molasses wastewater and the refractory character of melanoidins make difficult the development of effective treatment methods. Molasses wastewater is usually treated by using anaerobic treatment processes for removing organic matter and producing biogas (Coca *et al*., 2007). After the anaerobic treatment, an aerobic process must be added to meet discharge norms.

The high organic material (COD) content of molasses wastewater can be reduced by activated sludge processes. However, the dark color remains as the problem, which requires a pretreatment before its safe disposal into the environment. It is difficult to treat this effluent by normal processes such as anaerobic lagoons (Dahiya *et al*., 2001).

## 2.3 Anaerobic Filters

### *2.3.1 General*

Anaerobic filter was first proposed by Young and McCarty (1969) can be used to treat domestic, industrial and agricultural waste. Because of operation and maintenance are easy, anaerobic filters having large application area in developing countries.

Anaerobic filter is a promising alternative for wastewater treatment and has applications for a broad range of wastewaters (Kobayashi *et al*., 1983). Anaerobic filters represent a developing technology suitable for treatment of wastewaters containing soluble biodegradable organic materials.

Anaerobic filters operate as flow-through contact processes. In these processes, wastewater pass over or through a bed of biological solids, either supported as a biofilm on a fixed media or suspended as a mass of granules, within the reactor. Organic materials in the wastewater diffuse into the surfaces of the fixed biofilm layers or granules where they are converted to organic intermediates that subsequently are converted to methane gas (Young &Yang, 1989). Therefore, the media acts as a gas-solids separator, helps to provide uniform flow through the reactor, improves contact between the wastewater and the biomass also permits accumulation of the large amounts of biomass (Ahn & Forster, 2002).

The most important points in the anaerobic processes are the preservation of sufficient biomass within the system and the maintenance of necessary contact between the substrate and biomass. For this purpose, carriers were put into the reactors to keep the microorganisms at fixed surfaces in recent years (Eroğlu *et al*., 1991). The major advantage of carriers is their ability to retain higher biomass concentrations in the reactor that improves the reaction rate per unit volume.

The upflow anaerobic filter (UAF) process has been widely used for the treatment of a variety of types and strengths of organic wastewaters (Yu *et al*., 1998) since Young and McCarty (1969) demonstrated that it was an effective and feasible technology for wastewater treatment.

### *2.3.2 Design Parameters*

The efficiency of an anaerobic reactor depends on the dynamics and kinetics of the microbial populations within the reactor (Metcalf & Eddy, 2003). Most critical design factors affecting performance of anaerobic filter are; wastewater characteristics, influent wastewater concentration, media type and placement, hydraulic retention time, temperature, alkalinity, pH and organic loading rate.

#### *2.3.2.1 Wastewater characteristics*

Wastewater characteristics are of prime significance to the design and operation of any type of fixed-film anaerobic process. Generally, the wastewater must be biodegradable, free of toxic components and have temperature between 25°C and 40°C.

Materials commonly causing problems in anaerobic systems include heavy metals (Cu, Zn, Cd, Hg, and Pb), phenolics (phenol, chlorophenols and nitrophenols), salts (sodium, calcium and magnesium in high concentrations), cyanides, pesticides, chloroform, formaldehyde, disinfectants and ammonia. Sulfides, while necessary to support anaerobic reactions, also can be toxic in high concentrations (Speece, 1983).

#### *2.3.2.2 Media Type and Placement*

The solid support filling within reactor is the most important component of an anaerobic fixed film reactor. Some ideal characteristics of the packing material are high porosity, large surface area, adequate surface properties for adherence lightweight and economical (Acharya *et al*., 2007).

Media selection and placement is quite subjective. No trend is apparent in the type of media used in full-scale anaerobic filters. The media / height ratio in upflow reactors is the critical factor and reactors having 50% or less media volume generally experienced increased solids loss and reduced efficiency. The media is placed in the upper 2/3 of the height should be no less than 2 m (Steinbrecher, 1988).

Media surface area seems to have only a minor effect on wastewater treatment performance with less than 5% improvement in COD removal efficiency when the specific surface area is doubled (Song & Yang, 1986).

Plugging was a problem with fully packed designs using rock and loose-fill media (Sheridan, 1982). When plugging is occurred excess sludge must be removed from the media periodically. No instances of plugging have been reported for crossflow or tubular modular media having specific surface areas is about 100 $m^2/m^3$ (Okkes, 1983).

Many synthetic packing media made up of plastics, ceramic tiles of different configuration have been used in anaerobic filters. The void volume in these media ranges from 85-95 %. Moreover, these media provide high specific surface area typically 100 $m^2/m^3$ or above which enhance biofilm growth (Dohanyos *et al*., 1988).

*2.3.2.3 Influent Wastewater Concentration*

Wastewaters having influent COD concentrations greater than about 12000 mg/L can be treated effectively if proper pH control is applied. Recirculation is generally beneficial when wastewater strengths exceed 8000 to 12000 mg/L to reduce the organic acid concentrations and alkalinity requirements in the reactor. Recirculation is not needed for wastewater that COD concentrations below 8000 mg/L. However, if the influent COD concentrations decrease to about 1500 mg/L, system efficiency may be affected (Young & Yang, 1989).

*2.3.2.4 Organic Loading*

Anaerobic filters have performed satisfactorily when operating at COD loading rates as high as 96 kg COD/$m^3$.day in laboratory and small pilot-scale reactors, but maximum loadings of 10 to 16 kg COD/$m^3$.day seem to be more typical for full-scale units. Generally, design loadings below 12 kg COD/$m^3$.day are recommended (Guiot & Van der Berg, 1985).

*2.3.2.5 Temperature*

Anaerobic filters and other fixed-film reactors generally have performed sufficient when operated at 25°C to 38°C in the mesophilic range. Normally, complex wastewater that requires an initial hydrolysis step must be treated at temperatures above 25°C (Young & Yang, 1989). Otherwise, hydrolysis may become the rate-limiting step in the overall reaction. Operation at thermophilic temperatures (50°C to 60°C) is possible (Kato et al., 1997).

Temperature is an important factor for the process that can progress under psychrophilic (<25°C), mesophilic (25 - 40°C) and thermophilic (>45°C) conditions (Gomec *et al*., 2007).

Temperature not only influences the metabolic activities of the microbial population but also has a profound effect on such factors as gas transfer rates and the settling characteristics of biological solids (Kato et al., 1997).

### *2.3.3 Operation*

#### *2.3.3.1 Start-up*

Start-up full-scale anaerobic filters require seeding followed by close monitoring of the reactor contents. Seeding should be completed in two steps. First, a small amount of seed sludge from an active digester, approximately 1% of the reactor volume, should be added to the reactors followed by filling with the wastewater at COD concentrations not to exceed about 10000 mg/L (Young & Yang, 1989).

This mixture should be waited for 2 - 3 days to obtain condition in the reactor. This light seeding is followed by the addition of a relatively large quantity of active anaerobic sludge. Typically, 10% of the reactor volume is sufficient to promote reasonably rapid start-up. After adding this seed sludge, wastewater should be feed at a rate of about 1.0 kg COD/$m^3$.day. The reactor contents are monitored for pH, organic acid, soluble nitrogen and phosphorus concentration. If the pH falls below 6.8, additional alkalinity should be added. Nutrients are added if needed (Wilkie & Colleran, 1984).

The loading rate of wastewater should be increased gradually as COD removal and methane production begin to occur. When stable operation occurs, more seed sludge can be added to accelerate start-up. If excessive sludge occurs, aluminum chloride or polymers may be used to help promote flocculation and granulation (Wittle, 1988).

#### *2.3.3.2 Monitoring*

During start-up and operation period, the reactors must be monitored by analytical tests. Monitoring the system obtains understanding of performance and stability of the reactors. The required tests and approximate frequency is shown in Table 2.3.

Table 2.3 Suggested analytical schedule for anaerobic filter operation (Young & Yang, 1989)

| **Analysis** | **Start-up Frequency** | **Long-term Frequency** |
|---|---|---|
| COD or TOC | 8 – 12 hours | 1 – 2 times / day |
| pH | 8 – 12 hours | 1 – 2 times / day |
| Organic acids in sludge zone | Daily | 1 – 2 times / week |
| Organic acids in profile | Weekly | 1 – 2 times / month |
| Alkalinity | 2 - 3 times / week | 1 time / week |
| Ammonia - N | Daily | 1 time / week |
| Phosphorus | Daily | 1 time / week |
| Micro-nutrients | 1 time / week | 1 time / month |

### *2.3.4 Similar Studies in Literature with Thesis*

Although there are many studies with upflow anaerobic filters in the literature, there is only one study similar to this study.

The similar study was done by Wu *et al*. in 2000. Wu *et al*. (2000) were evaluated that the influence of filter material ratio on the performances of anaerobic hybrid reactors (AHRs) at low, medium and high organic loading rates in this study.

For this purpose, four laboratory upflow anaerobic hybrid reactors, each with a total unpacked volume of 7.85 L, with varying packing depths, were operated at organic loading rates from 1.0 to 24 kg COD/$m^3$ day. The anaerobic hybrid reactors (AHR) were randomly packed with rasching rings at different material ratios. The filter material ratios were 75%, 60%, 40% and 20% of the total reactor height in the AHRs. Depending on filter material ratio, the reactors were named AHR20 (20%), AHR40 (40%), AHR60 (60%) and AHR75 (75%).

According to this study, the filter material ratio had a significant effect on the performance of anaerobic hybrid reactors at high organic loading rates (>16 kg COD/$m^3$day). On the other hand, the filter material ratio showed an influence on the performance at medium organic loading rates (4 ± 12 kg COD/$m^3$day) and showed little effect on the performance of anaerobic hybrid reactor at low organic loading rates (<2 kg COD/$m^3$day).

In addition, the reactor AHR20, which has least filter material ratio, showed the best performance during this study.

# CHAPTER THREE
# MATERIALS AND METHODS

## 3.1 Introduction

This chapter gives information about the materials and methods used in this thesis.

## 3.2 Materials

### *3.2.1 Wastewater*

Molasses containing synthetic wastewater prepared in the laboratory was used to ensure a consistent organic substrate for all organic loading rates. Using of synthetic wastewater has several advantages such as; easy preparation and uniform waste characteristics. These advantages consequently minimize the problems during the start-up phase and the operation periods.

Molasses that is used as carbon source in synthetic wastewater was taken from Pakmaya Yeast Industry located in Izmir City, Turkey. During operation period, synthetic wastewater with a ratio of C/N/P = 100:2:1 was used. According to C/N/P ratio, the raw molasses was diluted to provide the suitable organic loading rates. Urea ($N_2H_4CO$) was added as nitrogen source and potassium dihydrogen phosphate ($KH_2PO_4$) was added as phosphorus source in the synthetic wastewater during experimental studies. The amount of urea and potassium dihydrogen phosphate was determined by using C/N/P ratio. Manganese sulfate ($MnSO_4$), ferrous sulfate ($FeSO_4$) and magnesium sulfate ($MgSO_4$) were used as trace elements at the concentrations of 0.05 g/L in the start-up period. These elements were only used once per week at the latest stages. Additionally, sodium thiosulfate ($Na_2S_2O_5$) was used in 2.5 – 3.0 g/L concentration to provide anaerobic conditions. Finally, these components were mixed together in the storage tank properly and then pumped into the reactors by using peristaltic pumps. Sodium hydroxide (NaOH) was used as a buffer for pH balance.

In experimental studies, different organic loadings and influent COD concentrations obtained by chancing the concentration of the chemicals in the synthetic wastewater. The characteristic of synthetic wastewater that used in this study is given in Table 3.1.

Table 3.1 Characteristic of the synthetic wastewater used in this study

| **Characteristics** | **Values** | | |
|---|---|---|---|
| COD (mg/L) | 1000 | 2000 | 4000 |
| C/N/P | 100:2:1 | 100:2:1 | 100:2:1 |
| pH | 7.50 | 7.50 | 7.50 |
| Molasses (ml/L) | 1 | 2 | 4 |
| Urea (g/L) | 0.043 | 0.086 | 0.172 |
| $KH_2PO_4$ (g/L) | 0.044 | 0.088 | 0.176 |
| $MnSO_4$ (g/L) | 0.05 | 0.05 | 0.05 |
| $MgSO_4$ (g/L) | 0.05 | 0.05 | 0.05 |
| $FeSO_4$ (g/L) | 0.05 | 0.05 | 0.05 |
| $Na_2S_2O_5$ (g/L) | 2.5 | 2.5 | 2.5 |
| Temperature (ºC) | 35 | 35 | 35 |

### *3.2.2 Seed Sludge*

Seed sludge obtained from Pakmaya Yeast Industry Anaerobic Wastewater Treatment Plant was used as inoculate the reactors. This sludge was taken from methanogenic and acidogenic tanks, which are situated at Pakmaya Anaerobic Wastewater Treatment Plant. Two kinds of sludge were mixed at laboratory before they were given to the reactors for seeding.

### *3.2.3 Reactors*

Four anaerobic filter reactors made of a plexiglas column with an inside diameter of 10.7 cm and a height of 31.0 cm were used in operation. The column was filled with plastic material that is called ring. The shape of the rings is tube. Diameter of rings are 1.5 cm and length of rings are 1.0 –1.5 cm.

Four upflow anaerobic filter reactors (UAF) were prepared with different filter bed height of 100%, 75%, 50% and 25% fullness, respectively. The first reactor filled 100 % was called as UAF 100, 75% was called as UAF 75, 50% was called as UAF 50 and 25% was called as UAF 25. The reactors were identical with typical upflow anaerobic filter applications in literature except their filter material ratio.

The anaerobic filter reactors with different filter material ratios were operated in different experimental periods. Filter materials were not fixed in the reactors except the UAF 100 reactor. Filter materials were randomly placed into the reactors.

The empty volume of anaerobic filter reactors is 2.95 L. Total void volume shows that reactor's volume except the total volume of filter materials in the reactor. Total void volume of them is 1.94 L for UAF 100, 2.14 L for UAF 75, 2.20 L for UAF 50 and 2.25 L for UAF 25, respectively.

Total effective area expresses the total surface area where filter materials are placed in the reactor in terms of the filter material number. Total effective area of the reactors is 1.012 $m^2$ for UAF 100, 0.760 $m^2$ for UAF 75, 0.508 $m^2$ for UAF 50 and 0.252 $m^2$ for UAF 25, respectively. The characteristics of the anaerobic filters used in this study are given in Table 3.2.

Table 3.2 Specifications of the upflow anaerobic filter reactors used in this study

| Characteristics | Values | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| Operation mode | Continuous, Semi-continuous | Continuous, Semi-continuous | Continuous, Semi-continuous | Continuous, Semi-continuous |
| Flow mode | Upflow | Upflow | Upflow | Upflow |
| Total height (cm) | 31.0 | 31.0 | 31.0 | 31.0 |
| Diameter (cm) | 10.7 | 10.7 | 10.7 | 10.7 |
| Total volume (L) | 2.95 | 2.95 | 2.95 | 2.95 |
| Total void volume (L) | 1.94 | 2.14 | 2.20 | 2.25 |
| Total effective area ($m^2$) | 1.012 | 0.760 | 0.508 | 0.252 |

The influents were pumped from same feeding tank to the bottom of the reactors by using peristaltic pumps. Moreover, the effluents were collected separately for each reactor. Schematic representation of UAF reactor system used in this study is given in Figure 3.1.

All reactors were operated in continuous and semi-continuous mode. In continuous operation mode, molasses containing synthetic wastewater was fed to the reactors continuously during hydraulic retention time. In semi-continuous operation mode, wastewater was kept during hydraulic retention time in the reactors after it was fed. Feeding the reactors were taken averagely 2 hours in this operation mode depends upon the characteristics of pumps.

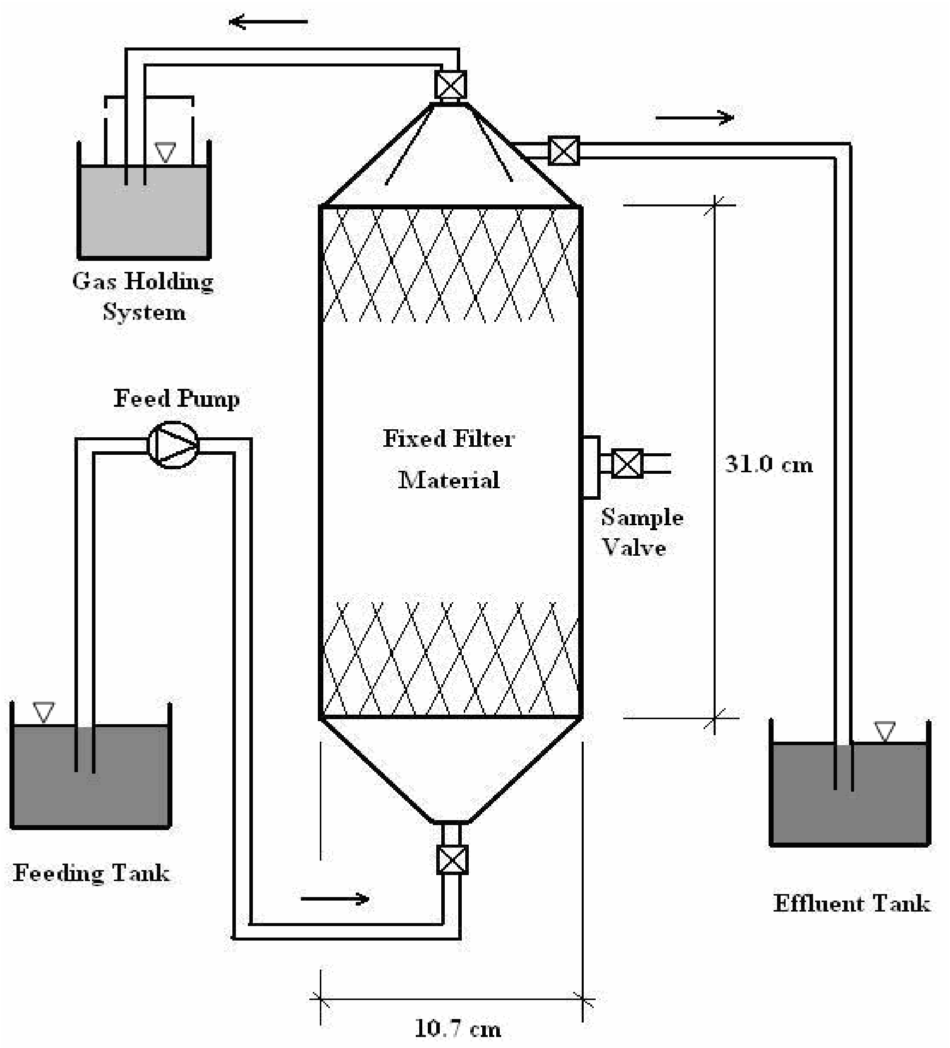


Figure 3.1 Schematic representation of UAF reactor system used in this study

The effluent gas was collected by using gas valve that was existed at the top of the reactors. The sludge was removed from the bottom of reactor whenever necessary. Sampling valve was placed in the medium of the reactor for taking samples from reactor inlet. Effluent samples were taken from the valve that was situated at the upper part of the reactors.

### *3.2.4 Filter Material*

Hard plastic hoses that are called “ring” were used as filter material in the UAF reactors. These rings had high specific surface area for providing maximum holding area to the microorganisms. In addition, the rings had high porosity value. Porosity shows void volume of filter material in the reactor. Porosity of filter material must be high to prevent clogging problem in the reactor. Characteristics of filter materials are given in Table 3.3 and their shapes are shown in Figure 3.2.

Table 3.3 Characteristics of filter materials

| **Characteristics** | **Values** | | | |
|---|---|---|---|---|
| | **UAF 100** | **UAF 75** | **UAF 50** | **UAF 25** |
| Length (cm) | 1.0 – 1.5 | 1.0 – 1.5 | 1.0 – 1.5 | 1.0 – 1.5 |
| Diameter (cm) | 1.5 | 1.5 | 1.5 | 1.5 |
| Specific surface area ($m^2/m^3$) | 313 | 313 | 313 | 313 |
| Porosity (%) | 89 | 89 | 89 | 89 |
| Filter material number | 506 | 380 | 254 | 126 |

Figure 3.2 Filter material used in the reactors

## 3.3 Methods

### *3.3.1 Analyses*

For performance evaluations, temperature, pH, chemical oxygen demand (COD), total solids content (TS), total volatile solids content (TVS), alkalinity and Oxidation Reduction Potential (ORP) were analyzed during the experimental studies. All experimental studies were carried out according to Standard Methods (APHA - AWWA, 1992).

#### *3.3.1.1 Temperature Measurements*

Temperature measurement was done every day by using WTW 330i pH METER.

#### *3.3.1.2 pH Measurements*

pH measurements were done every day by using WTW 330i pH METER.

#### *3.3.1.3 Chemical Oxgen Demand (COD) Analyses*

COD measurements were carried out according to Standard Methods (APHA - AWWA, 1992). Closed reflux colorimetric methods were used.

In closed reflux colorimetric method, borosilicate culture tubes with 10 ml capacity were used. A visible spectrophotometer was used to measure absorbance at 600 nm. Digestion solution was prepared by adding 10.216 g $K_2Cr_2O_7$, 167 ml concentrated $H_2SO_4$ and 33.3 g $HgSO_4$ into distilled water to be 1000 ml and the solution was cooled to room temperature. Sulfuric acid reagent and potassium hydrogen phthalate (KHP) standard were used. KHP was used for the preparation of the calibration curve. KHP was lightly crushed and then dried to constant weight at 120°C. Then different initial KHP concentrations were dissolved in distilled water for different concentrations. KHP solution had a theoretical COD of 900 mg/L for

0.765 g KHP/L. 8 standards of KHP were prepared to obtain COD concentration of 50 – 900 mg COD/L. The calibration curve was used for determination of COD contents of samples. The absorbencies of samples are placed to the equation for calculating the COD concentration.

*3.3.1.4 Total Solid (TS) Analyses*

Total solid; the residue remaining after a wastewater sample, which has a definite volume, is evaporated in a weighed dish and dried to constant weight in an oven at 103 to 105°C. The increase in weight over that of the empty dish represents the total solids. The result may not represent the weight of actual dissolved and suspended solids in wastewater samples (APHA - AWWA, 1992). Calculations were made by using the equation 3.1;

$$\text{Total Solid (g/L)} = [(A - B)*1000] / V \tag{3.1}$$

A= total weight of sample and tare, mg
B= weight of tare, mg
V= volume of sample, L

*3.3.1.5 Total Volatile Solid (TVS) Analyses*

Volatile solid; the residue from total solid is ignited to constant weight at 500 ± 50°C. The remaining solids represent the fixed total, dissolved or suspended solids while the weight lost on is the volatile solids. The determination is useful in control of wastewater treatment plant's operation because it offers a rough approximation of the amount of organic matter present in solid fraction of wastewater, activated sludge and industrial wastes (APHA-AWWA, 1992). Calculations were made by using the equation 3.2;

Volatile Total Solid (g/L) = [(A – B)*1000] / V (3.2)

A= weight of sample and tare before ignition, mg
B= weight of residue and tare after ignition, mg
V= volume of the sample, L

*3.3.1.6 Alkalinity Analyses*

Total alkalinity measurements were carried out according to Standard Methods by using titration method.

Alkalinity was measured using sulfuric acid. Firstly, 0.02 N $H_2SO_4$ solution was prepared, 3 or 4 drops phenol phitalein were added into the sample of 100 ml If the color of sample turns to pink, the sample is titrated 0.02 N $H_2SO_4$ solution until color disappears. Unless it turns to pink, any process is not made. After this process, 3 or 4 drops methyl orange indicator were added into the sample in the baker. The sample is titrated with 0.02 N $H_2SO_4$ solution until color turns to the dark red from orange yellow. Calculations were made by using the equation 3.3;

Alkalinity (mg $CaCO_3$ / L) = (A * N * 50 * 1000) / V (3.3)

A= Consumption of $H_2SO_4$ solution, ml
N= Normality of $H_2SO_4$ solution
V= Volume of the sample

*3.3.1.7 Oxidation Reduction Potential (ORP) Measurements*

ORP measurements were done every other day by using ORP probe WTW Electode Sen Tix ORP.

# CHAPTER FOUR
# RESULTS AND DISCUSSION

## 4.1 Introduction

This thesis mainly focused on the anaerobic treatability of molasses containing synthetic wastewater. Organic loading rates and operation modes were changed to evaluate the treatment efficiency of four upflow anaerobic filter reactors having different filter material ratio. Anaerobic filters were fed with the molasses containing synthetic wastewater during experimental studies. The reactors were operated at 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day organic loading rates for 2 days of hydraulic retention time (HRT) at mesophilic conditions (37 ± 1°C).

At the experimental studies, the four anaerobic filter reactors were operated in continuous and semi-continuous operation mode at the same organic loading rates. All analyses were done in both continuous and semi-continuous mode.

This chapter gives the results and evaluations of the experimental studies depending on the operation modes and organic loading rates.

## 4.2 Start-up of the Anaerobic Filter Reactors

In seeding phase, diluted synthetic wastewater, which organic loading rate is 0.1 kg COD/m$^3$.day and inoculum sludge that obtained from Pakmaya Yeast Industry Anaerobic Wastewater Treatment Plant mixed the rate of 50% by volume. This mixture was fed to four anaerobic filter reactors and the reactors were operated with recycle during three weeks to obtain microorganism growth.

In the start-up phase, initially the four anaerobic filter reactors were fed with 0.166 kg COD/m$^3$.day of organic loading rates at a hydraulic retention time (HRT) of 25 days and then reactors were fed with 0.333 kg COD/m$^3$.day of organic loading rates at a hydraulic retention time (HRT) of 15 days. These loadings were made to allow acclimation of biomass to the new environment. To provide the attachment of the microorganisms, model reactors were operated with recycling during start-up period. Until steady-state conditions obtained the reactors operated, after constant 70% COD removal efficiency and the produced gas were obtained for UAF 100, the operation period was started for all of the reactors.

In the operation period, the reactors were operated at 0.5 kg COD/m$^3$day, 1.0 kg COD/m$^3$day and 2.0 kg COD/m$^3$day organic loading rates for HRT of 2 days, in continuous and semi-continuous mode, respectively. In every operation period, the measurements were not done during first two weeks for provide acclimation of microorganisms to new organic loading. In this transition phase, reactors were fed increased value of 50% of the last organic loading rate. After two weeks, during the operation period, measurements started and continued until constant effluent COD, TS and TVS removal efficiency was provided in the consecutive measurements of least 7 days. The reactors were operated until the system reached the steady state with the same effluent COD, TS and TVS removal values for every experiment, which took nearly 40 days for all reactors.

These anaerobic filter reactors were operated at mesophilic temperature at 37 ± 1°C. To provide this temperature, the anaerobic filter reactors were put in a hard plastic basin which heated by five heaters. Two of them were resistors and the others were aquarium heaters.  The temperature value of the heaters was configured to work at 37°C. Timer was used to obtain stable temperature in the basin. In winter, the top of the basin was covered with thick nylon for preventing the temperature drop. On the side, to provide the anaerobic conditions at 37ºC feeding wastewater was heated.

All of these procedures were applied for continuous and semi-continuous operation modes. Table 4.1 shows the operational conditions applied to all reactors throughout the study. Monitored parameters and sampling frequency during operation periods are given in Table 4.2.

Table 4.1 Operational conditions applied to the reactors during the study

| Operation Mode | Organic Loading Rate (kg COD/m³.day) | Influent COD Concentration (mg/L) | Hydraulic Retention Time (day) |
|---|---|---|---|
| Continuous | 0.5 | 1000 | 2 |
| | 1.0 | 2000 | 2 |
| | 2.0 | 4000 | 2 |
| Semi - Continuous | 0.5 | 1000 | 2 |
| | 1.0 | 2000 | 2 |
| | 2.0 | 4000 | 2 |

Table 4.2 Monitored parameters and sampling frequency during operation periods

| Parameters | Sampling Points | Sampling Frequency | Applied Methods |
|---|---|---|---|
| Temperature (°C) | Influent, effluent | Daily | Instrument |
| pH | Influent, effluent | Daily | pHmeter |
| Alkalinity (mg $CaCO_3$/L) | Reactors, influent | Every other days | Standard Meth. |
| ORP (mV) | Inside of reactors | Every other days | Instrument |
| COD (mg/L) | Influent, effluent | Every other days | Standard Meth. |
| Total Solid (mg/L) | Influent, effluent | Every other days | Standard Meth. |
| Total Volatile Solids (mg/L) | Influent, effluent | Every other days | Standard Meth. |

## 4.3. Results of Continuous Operation Mode

### *4.3.1 Results of UAF 100 Reactor in Continuous Mode*

Results of UAF 100 reactor in continuous mode are given in Table 4.3.

Table 4.3 Laboratory results for the UAF 100 reactor at different organic loading rates in continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf}$. (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff}$. (mg/L) | 154 | 394 | 1107 |
| COD Removal Efficiency (%) | 85 ± 1.0 | 81 ± 0.6 | 73 ± 0.5 |
| $pH_{Inf}$. | 7.50 | 7.50 | 7.50 |
| $pH_{Eff}$. | 7.07 | 6.98 | 6.89 |
| $Temperature_{Inf.}$ (°C) | 35 | 35 | 35 |
| $Temperature_{Eff}$. (°C) | 38 ± 0.7 | 37 ± 0.6 | 38 ± 0.9 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 2017 | 1954 | 1895 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1959 | 1857 | 1774 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 206 | 301 | 247 |
| Total Solid $(TS)_{Eff.}$. (mg/L) | 50 | 80 | 86 |
| TS Removal Efficiency (%) | 76 ± 1.0 | 73 ± 1.2 | 65 ± 1.3 |
| Total Volatile Solid $(TVS)_{Inf}$. (mg/L) | 121 | 206 | 131 |
| Total Volatile Solid $(TVS)_{Eff.}$.(mg/L) | 35 | 66 | 52 |
| TVS Removal Efficiency (%) | 71 ± 1.3 | 68 ± 1.2 | 60 ± 1.1 |
| ORP (mV) | -337 | -351 | -366 |

Chemical Oxygen Demand (COD) is an important parameter for treatment efficiency of anaerobic processes. The results of COD measurements are shown in Figure 4.1. As seen in Figure 4.1, 85%, 81% and 73% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. Maximum COD removal efficiency was obtained with 0.5 kg COD/m$^3$.day which was the minimum tested organic loading rate and the minimum COD removal efficiency was obtained with 2.0 kg COD/m$^3$.day with the maximum organic loading rate tested. The results indicate that while organic loading rates increased, COD removal efficiency values decreased.

The reduction of COD removal efficiency occurs due to accumulation of volatile fatty acids and large amounts of dead space due to the accumulation of biomass which reduces the effective volume of the reactor available for liquid flow (Weiland & Wulfert,1990). Also, considerable channeling and short-circuiting occur in the pall rings due to their random placement and variations in the feed rates (Athanasopolos & Karadimitris, 1988).

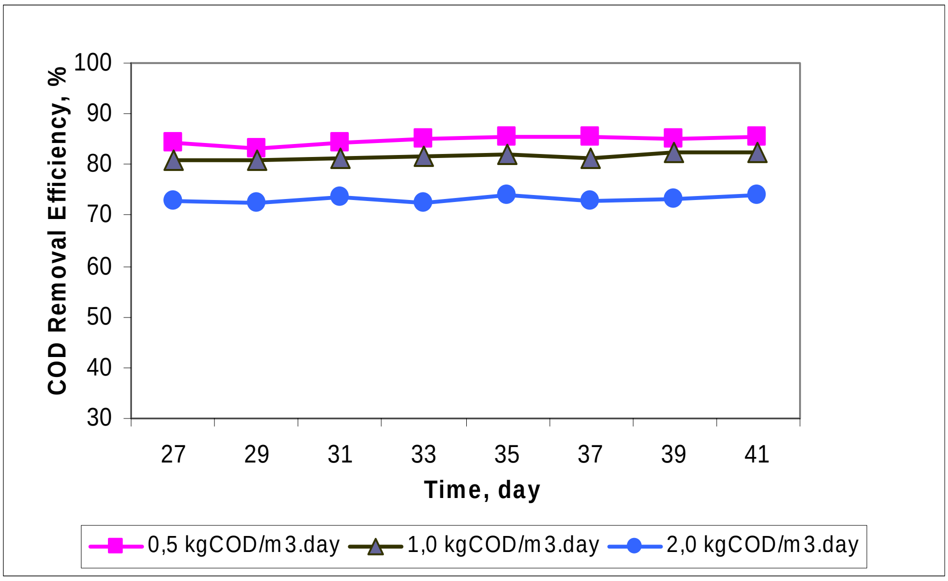


Figure 4.1 COD removal efficiencies depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

pH is an indicator for stability of anaerobic process. In this operation period, pH of the reactors was varied between 6.7 and 7.2. The measurements were done every other day and the results are shown in Figure 4.2.

As seen in Figure 4.2, while OLR increased, pH values decreased. The results are similar to study reported by Murto *et. al*. in 2004. In such a way that, the researchers reported that the small accumulations of VFA's in the reactors resulted in the consumption of bicarbonate and a decrease in pH due to the low buffering capacity. It seems that accumulation of volatile fatty acids (VFA) occured in the reactors due to the low buffering capacity. This situation resulted in decreasing pH. Also, it complicates that amount of alkalinity in the reactors was not enough to prevent decrease in buffering capacity and to neutralize VFA accumulation.

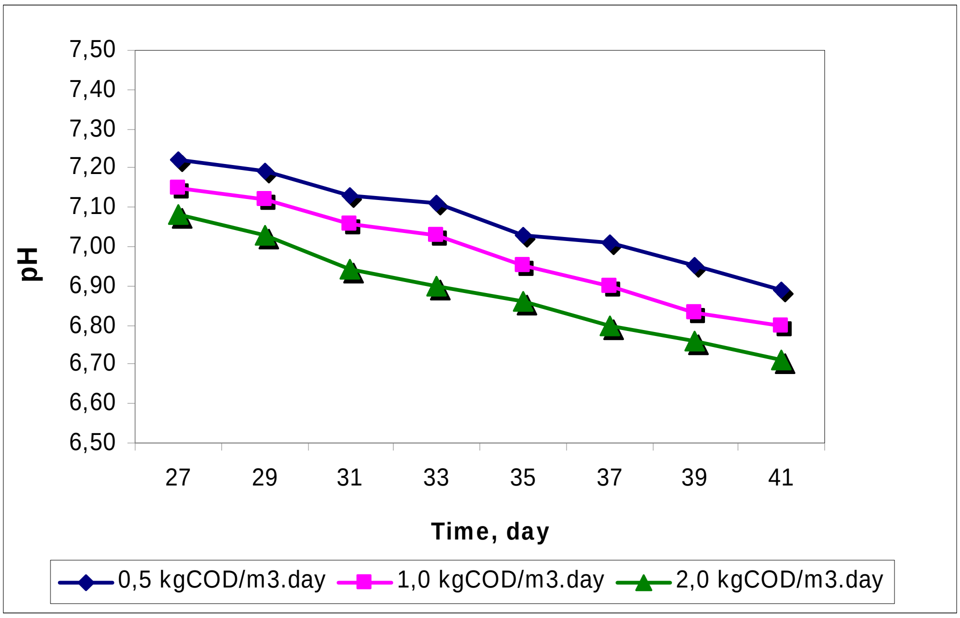


Figure 4.2 pH values depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

The temperature of anaerobic reactors for this operation period was kept at 37 ± 1°C. The temperature measurements are shown in Figure 4.3.

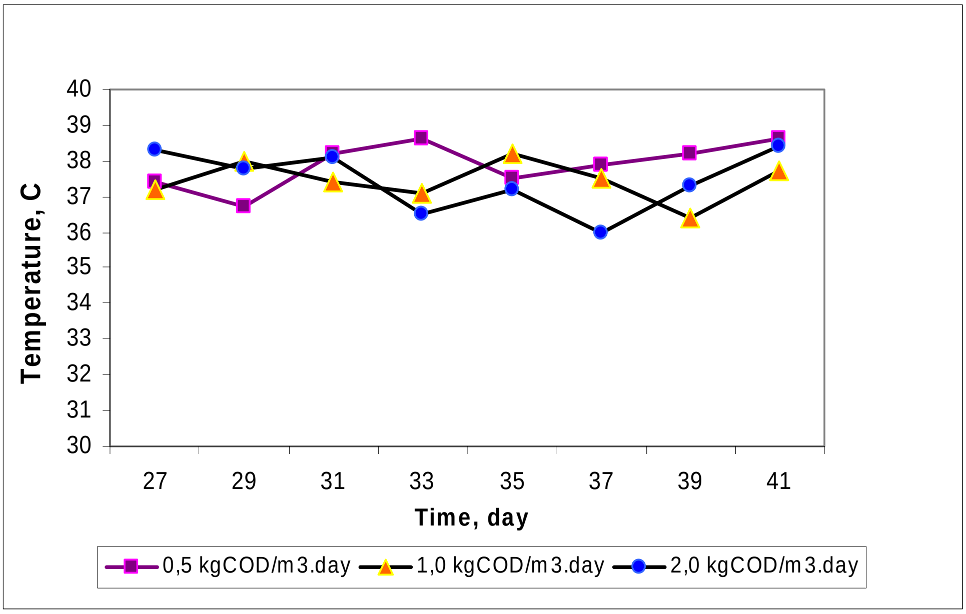


Figure 4.3 Temperature values depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

Total alkalinity measurements in the reactors were done three times in a week. The range of alkalinity was measured between 1700 and 2010 mg $CaCO_3$/L. Figure 4.4 illustrates the alkalinity results. The results are similar to study reported by Murto *et. al*. in 2004.

As seen in Figure 4.2 and 4.4, when pH values decreased, alkalinity values decreased. So, there is a lineer correlation between alkalinity and pH. Because of the alkalinity was affected by the balance between [$CO_2$] and [$HCO^{-3}$ ], low pH and alkalinity were expected at high VFA concentration due to the consumption of $HCO^{-3}$ (Jianzheng *et. al*., 2007). A higher alkalinity enhanced the system neutralization capability for VFAs and led to a stable pH value. It seems that alkalinity decreased due to the accumulation of volatile fatty acids and washout of methanogenic population in the reactors.

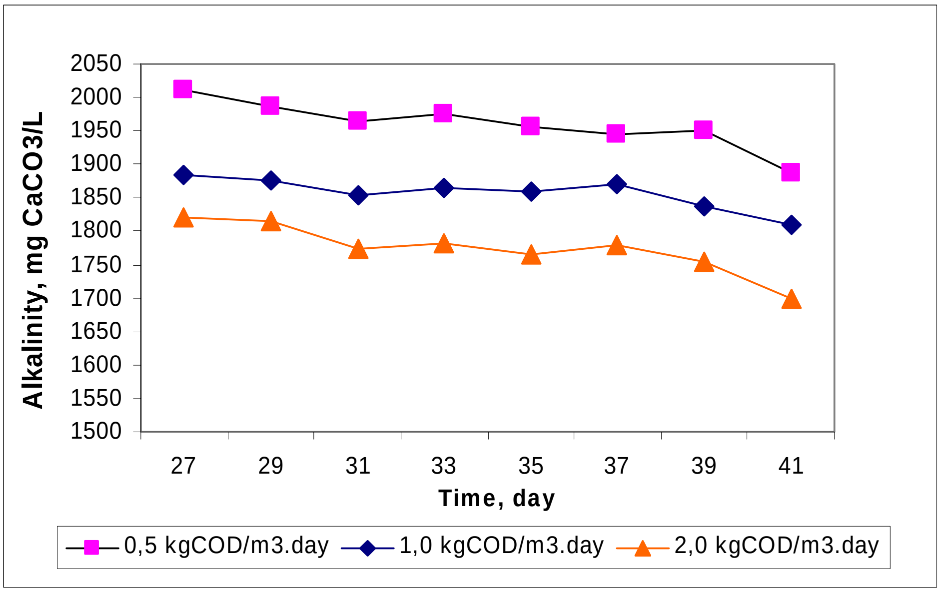


Figure 4.4 Alkalinity values depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

As average, 76%, 73% and 65% total solids reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested. The results indicate that while organic loading rates increased, total solid removal efficiency values decreased. The average removal efficiency values of 0.5 kg COD/$m^3$.day and 1.0 kg COD/$m^3$.day were close to each other. These results are shown in Figure 4.5.

The results are similar to study reported by Show and Tay in 1999. It seems that plugging and chanelling occured by the accumulation of biomass and inert suspended matter in the spaces of packing media.

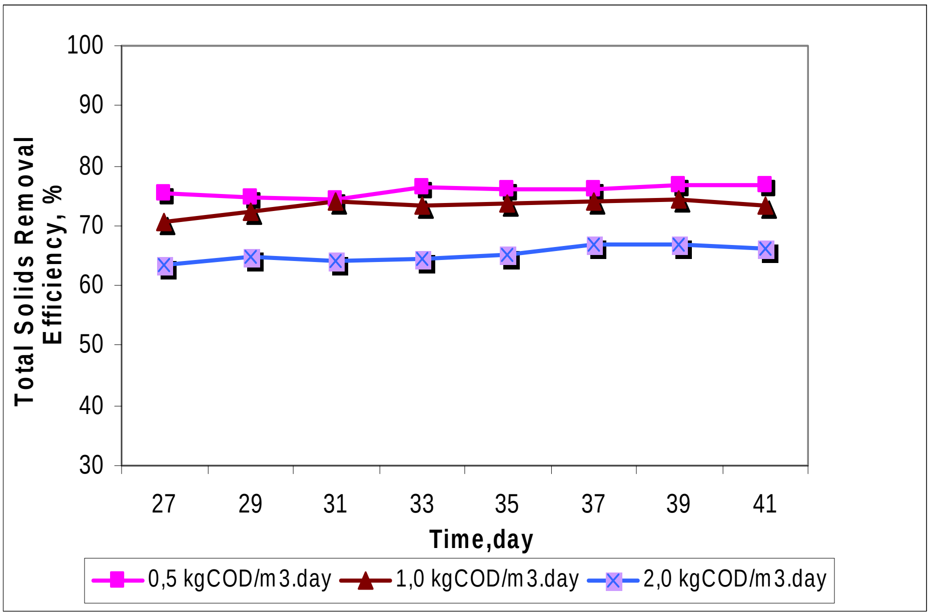


Figure 4.5 Total solids removal efficiency values depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

As average, 71%, 68% and 60% total volatile solids reductions were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. Depending on increasing organic loading rates, total volatile solid removal efficiency values decreased. When the results are compared, minimum removal efficiency was observed with 2.0 kg COD/m$^3$.day of organic loading rate. Figure 4.6 shows the values of total volatile solids removal efficiency. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

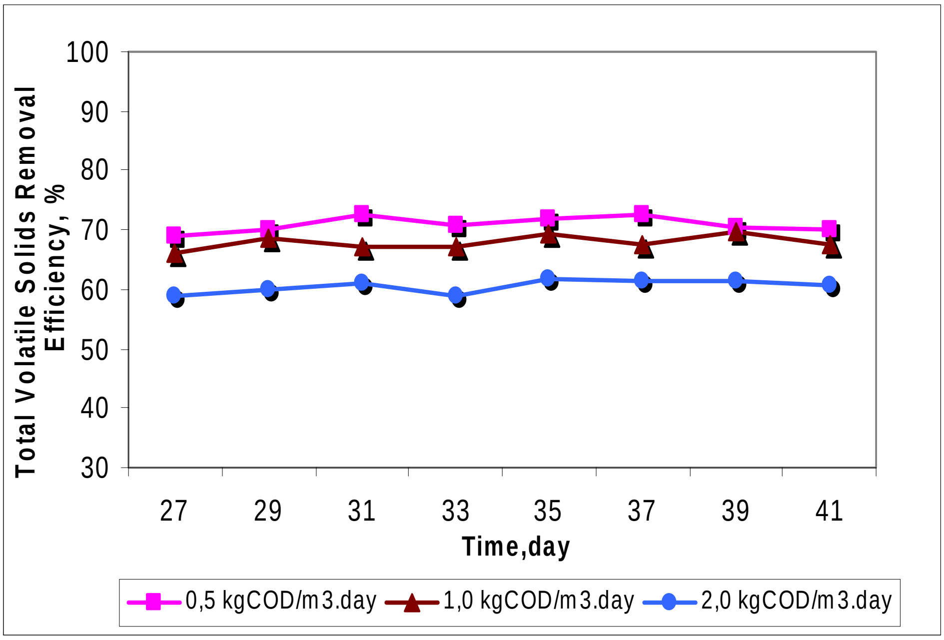


Figure 4.6 Total volatile solid removal values depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values varied between -335 and -373. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.7.

Oxidation - reduction potential (ORP) "redox" indicates the relative capacity of a solution to oxidize or reduce. For anaerobic treatment, ORP values should be in very negative range. The parameter ORP also reflects the concentration of organic substrate, activity of organism and some toxic compounds in the reactor system. It is also an indicator of some operational conditions such as overloading, underloading, over-aeration and under-aeration. ORP values were mainly affected by pH in an anaerobic system (Acharya *et. al.*, 2007).

ORP was inversely related with pH in most cases, with low ORP corresponding to high pH. The results are suitable this situation.

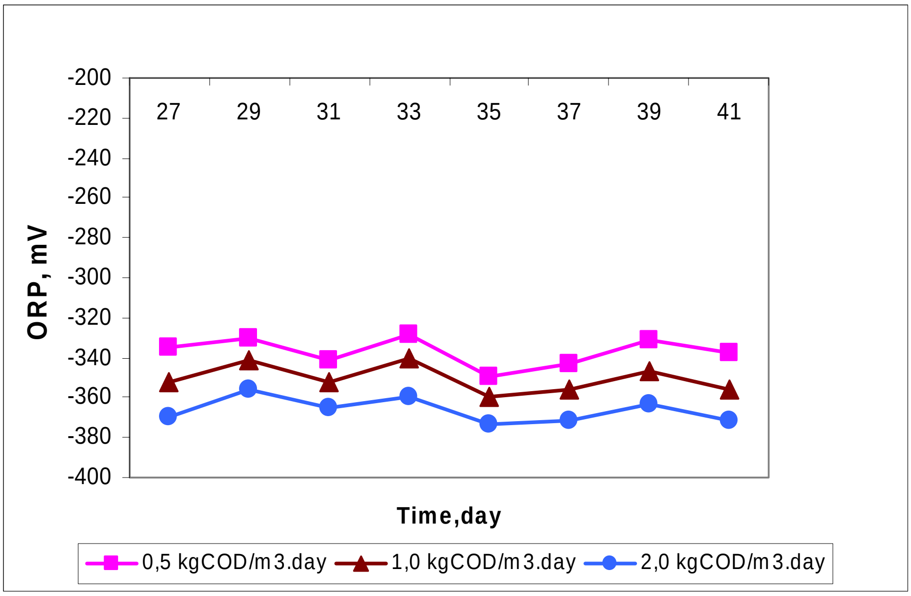


Figure 4.7 ORP values depending on organic loading rates for UAF 100 reactor in continuous mode at HRT = 2 days

### *4.3.2 Results of UAF 75 Reactor in Continuous Mode*

Results of UAF 75 reactor in continuous mode are given in Table 4.4.

Table 4.4 Laboratory results for the UAF 75 reactor at different organic loading rates in continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kgCOD/m$^3$.d** |
| $COD_{Inf.}$ (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff.}$ (mg/L) | 186 | 473 | 1299 |
| COD Removal Efficiency (%) | 82 ± 1.3 | 78 ± 1.7 | 69 ± 1.7 |
| $pH_{Inf.}$ | 7.50 | 7.50 | 7.50 |
| $pH_{Eff.}$ | 6.97 | 6.90 | 6.80 |
| $Temperature_{Inf.}$ (°C) | 35 | 35 | 35 |
| $Temperature_{Eff.}$ (°C) | 38 ± 0.8 | 38 ± 0.5 | 38 ± 0.7 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 1902 | 1836 | 1778 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1753 | 1618 | 1503 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 180 | 288 | 237 |
| Total Solid $(TS)_{Eff.}$ (mg/L) | 53 | 97 | 94 |
| TS Removal Efficiency (%) | 70 ± 1.4 | 66 ± 1.3 | 60 ± 1.8 |
| Total Volatile Solid $(TVS)_{Inf.}$ (mg/L) | 123 | 205 | 136 |
| Total Volatile Solid $(TVS)_{Eff.}$ (mg/L) | 43 | 81 | 61 |
| TVS Removal Efficiency (%) | 65 ± 0.9 | 60 ± 1.3 | 55 ± 1.1 |
| ORP (mV) | -318 | -329 | -342 |

82%, 78% and 69% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. These results are shown in Figure 4.8. As mentioned before in this section, the reasons of reduction of COD removal efficiency are satisfactory.

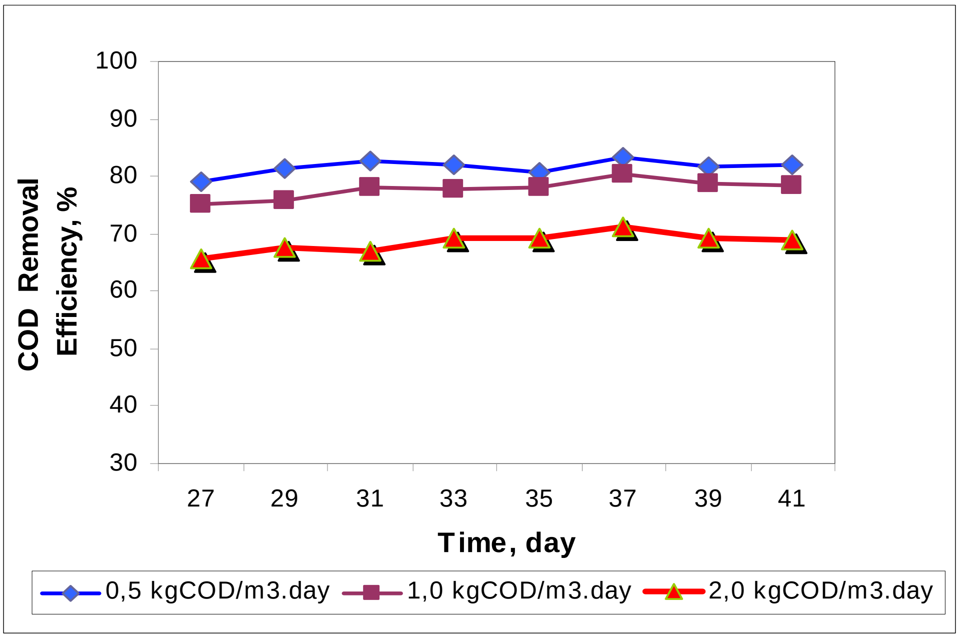


Figure 4.8 COD values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

In this operation period, pH of the reactors was changed between 6.59 and 7.18. The results are shown in Figure 4.9. The results are similar to study reported by Murto et. al. in 2004 as mentioned before.

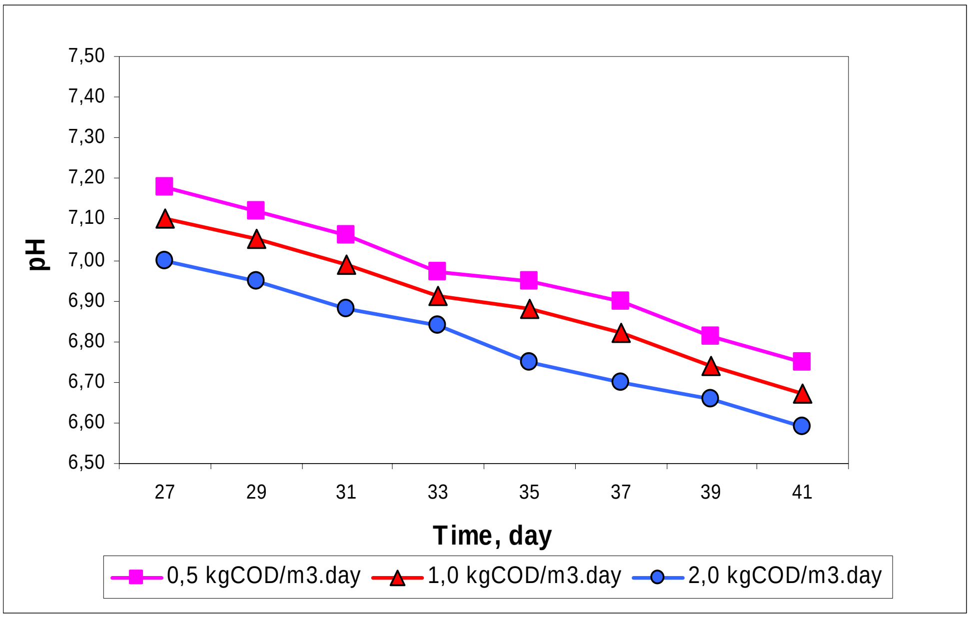


Figure 4.9 pH values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

The temperature of anaerobic reactors for this operation period was kept at 37 ± 1°C. The temperature measurements are shown in Figure 4.10.

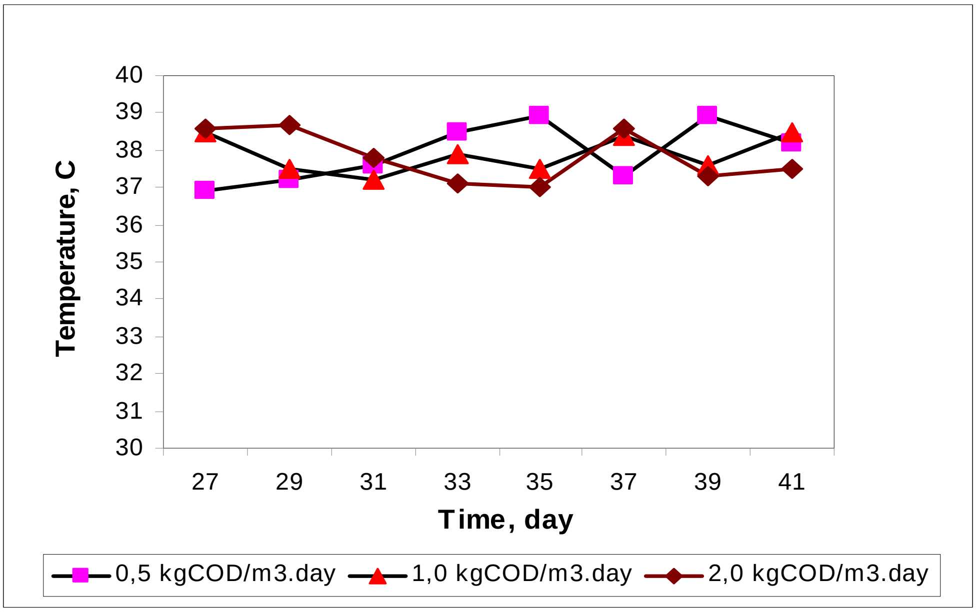


Figure 4.10 Temperature values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

Total alkalinity measurements in the reactors were done three times in a week. The values of alkalinity were measured between 1320 and 1895 mg $CaCO_3$/L. Figure 4.11 shows the alkalinity results. The results are similar to study reported by Murto *et. al*. in 2004. It seems that alkalinity decreased due to the accumulation of volatile fatty acids and washout of methanogenic population in the reactors.

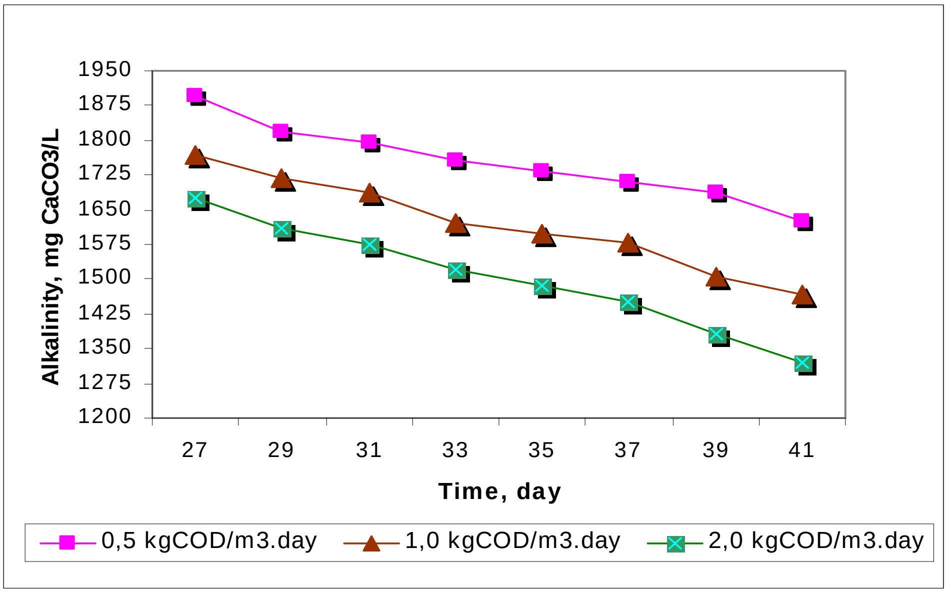


Figure 4.11 Alkalinity values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

As average, 70%, 66% and 60% total solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested. The results indicate that when organic loading rates increased, total solid removal efficiency values decreased. These results are shown in Figure 4.12. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

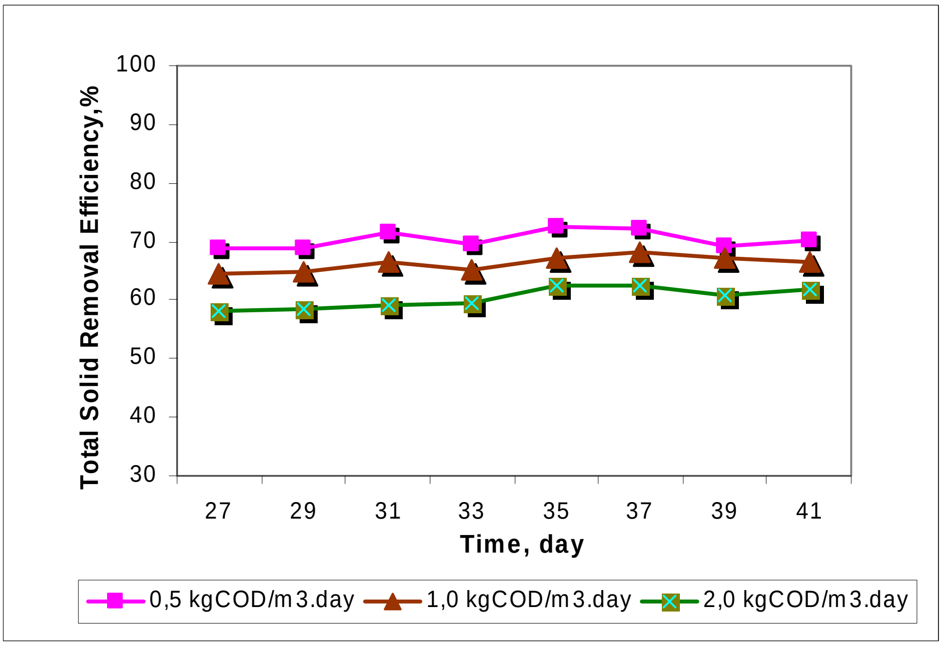


Figure 4.12 Total solid removal efficiency values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

As average, 65%, 60% and 55% total volatile solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Depending on increasing organic loading rates, total volatile solid removal efficiency values decreased. When the results are compared, maximum removal efficiency was observed with 0.5 kg COD/$m^3$.day of organic loading rate. Figure 4.13 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

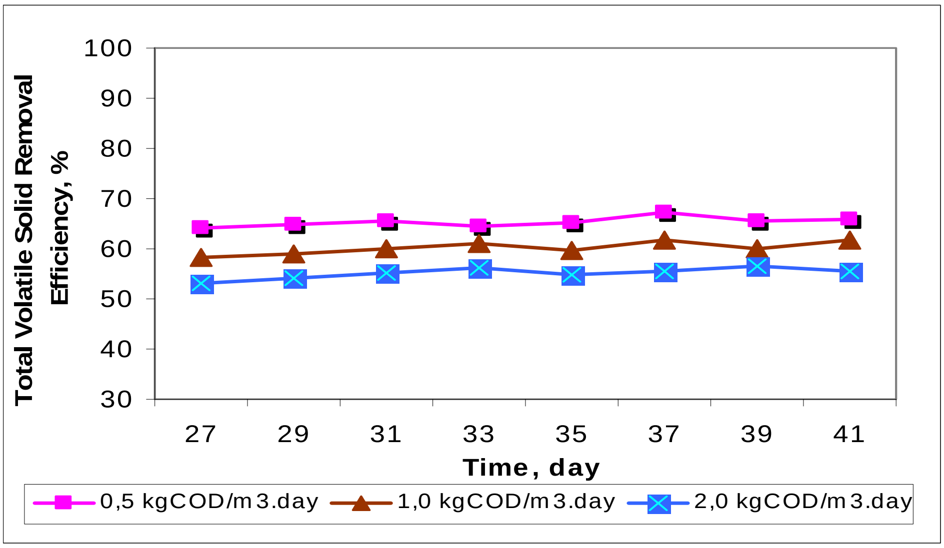


Figure 4.13 Total volatile solid removal efficiency values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values varied between -311 and -354. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.14. The results are similar to study reported by Acharya et. al. in 2007 as mentioned before.

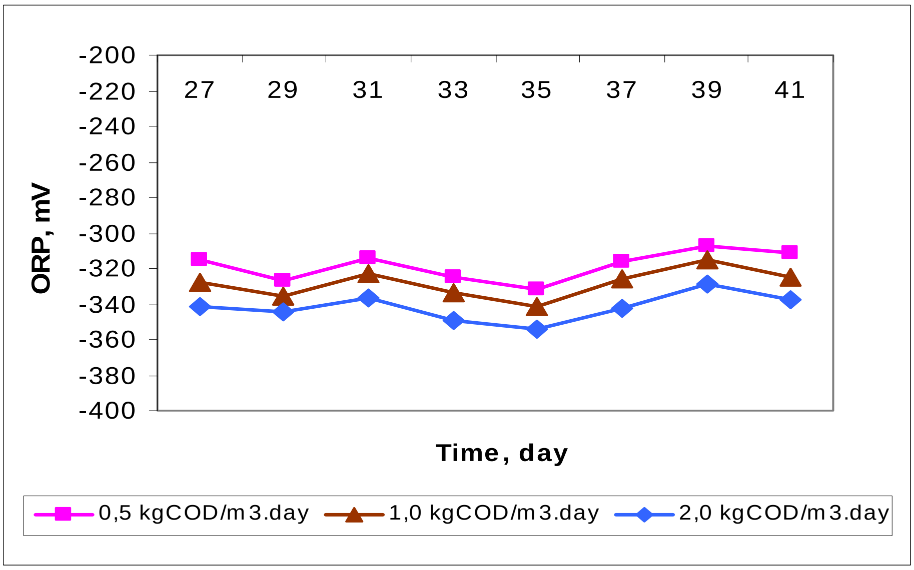


Figure 4.14 ORP values depending on organic loading rates for UAF 75 reactor in continuous mode at HRT = 2 days

### *4.3.3 Results of UAF 50 Reactor in Continuous Mode*

Results of UAF 50 reactor in continuous mode are given in Table 4.5.

Table 4.5 Laboratory results for the UAF 50 reactor at different organic loading rates in continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf.}$ (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff.}$ (mg/L) | 309 | 720 | 1890 |
| COD Removal Efficiency (%) | 70 ± 0.9 | 66 ± 0.8 | 54 ± 0.6 |
| $pH_{Inf.}$ | 7.50 | 7.50 | 7.50 |
| $pH_{Eff.}$ | 6.97 | 6.88 | 6.81 |
| $Temperature_{Inf.}$ (°C) | 35 | 35 | 35 |
| $Temperature_{Eff.}$ (°C) | 38 ± 0.4 | 37 ± 0.6 | 38 ± 0.6 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 2017 | 1954 | 1895 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1715 | 1608 | 1491 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 206 | 301 | 247 |
| Total Solid $(TS)_{Eff.}$ (mg/L) | 73 | 124 | 125 |
| TS Removal Efficiency (%) | 65 ± 1.1 | 59 ± 1.1 | 50 ± 1.1 |
| Total Volatile Solid $(TVS)_{Inf.}$ (mg/L) | 121 | 206 | 131 |
| Total Volatile Solid $(TVS)_{Eff.}$ (mg/L) | 50 | 95 | 74 |
| TVS Removal Efficiency (%) | 59 ± 1.5 | 54 ± 1.1 | 43 ± 0.9 |
| ORP (mV) | -315 | -328 | -344 |

70%, 66% and 54% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. These results are shown in Figure 4.15. As mentioned before in this section, the reasons of reduction of COD removal efficiency are satisfactory.

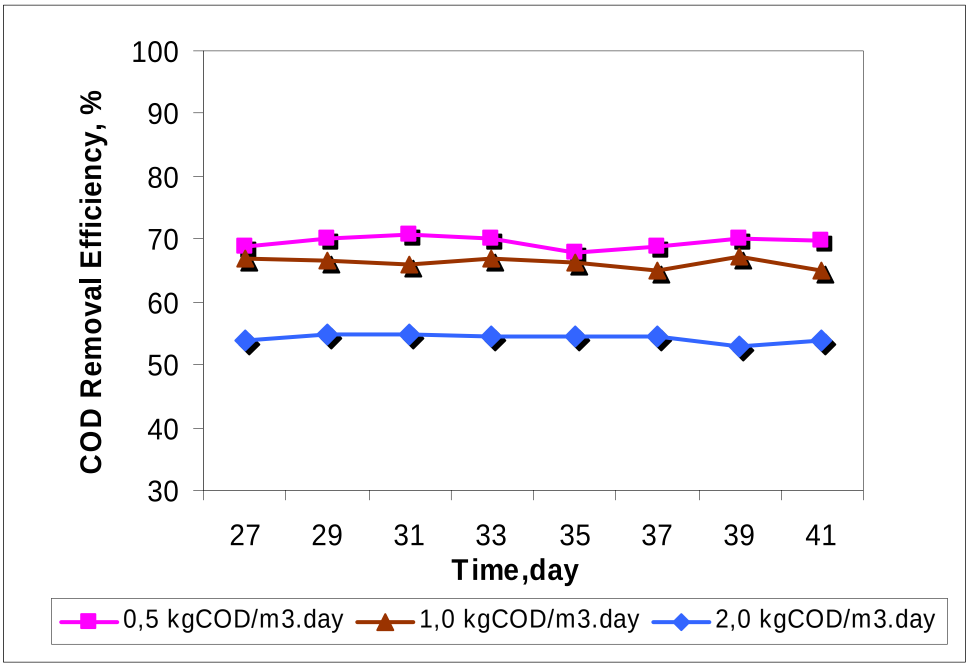


Figure 4.15 COD removal efficiency values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

The pH values were measured between 6.63 and 7.15 in this operation period. The results are shown in Figure 4.16. The results are similar to study reported by Murto et. al. in 2004 as mentioned before.

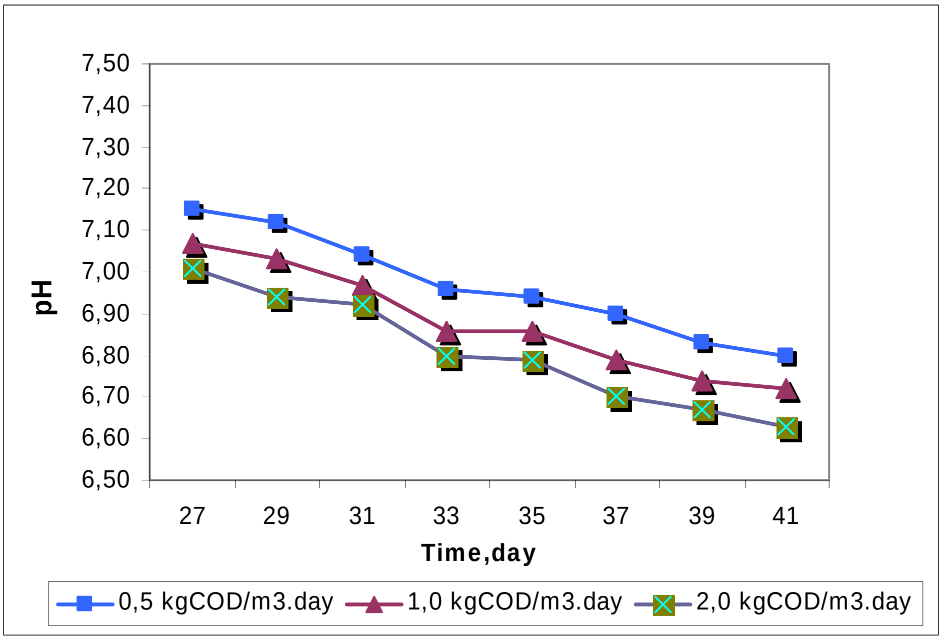


Figure 4.16 pH values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

The temperature range was kept at 37 ± 1°C in this period. The measurements are shown in Figure 4.17.

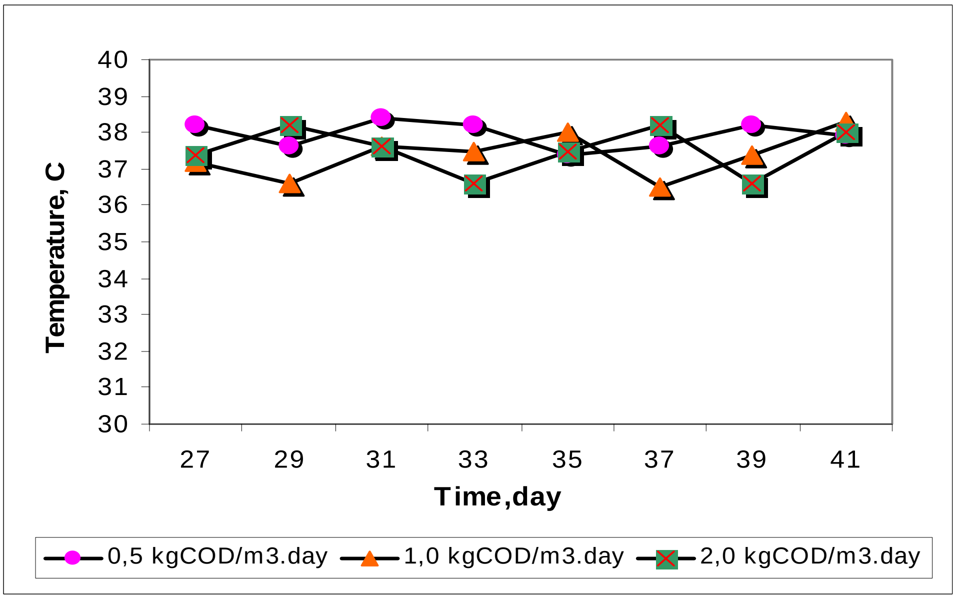


Figure 4.17 Temperature values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

The values of alkalinity were measured between 1342 and 1826 mg $CaCO_3$/L. Results are shown in Figure 4.18. The results are similar to study reported by Murto *et. al*. in 2004 as mentioned before.

It seems that alkalinity decreased due to the accumulation of volatile fatty acids and washout of methanogenic population in the reactors. The addition of alkalinity to the influent of an anaerobic reactor becomes important as it provides buffer capacity to counter the pH depression caused by the accumulation of volatile fatty acids (Kanat, 1997).

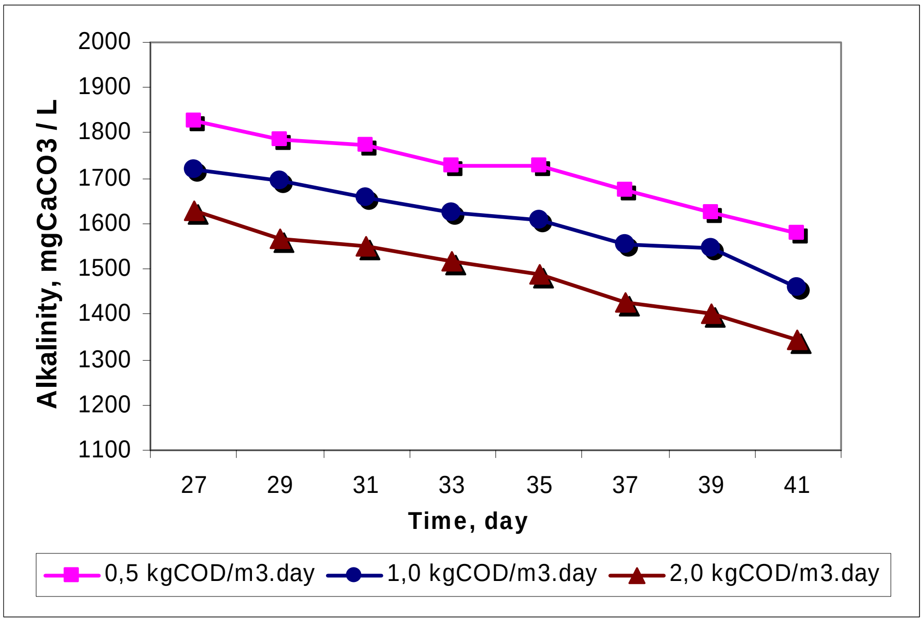


Figure 4.18 Alkalinity values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

As average, 65%, 59% and 50% total solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested.

The results indicate that when organic loading rate increased, total solid removal efficiency values decreased. These results are shown in Figure 4.19. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

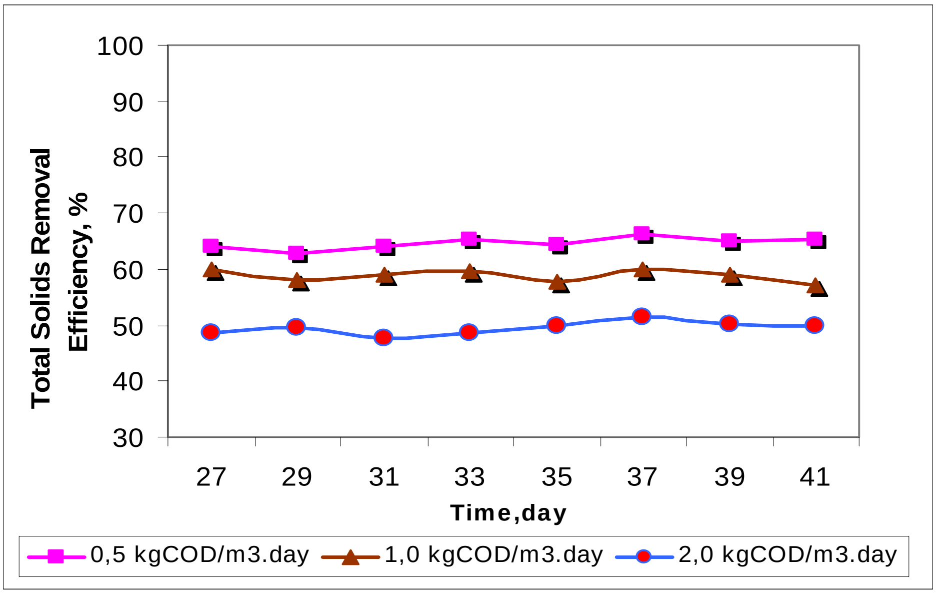


Figure 4.19 Total solids removal efficiency values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

As average, 59%, 54% and 43% total volatile solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Depending on increasing organic loading rates, total volatile solid removal efficiency values decreased. Figure 4.20 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

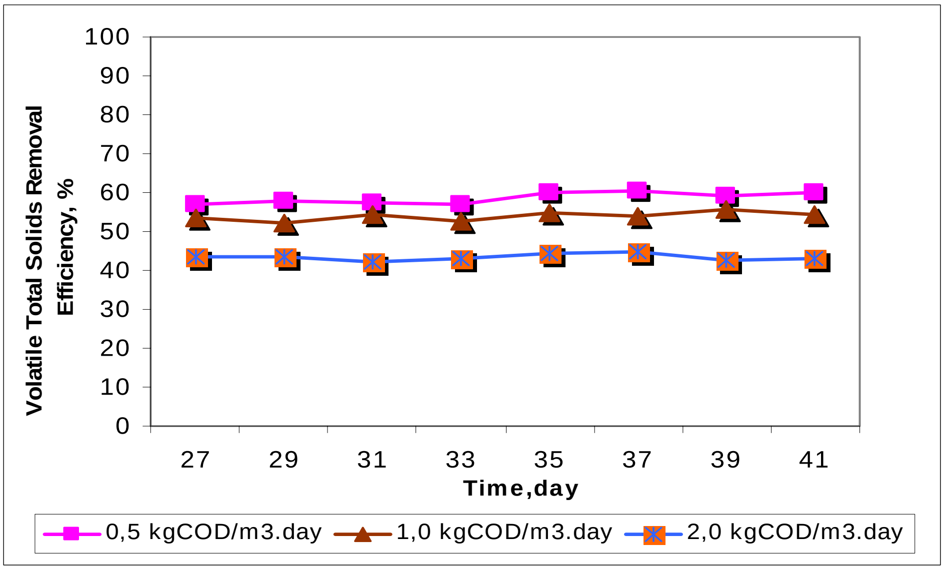


Figure 4.20 Total volatile solids removal efficiency values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values varied between -309 and -354. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.21. The results are similar to study reported by Acharya et. al. in 2007 as mentioned before.

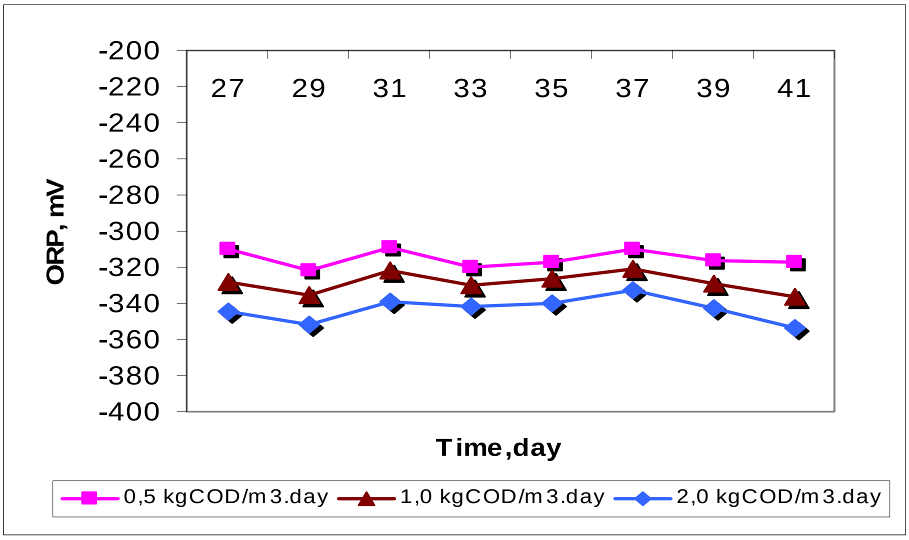


Figure 4.21 ORP values depending on organic loading rates for UAF 50 reactor in continuous mode at HRT = 2 days

### *4.3.4 Results of UAF 25 Reactor in Continuous Mode*

Results of UAF 25 reactor in continuous mode are given in Table 4.6.

Table 4.6 Laboratory results for the UAF 25 reactor at different organic loading rates in continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf.}$ (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff.}$ (mg/L) | 359 | 831 | 2218 |
| COD Removal Efficiency (%) | 65 ± 0.7 | 61 ± 0.8 | 46 ± 1.2 |
| $pH_{Inf.}$ | 7.50 | 7.50 | 7.50 |
| $pH_{Eff.}$ | 6.91 | 6.84 | 6.76 |
| $Temperature_{Inf.}$ (°C) | 35 | 35 | 35 |
| $Temperature_{Eff.}$ (°C) | 38 ± 0.6 | 38 ± 0.7 | 38 ± 0.5 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 1902 | 1836 | 1778 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1698 | 1595 | 1489 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 180 | 288 | 237 |
| Total Solid $(TS)_{Eff.}$ (mg/L) | 76 | 142 | 141 |
| TS Removal Efficiency (%) | 58 ± 1.1 | 50 ± 1.2 | 41 ± 1.5 |
| Total Volatile Solid $(TVS)_{Inf.}$ (mg/L) | 123 | 205 | 136 |
| Total Volatile Solid $(TVS)_{Eff.}$ (mg/L) | 61 | 112 | 89 |
| TVS Removal Efficiency (%) | 51 ± 1.5 | 45 ± 1.3 | 34 ± 1.2 |
| ORP (mV) | -312 | -327 | -342 |

65%, 61% and 46% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. 2.0 kg COD/m$^3$.day of organic loading rate was caused very high performance reduction in this period. The results are shown in Figure 4.22. As mentioned before in this section, the reasons of reduction of COD removal efficiency are satisfactory.

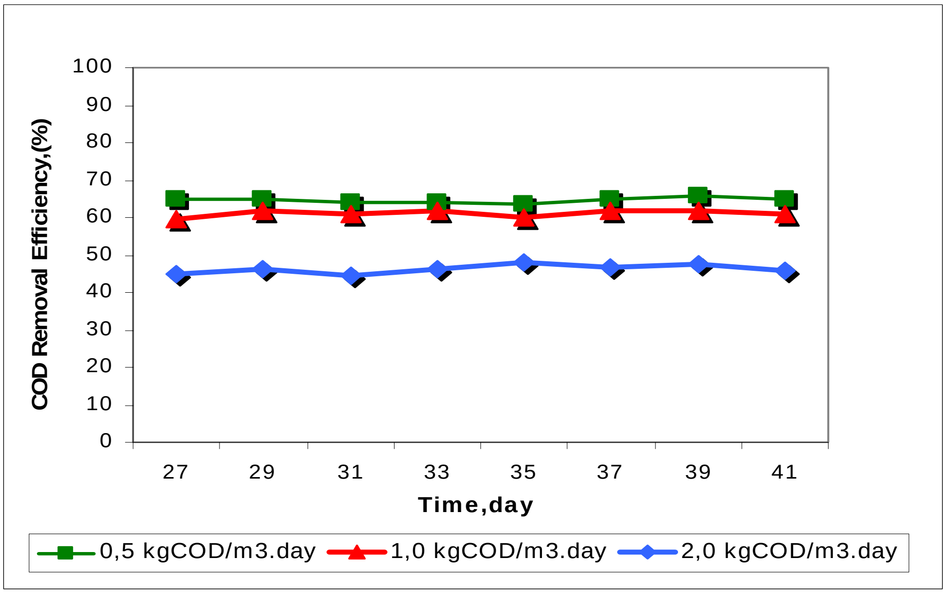


Figure 4.22 COD removal efficiency values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

The pH values were measured between 6.52 and 7.15 in this operation period. The results are shown in Figure 4.23. The results are similar to study reported by Murto et. al. in 2004 as mentioned before.

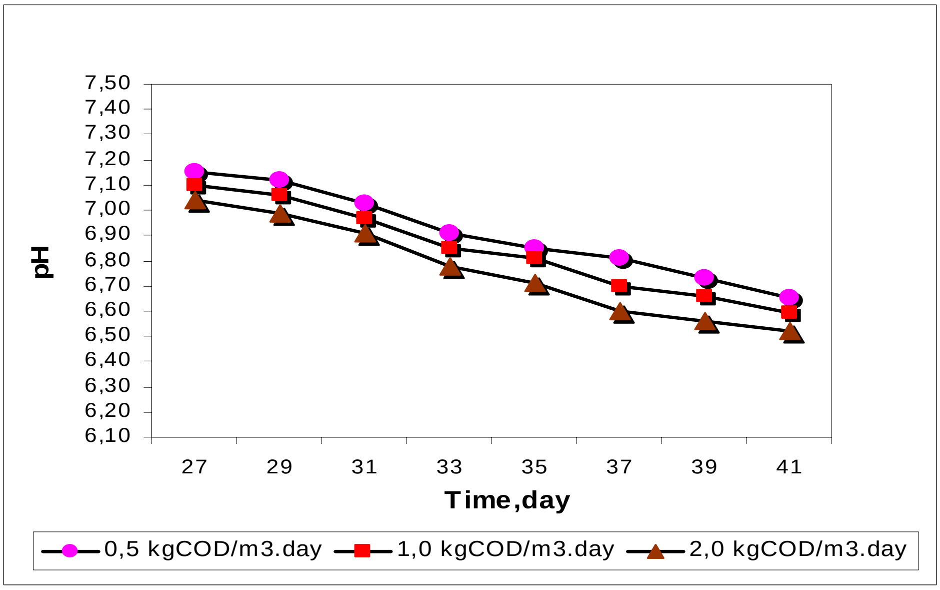


Figure 4.23 pH values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

The temperature values were kept at 37 ± 1°C. The measurements are shown in Figure 4.24.

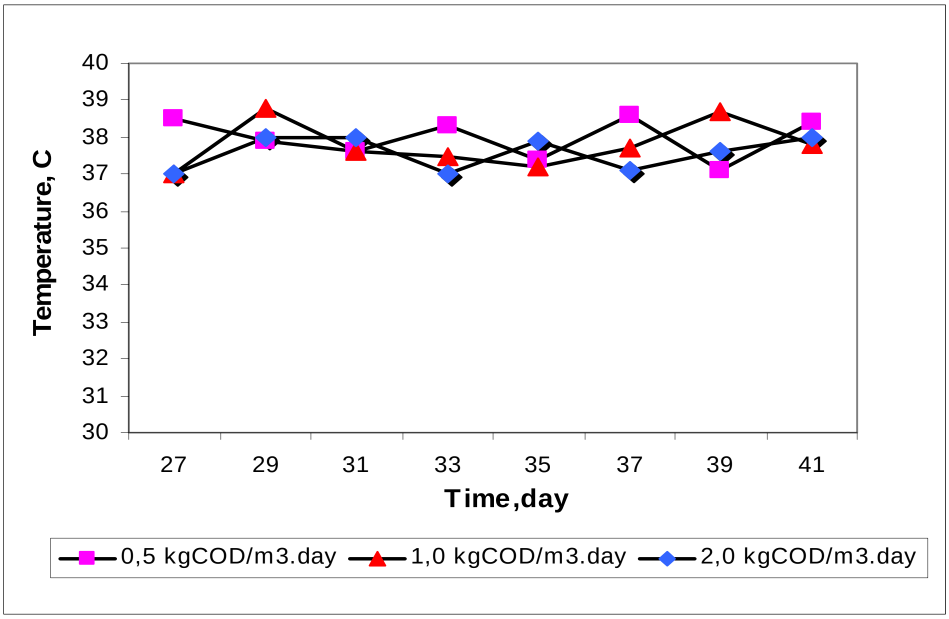


Figure 4.24 Temperature values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

The values of alkalinity were measured between 1391 and 1795 mg $CaCO_3$/L. Results are shown in Figure 4.25. The results are similar to study reported by Kanat in 1997 as mentioned before.

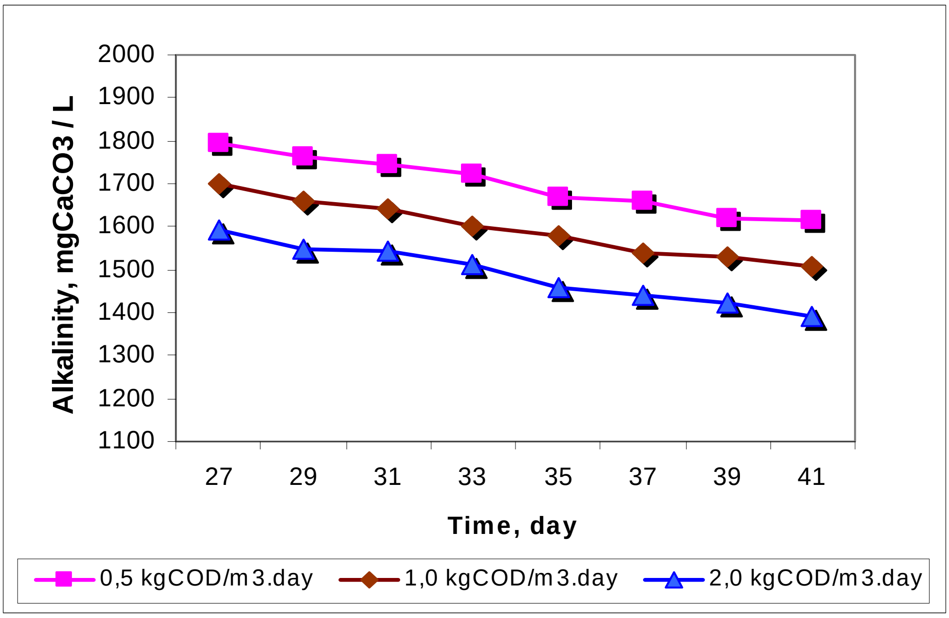


Figure 4.25 Alkalinity values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

As average, 58%, 50% and 41% total solid reductions were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/m$^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/m$^3$.day with the maximum organic loading rate tested. The results indicate that when organic loading rate increased, total solid removal efficiency values decreased. The results are shown in Figure 4.26. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

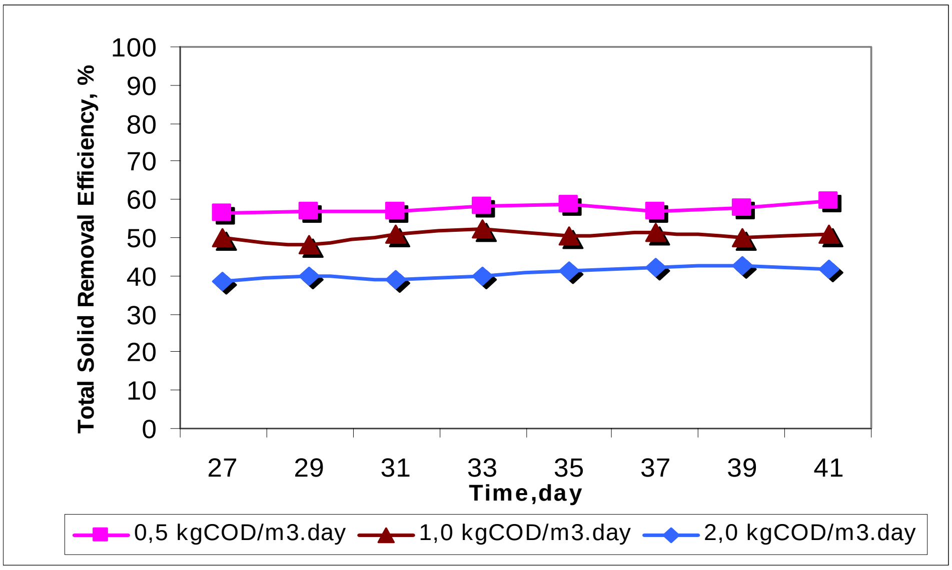


Figure 4.26 Total solid removal efficiency values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

As average, 51%, 45% and 34% total volatile solid reductions were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. Depending on increasing organic loading rates, total volatile solid removal efficiency values decreased. Figure 4.27 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

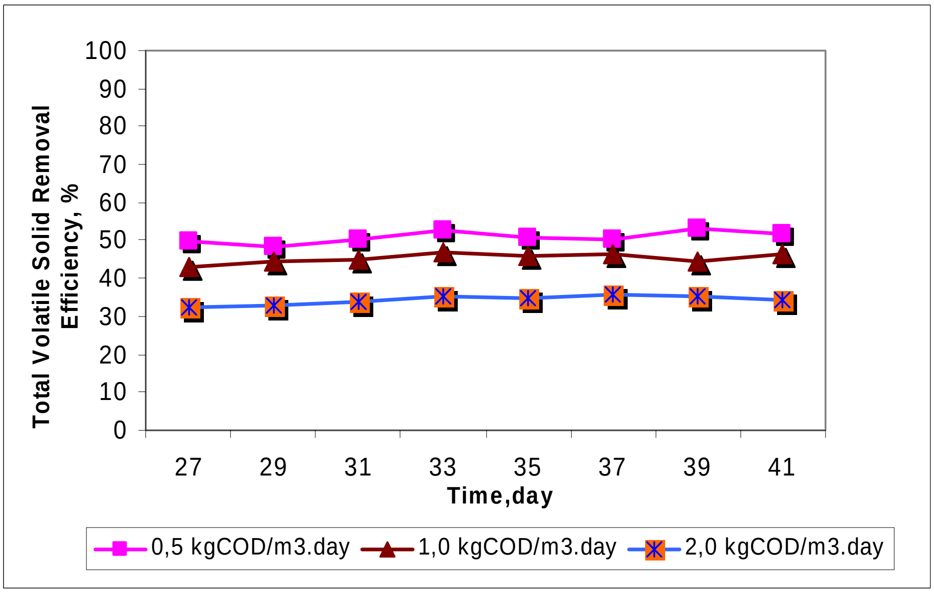


Figure 4.27 Total volatile solid removal efficiency values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values measured between -308 and -348. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.28. The results are similar to study reported by Acharya et. al. in 2007 as mentioned before.

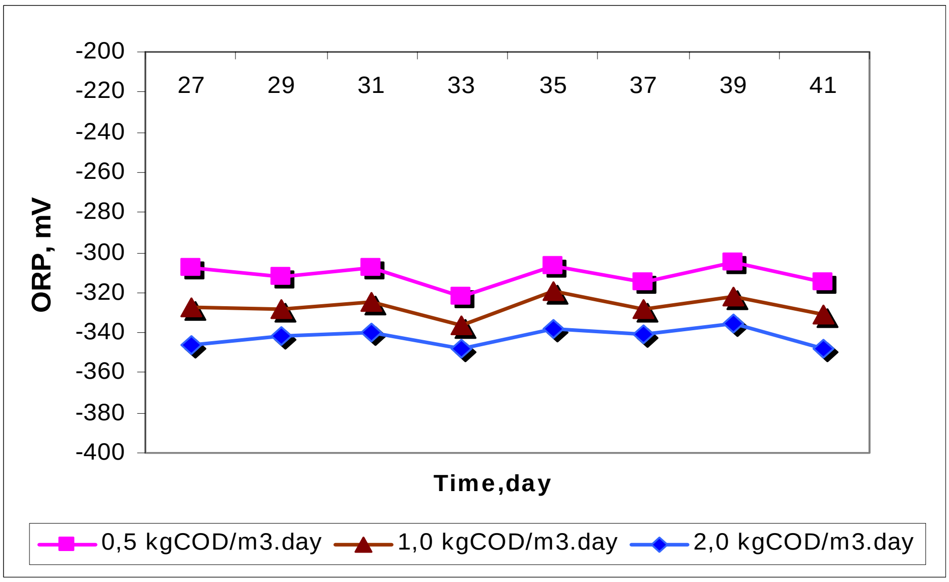


Figure 4.28 ORP values depending on organic loading rates for UAF 25 reactor in continuous mode at HRT = 2 days

### *4.3.5 Comparison of Reactors in Continuous Operation Mode*

#### *4.3.5.1 Effects of Filter Material Ratio with COD Removal Efficiency at Different Organic Loading Rates*

Average COD removal efficiency values of reactors depending on organic loading rates are given in Table 4.7. The results are shown in Figure 4.29.

Table 4.7 Average COD removal efficiency values of reactors depending on organic loading rates at continuous operation mode

| OLR (kg COD/$m^3$.day) | Average COD Removal Efficiency Values (%) | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| 0.5 | 85 | 82 | 70 | 65 |
| 1.0 | 81 | 78 | 66 | 61 |
| 2.0 | 73 | 69 | 54 | 46 |

As seen in Figure 4.29, while OLR values increased, COD removal efficiency values decreased due to the filter material ratios. Filter material reduction of reactor's affected COD removal efficiency for all organic loading rates in continuous operation mode. When filter material ratio in the reactor decreased, biofilm and amounts of microorganism decreased. Because of that COD removal efficiency decreased.

COD removal efficiencies decreased with reduction of filter material ratios which were averagely 4%, 21% and 28% for 25%, 50%, 75% reducing filter material ratios, respectively. Otherwise, maximum COD removal efficiency was obtained by using UAF 100 at 0.5 kg COD/$m^3$.day of organic loading rate.

COD removal efficiencies of UAF 100 and UAF 75 were very similar for all organic loading rates. Because of that, UAF 75 can be used economically instead of UAF 100 for treatment. In addition, the COD removal efficiency values of UAF 50 and UAF 25 were also very near. Filter material's 50% reduction results the decrease of the COD removal efficiencies of 15%.

Finally, when filter material ratio of upflow anaerobic filter reactor is less than 75%, the COD removal efficiency effects very significantly at continuous operation mode.

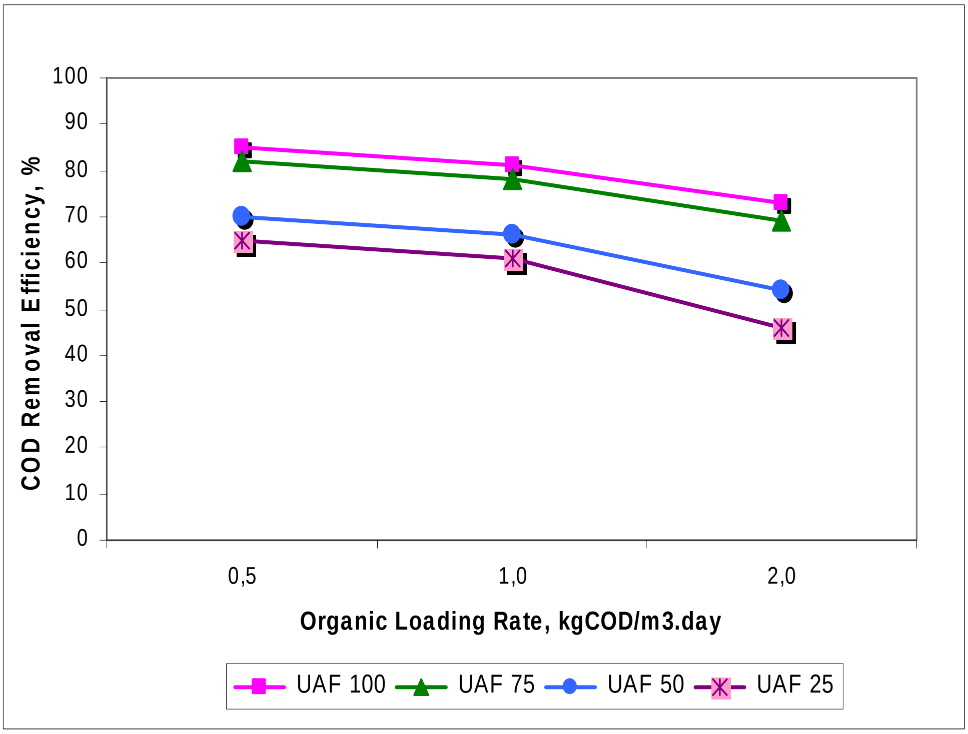


Figure 4.29 Average COD removal efficiency values of reactors depending on organic loading rates at continuous mode at HRT = 2 days

*4.3.5.2 Effects of Filter Material Ratio with TS Removal Efficiency at Different Organic Loading Rates*

Average TS removal efficiency values of reactors depending on organic loading rates are given in Table 4.8. The results are shown in Figure 4.30.

Table 4.8 Average TS removal efficiency values of reactors depending on organic loading rates at continuous operation mode

| OLR (kg COD/$m^3$.day) | Average TS Removal Efficiency Values, % | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| 0.5 | 76 | 70 | 65 | 58 |
| 1.0 | 73 | 66 | 59 | 50 |
| 2.0 | 65 | 60 | 50 | 41 |

As seen in Figure 4.30, while OLR values increased, TS removal efficiency values decreased due to the filter material ratios. Filter material reduction of reactor's affected TS removal efficiency for all organic loading rates in continuous operation mode. When filter material ratio in the reactor decreased, biofilm and amounts of microorganism decreased. Because of that TS removal efficiency decreased.

TS removal efficiencies decreased with reduction of filter material ratios which were averagely 8%, 19% and 31% for 25%, 50%, 75% reducing filter material ratios, respectively. Otherwise, maximum TS removal efficiency was obtained by using UAF 100 at 0.5 kg COD/$m^3$.day of organic loading rate.

Finally, it is seen that filter material ratio has a significant effect on total solid removal efficiency in upflow anaerobic filter reactor at continuous operation mode.

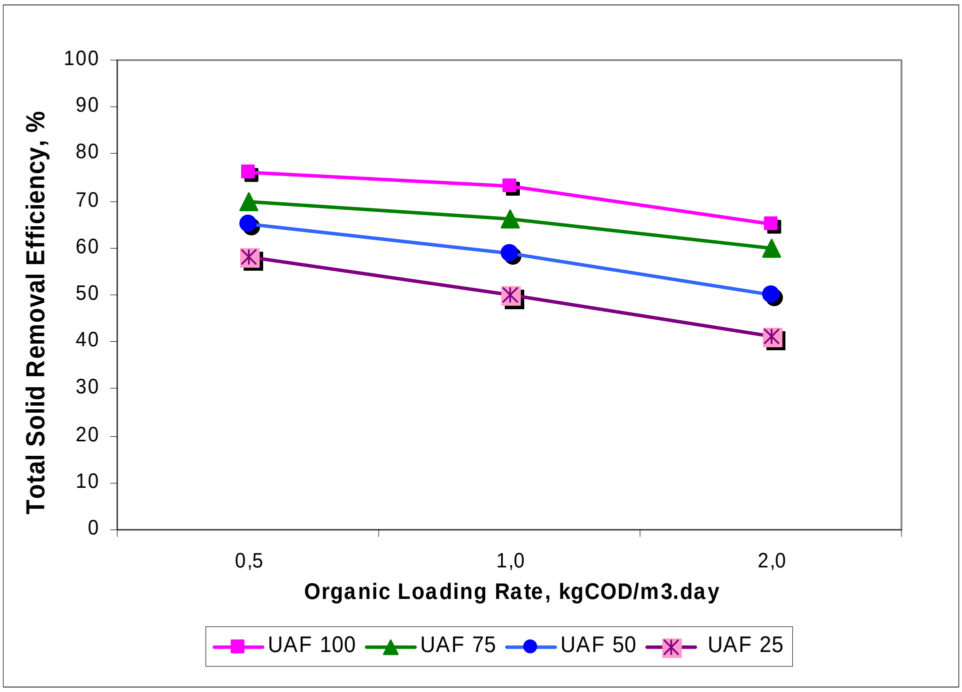


Figure 4.30 Average TS removal efficiency values of reactors depending on organic loading rates at continuous mode at HRT = 2 days

*4.3.5.3 Effects of Filter Material Ratio with TVS Removal Efficiency at Different Organic Loading Rates*

Average TVS removal efficiency values of reactors depending on organic loading rates are given in Table 4.9. The results are shown in Figure 4.31.

Table 4.9 Average TVS removal efficiency values of reactors depending on organic loading rates at continuous operation mode

| OLR (kg COD/$m^3$.day) | Average TVS Removal Efficiency Values, % | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| 0.5 | 71 | 65 | 59 | 51 |
| 1.0 | 68 | 60 | 54 | 45 |
| 2.0 | 60 | 55 | 43 | 34 |

As seen in Figure 4.31 while OLR values increased, TVS removal efficiency values decreased due to the filter material ratios. Filter material reduction of reactor's affected TVS removal efficiency for all organic loading rates in continuous operation mode. When filter material ratio in the reactor decreased, biofilm and amounts of microorganism decreased. Because of that TVS removal efficiency decreased.

TVS removal efficiencies decreased with reduction of filter material ratios which were averagely 10%, 22% and 35% for 25%, 50%, 75% reducing filter material ratios, respectively. Otherwise, maximum TVS removal efficiency was obtained by using UAF 100 at 0.5 kg COD/m$^3$.day of organic loading rate. On the other hand, minimum TVS removal efficiency was obtained by using UAF 25 at 2.0 kg COD/m$^3$.day of organic loading rate.

Finally, it is seen that filter material ratio has a significant effect on total volatile solid removal efficiency in upflow anaerobic filter reactor at continuous operation mode.

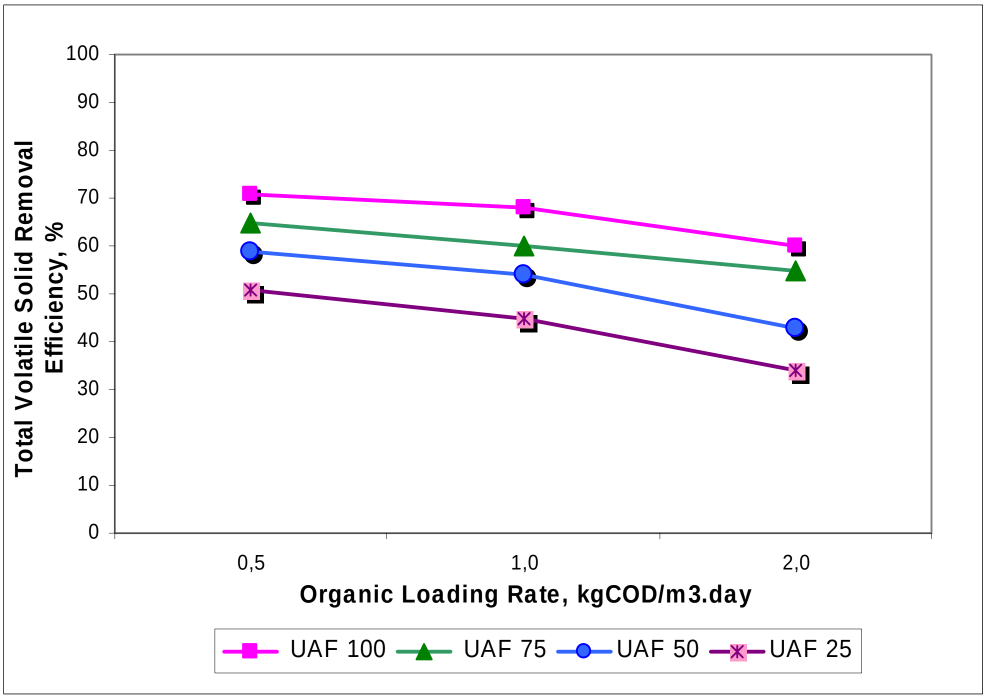


Figure 4.31 Average TVS removal efficiency values of reactors depending on organic loading rates at continuous mode at HRT = 2 days

## 4.4 Results of Semi-Continuous Operation Mode

### *4.4.1 Results of UAF 100 Reactor in Semi-Continuous Mode*

Results of UAF 100 reactor in semi-continuous mode are given in Table 4.8.

Table 4.8 Laboratory results for the UAF 100 reactor at different organic loading rates in semi-continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf.}$ (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff.}$ (mg/L) | 202 | 546 | 1478 |
| COD Removal Efficiency (%) | 80 ± 1.1 | 74 ± 0.8 | 64 ± 1.0 |
| $pH_{Inf.}$ | 7.50 | 7.50 | 7.50 |
| $pH_{Eff.}$ | 7.10 | 6.97 | 6.86 |
| $Temperature_{Inf.}$ (°C) | 35 | 34 | 34 |
| $Temperature_{Eff.}$ (°C) | 37 ± 0.7 | 37 ± 0.8 | 38 ± 0.6 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 1902 | 1836 | 1778 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1884 | 1814 | 1725 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 180 | 288 | 237 |
| Total Solid $(TS)_{Eff.}$. (mg/L) | 55 | 97 | 94 |
| TS Removal Efficiency (%) | 70 ± 1.4 | 66 ± 1.8 | 60 ± 1.6 |
| Total Volatile Solid $(TVS)_{Inf.}$ (mg/L) | 123 | 205 | 136 |
| Total Volatile Solid $(TVS)_{Eff.}$.(mg/L) | 42 | 80 | 61 |
| TVS Removal Efficiency (%) | 66 ± 0.9 | 61 ± 1.6 | 55 ± 1.3 |
| ORP (mV) | -332 | -348 | -365 |

80%, 74% and 64% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. 2.0 kg COD/m$^3$.day of organic loading rate was caused very high performance reduction in this period. Maximum COD removal efficiency was obtained with 0.5 kg COD/m$^3$.day which was the minimum tested organic loading rate and the minimum COD removal efficiency was obtained with 2.0 kg COD/m$^3$.day with the maximum organic loading rate tested. The results indicate that while organic loading rates increased, COD removal efficiencies decreased. The results are shown in Figure 4.32.

There are several reasons relating to reduction of COD removal efficiency; accumulation of volatile fatty acids, large amounts of dead space occurs due to the accumulation of biomass which reduces the effective volume of the reactor available for liquid flow (Weiland & Wulfert,1990) and considerable channeling and short-circuiting occur in the pall rings due to their random placement and variations in the feed rates (Athanasopolos & Karadimitris, 1988).

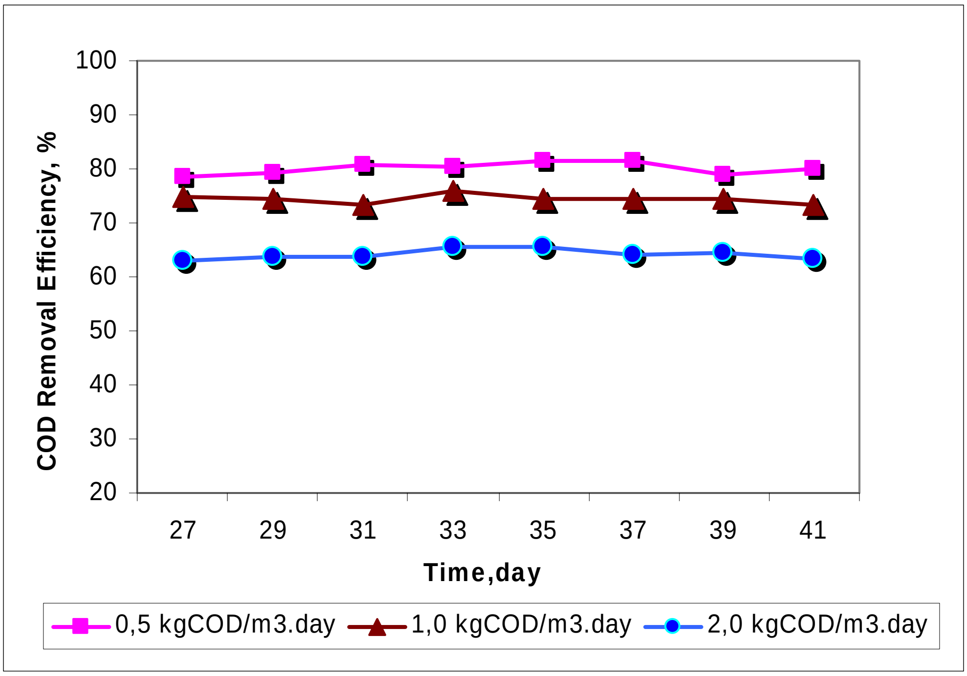


Figure 4.32 COD removal efficiency values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

The pH values were measured between 6.64 and 7.25 in this operation period. The results are shown in Figure 4.33. It may be the small accumulations of VFA's in the reactors resulted in the consumption of bicarbonate and a decrease in pH due to the low buffering capacity. It seems that accumulation of volatile fatty acids (VFA) occured in the reactors due to the low buffering capacity. This situation resulted in decreasing pH. Also, it complicates that amount of alkalinity in the reactors was not enough to prevent decrease in buffering capacity and to neutralize VFA accumulation (Murto et. al., 2004).

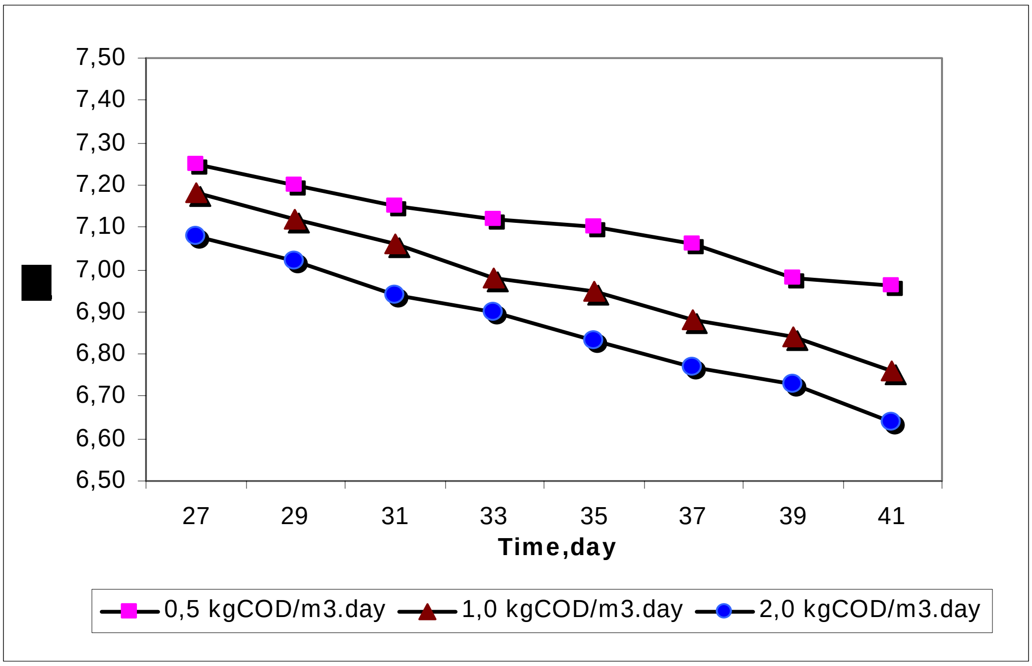


Figure 4.33 pH values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

Temperature of reactors was kept at 37 ± 1°C in this period. Results are shown in Figure 4.34.

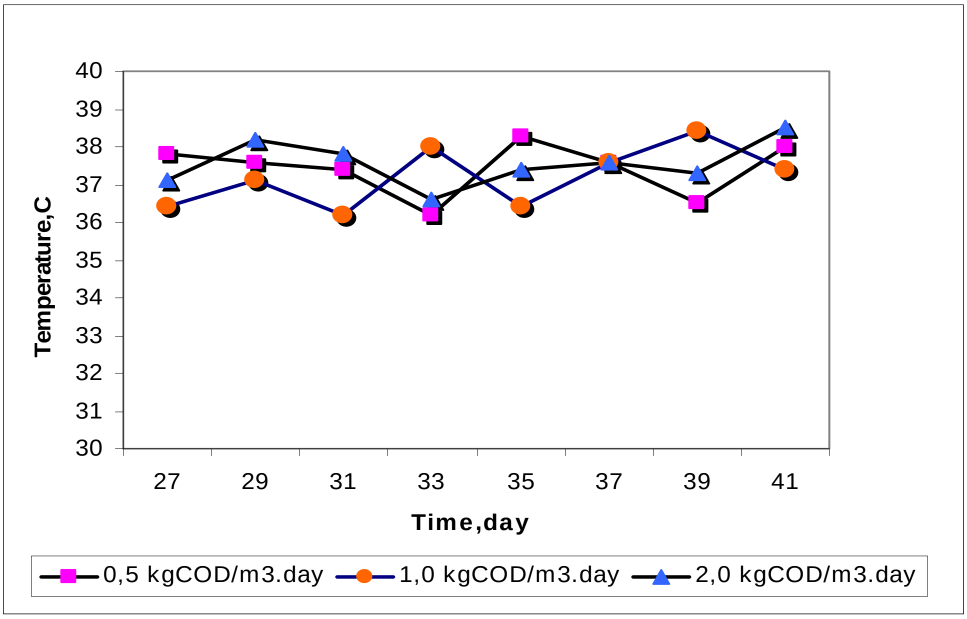


Figure 4.34 Temperature values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

The values of alkalinity were measured between 1642 and 1950 mg $CaCO_3$/L. Results are shown in Figure 4.35. The results are similar to study reported by Murto *et. al*. in 2004. It seems that alkalinity decreased due to the accumulation of volatile fatty acids and washout of methanogenic population in the reactors.

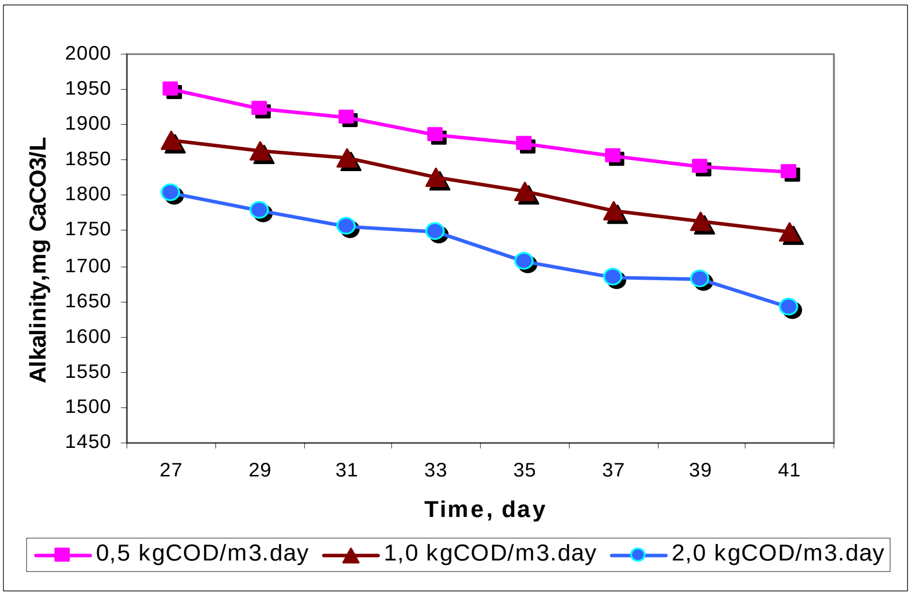


Figure 4.35 Alkalinity values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

As average, 70%, 66% and 60% total solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested. The results indicate that while OLR increased, total solid removal efficiency values decreased. The results are shown in Figure 4.36. The results are similar to the literature. It is possible that the plugging and channeling occurred by the accumulation of biomass and inert suspended matter in the spaces of packing media as reported before by Show and Tay in 1999.

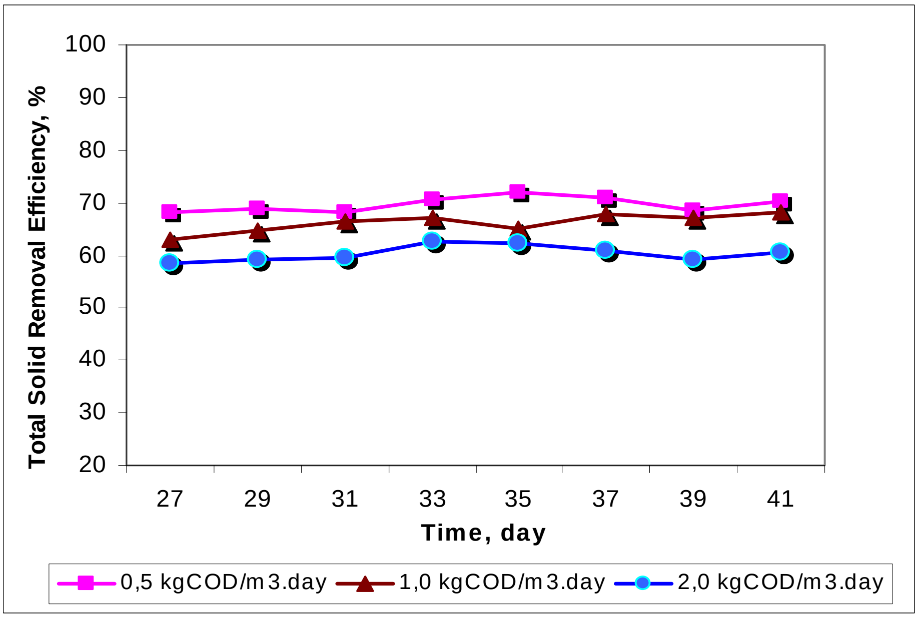


Figure 4.36 Total solid removal efficiency values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

As average, 66%, 61% and 55% total volatile solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Depending on increasing organic loading rates, total volatile solid removal efficiency values decreased. Figure 4.37 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

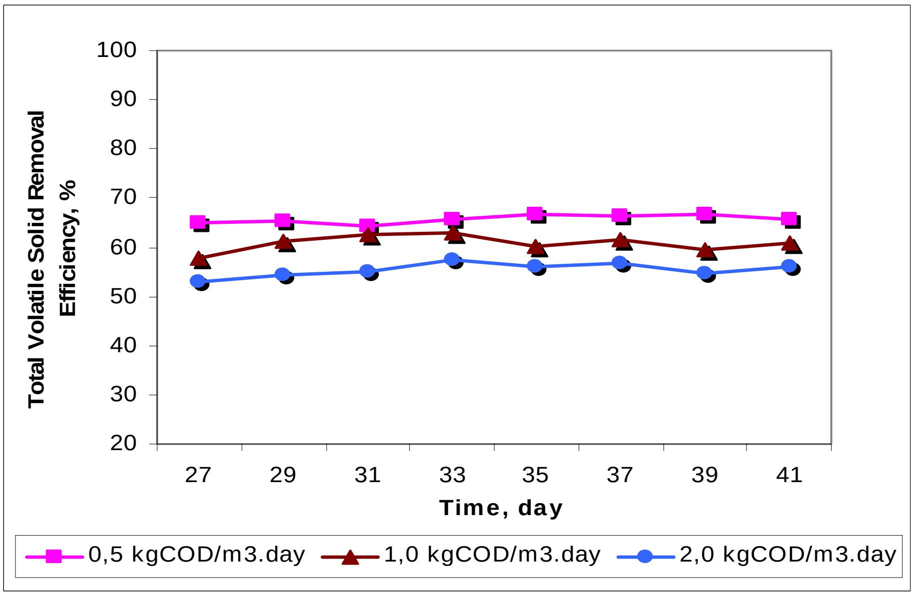


Figure 4.37 Total volatile solid removal efficiency values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values measured between -325 and -370. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.38. Acharya et. al. (2007) reported that ORP values which were mainly affected by pH in an anaerobic system is an indicator of some operational conditions such as overloading, underloading, over-aeration and under-aeration.

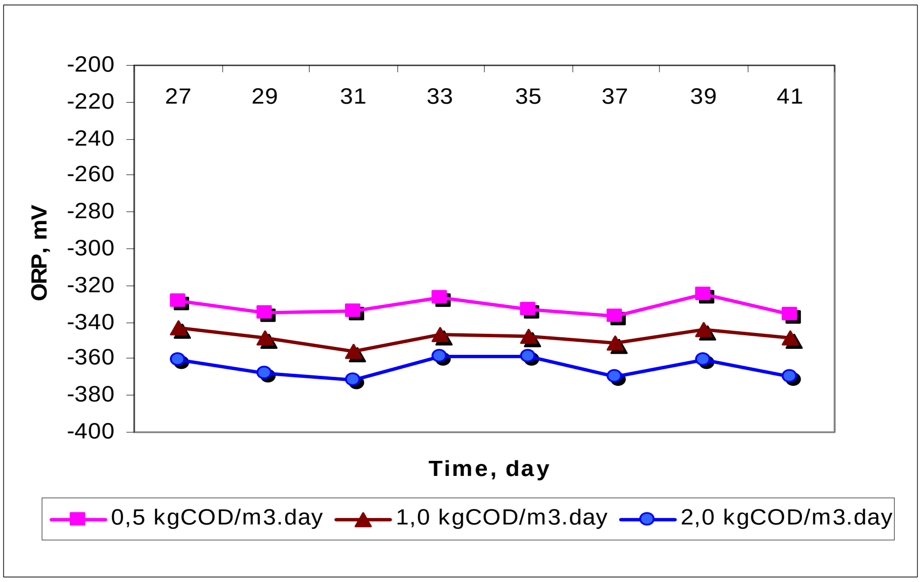


Figure 4.38 ORP values depending on organic loading rates for UAF 100 reactor in semi-continuous mode at HRT = 2 days

### *4.4.2 Results of UAF 75 Reactor in Semi-Continuous Mode*

Results of UAF 75 reactor in semi-continuous mode are given in Table 4.9.

Table 4.9 Laboratory results for the UAF 75 reactor at different organic loading rates in semi-continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf}$. (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff}$. (mg/L) | 275 | 671 | 1870 |
| COD Removal Efficiency (%) | 73 ± 1.2 | 68 ± 1.5 | 55 ± 1.9 |
| $pH_{Inf}$. | 7.50 | 7.50 | 7.50 |
| $pH_{Eff}$. | 6.97 | 6.85 | 6.73 |
| $Temperature_{Inf.}$ (°C) | 35 | 34 | 34 |
| $Temperature_{Eff}$. (°C) | 38 ± 0.7 | 38 ± 0.9 | 38 ± 0.7 |
| $Alkalinity_{Inf}$ (mg $CaCO_3$/L) | 2017 | 1954 | 1895 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1809 | 1652 | 1495 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 206 | 301 | 247 |
| Total Solid $(TS)_{Eff.}$. (mg/L) | 76 | 122 | 120 |
| TS Removal Efficiency (%) | 63 ± 1.1 | 59 ± 1.0 | 51 ± 1.5 |
| Total Volatile Solid $(TVS)_{Inf}$. (mg/L) | 121 | 242 | 131 |
| Total Volatile Solid $(TVS)_{Eff.}$.(mg/L) | 48 | 104 | 68 |
| TVS Removal Efficiency (%) | 61 ± 1.2 | 57 ± 1.0 | 48 ± 1.5 |
| ORP (mV) | -318 | -334 | -349 |

73%, 68% and 55% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. 2.0 kg COD/m$^3$.day of organic loading rate was caused very high performance reduction in this period. Maximum COD removal efficiency was obtained with 0.5 kg COD/m$^3$.day which was the minimum tested organic loading rate and the minimum COD removal efficiency was obtained with 2.0 kg COD/m$^3$.day with the maximum organic loading rate tested. The results indicate that

while organic loading rates increased, COD removal efficiencies decreased. The results are shown in Figure 4.39. As mentioned before in this section, the reasons of reduction of COD removal efficiency are satisfactory.

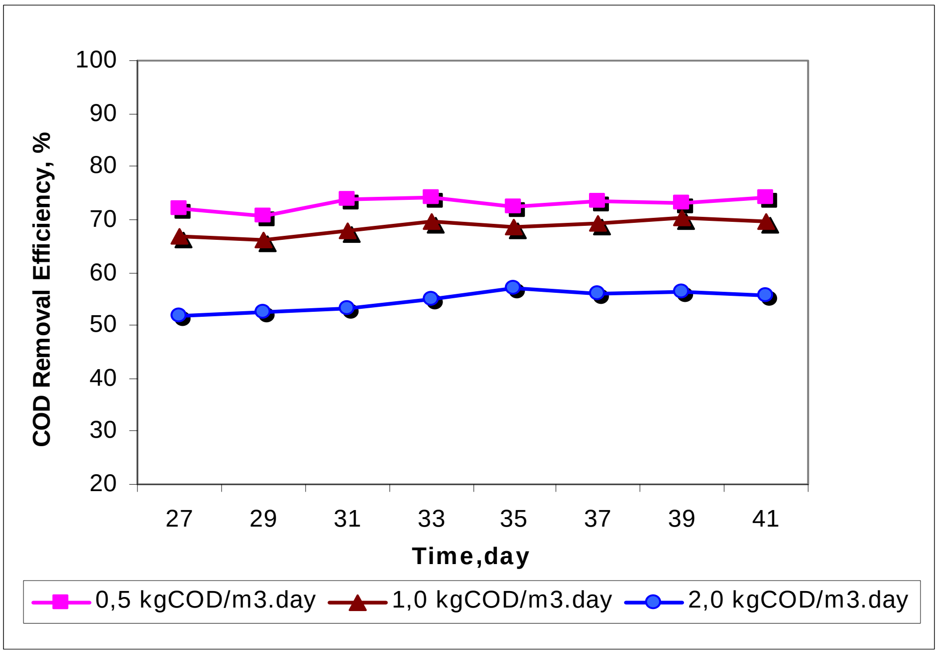


Figure 4.39 COD removal efficiency values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

The pH values were measured between 6.56 and 7.16 in this operation period. Temperature of reactors was kept at 37 ± 1°C. The results are shown in Figure 4.40 and Figure 4.41, respectively. The results are similar to study reported by Murto et. al. in 2004 as mentioned before.

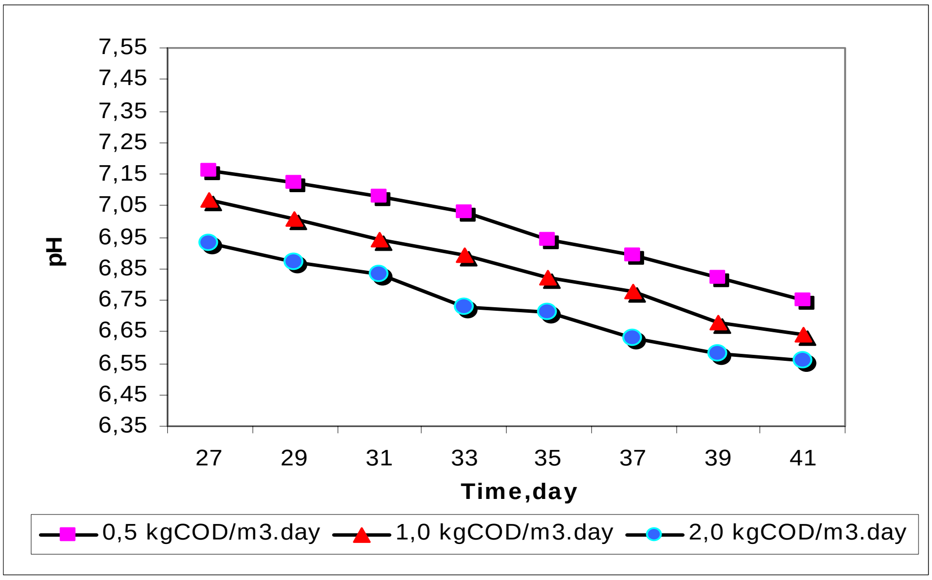


Figure 4.40 pH values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

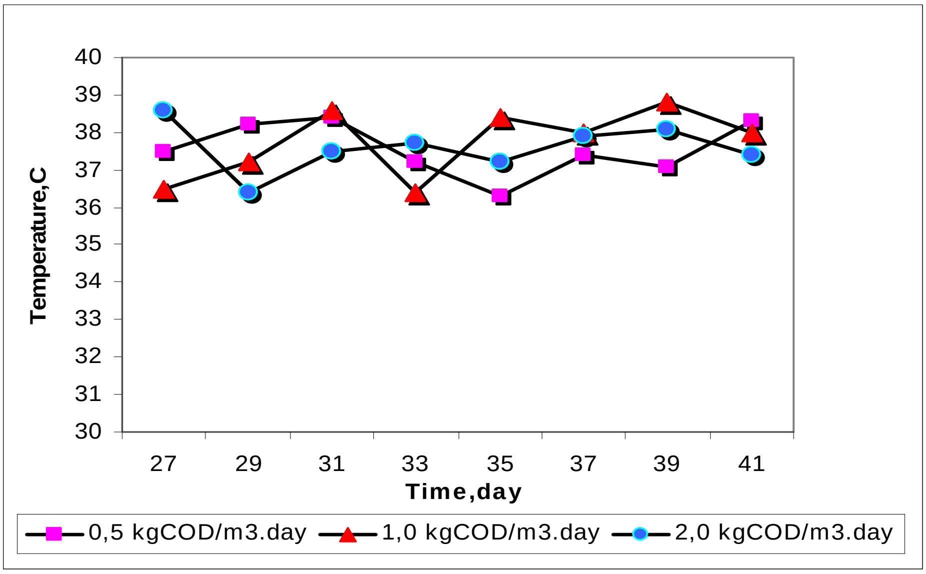


Figure 4.41 Temperature values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

The values of alkalinity were measured between 1332 and 1900 mg $CaCO_3$/L. The results are shown in Figure 4.42. The results are similar to study reported by Murto *et. al*. in 2004 as mentioned before.

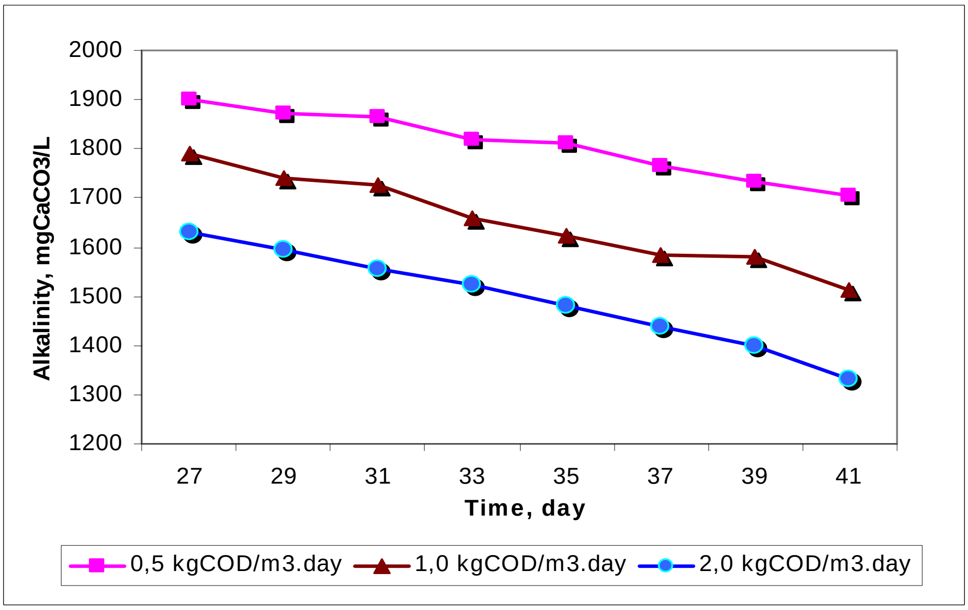


Figure 4.42 Alkalinity values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

As average, 63%, 59% and 51% total solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested. The results indicate that while OLR increased, total solid removal efficiencies decreased. The results are shown in Figure 4.43. The results are similar to study reported by  Show and Tay in 1999 as mentioned before.

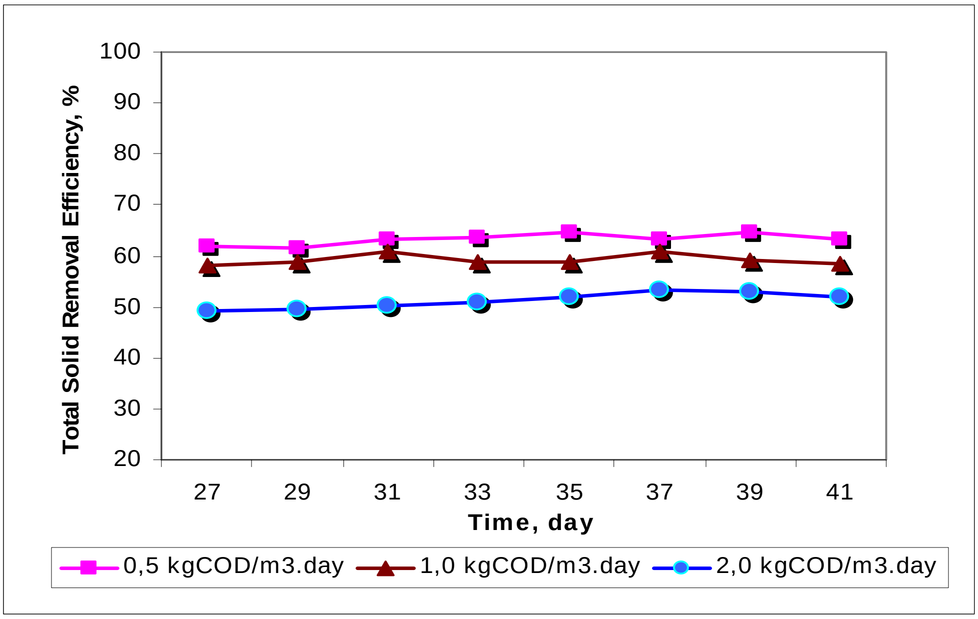


Figure 4.43 Total solid removal efficiency values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

As average, 61%, 57% and 48% total volatile solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Depending on increasing organic loading rates, total volatile solid removal efficiency values decreased. Figure 4.44 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

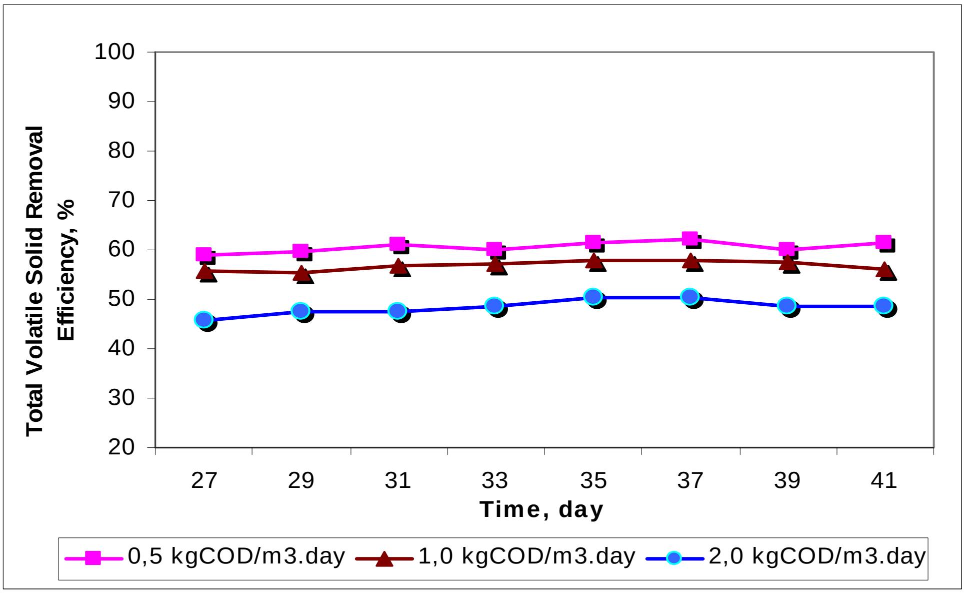


Figure 4.44 Total volatile solid removal efficiency values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values measured between -310 and -354. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.45. The results are similar to study reported by Acharya et. al. in 2007 as mentioned before.

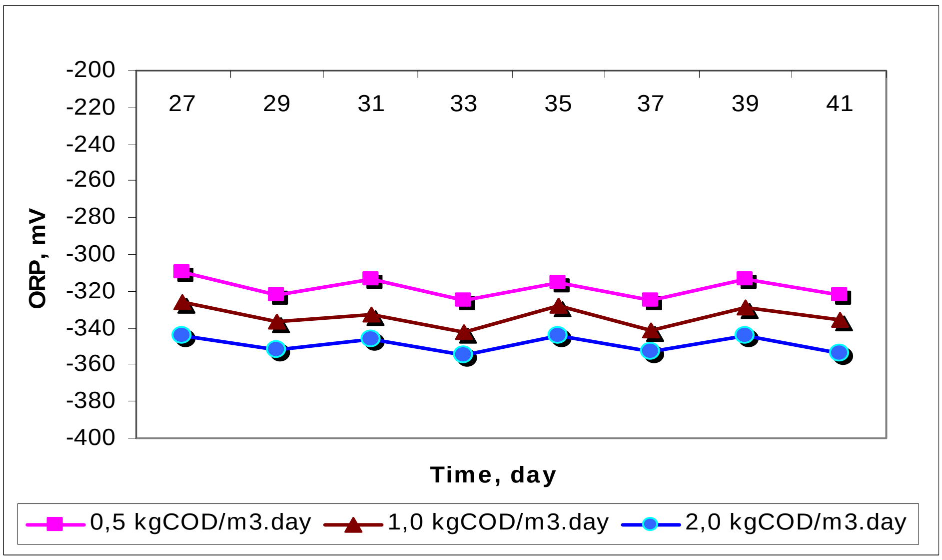


Figure 4.45 ORP values depending on organic loading rates for UAF 75 reactor in semi-continuous mode at HRT = 2 days

### *4.4.3 Results of UAF 50 Reactor in Semi-Continuous Mode*

Results of UAF 50 reactor in semi-continuous mode are given in Table 4.10.

Table 4.10 Laboratory results for the UAF 50 reactor at different organic loading rates in semi-continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf}$. (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff}$. (mg/L) | 366 | 877 | 2287 |
| COD Removal Efficiency (%) | 64 ± 0.8 | 59 ± 0.8 | 45 ± 0.9 |
| $pH_{Inf}$. | 7.50 | 7.50 | 7.50 |
| $pH_{Eff}$. | 7.00 | 6.88 | 6.77 |
| $Temperature_{Inf.}$ (°C) | 35 | 34 | 34 |
| $Temperature_{Eff}$. (°C) | 38 ± 0.5 | 38 ± 0.8 | 38 ± 0.7 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 1902 | 1836 | 1778 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1682 | 1552 | 1405 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 180 | 288 | 237 |
| Total Solid $(TS)_{Eff.}$. (mg/L) | 77 | 145 | 144 |
| TS Removal Efficiency (%) | 58 ± 0.8 | 50 ± 1.4 | 39 ± 1.1 |
| Total Volatile Solid $(TVS)_{Inf}$. (mg/L) | 123 | 205 | 136 |
| Total Volatile Solid $(TVS)_{Eff.}$.(mg/L) | 58 | 109 | 88 |
| TVS Removal Efficiency (%) | 53 ± 1.0 | 46 ± 1.6 | 35 ± 0.9 |
| ORP (mV) | -315 | -336 | -352 |

64%, 59% and 45% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. 2.0 kg COD/m$^3$.day of organic loading rate was caused very high performance reduction in this period. Maximum COD removal efficiency was obtained with 0.5 kg COD/m$^3$.day which was the minimum tested organic loading rate and the minimum COD removal efficiency was obtained with 2.0 kg COD/m$^3$.day with the maximum organic loading rate tested. The results indicate that

while organic loading rates increased, COD removal efficiencies decreased. The results are shown in Figure 4.46. As mentioned before in this section, the reasons of reduction of COD removal efficiency are satisfactory.

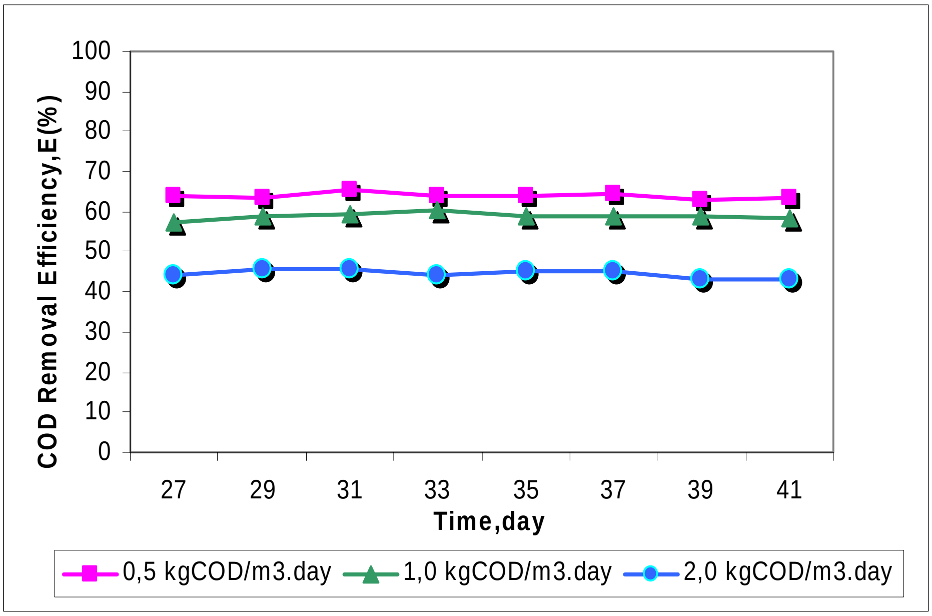


Figure 4.46 COD removal efficiency values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

The pH values were measured between 6.54 and 7.24 in this operation period. Temperature of reactors was kept at 37 ± 1°C. The results are shown in Figure 4.47 and Figure 4.48, respectively. The results are similar to study reported by Murto et. al. in 2004 as mentioned before.

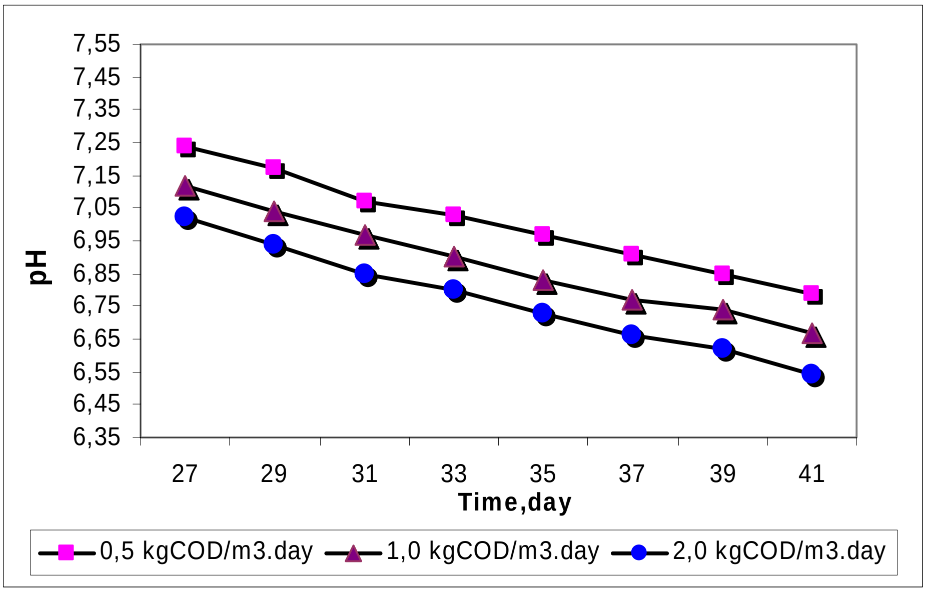


Figure 4.47 pH values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

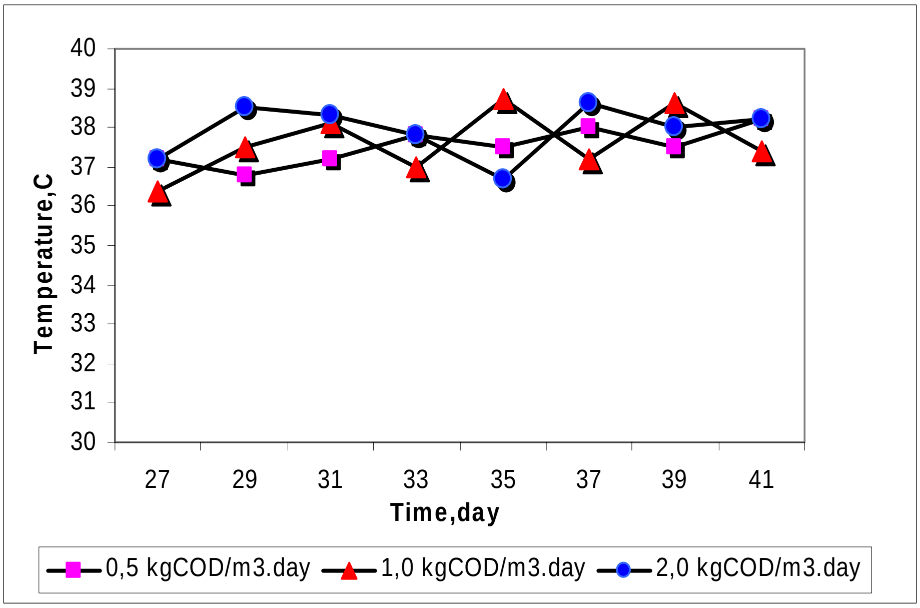


Figure 4.48 Temperature values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

The values of alkalinity were measured between 1265 and 1820 mg $CaCO_3$/L. The results are shown in Figure 4.49. The results are similar to study reported by Murto *et. al*. in 2004 as mentioned before.

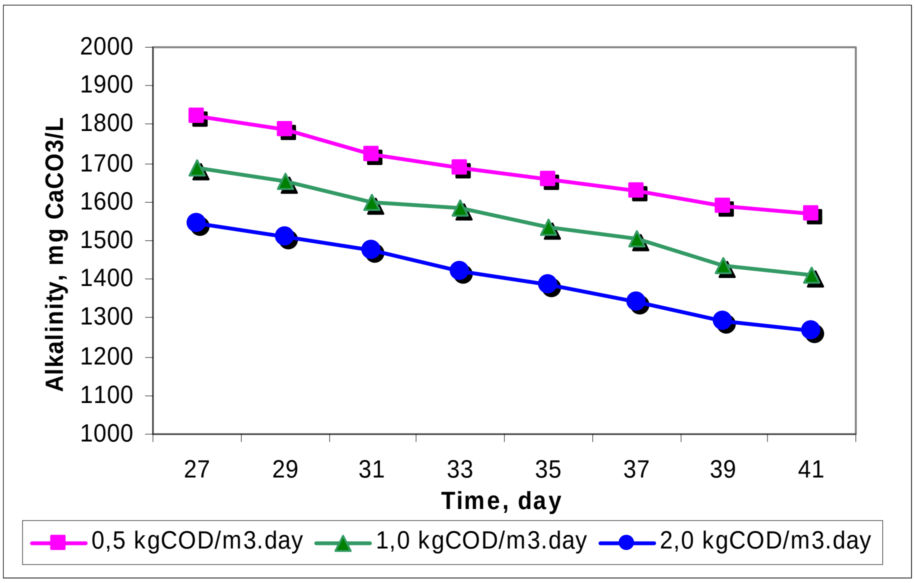


Figure 4.49 Alkalinity values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

As average, 58%, 50% and 39% total solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested. The results indicate that while OLR increased, total solid removal efficiencies decreased. The results are shown in Figure 4.50. The results are similar to study reported by  Show and Tay in 1999 as mentioned before.

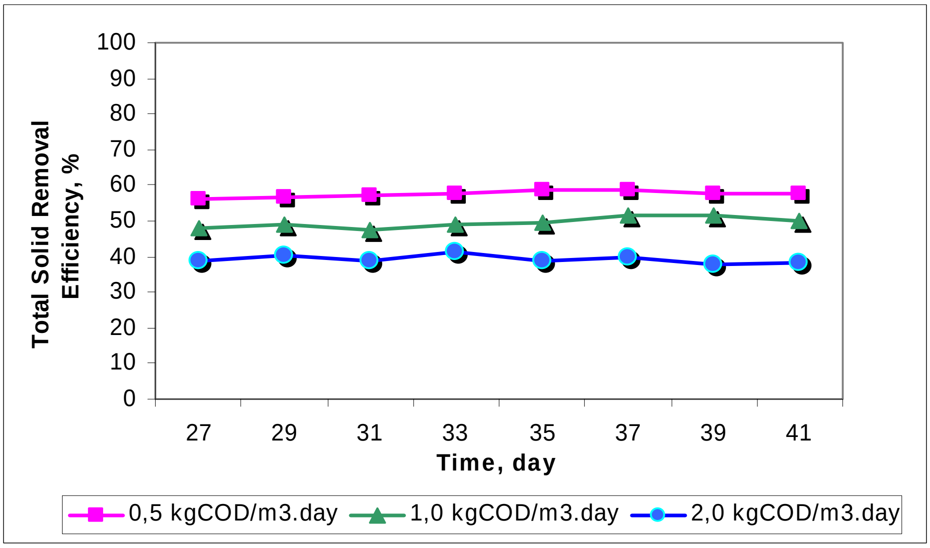


Figure 4.50 Total solid removal efficiency values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

As average, 53%, 46% and 35% total volatile solid reductions were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. Maximum total volatile solid reduction was obtained at 0.5 kg COD/m$^3$day. Figure 4.51 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

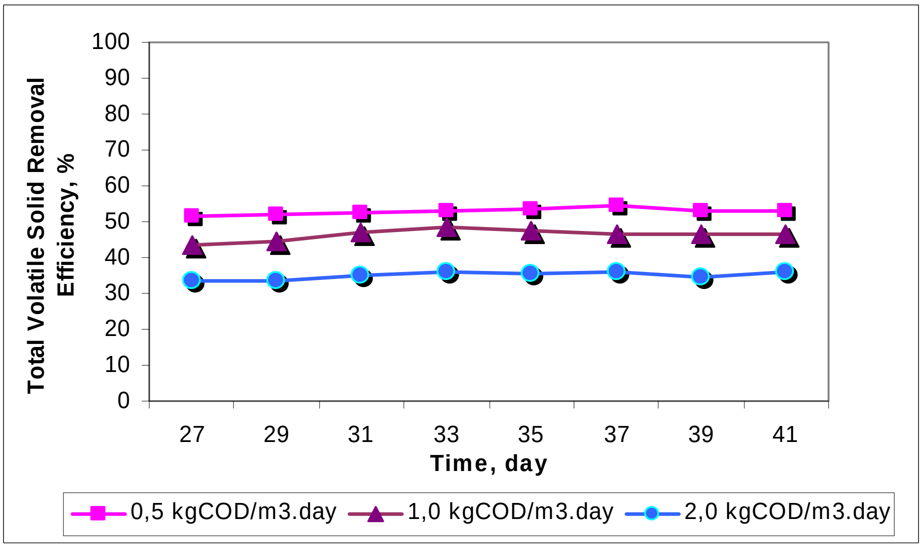


Figure 4.51 Total volatile solid removal efficiency values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values measured between -306 and -363. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.52. The results are similar to study reported by  Acharya et. al. in 2007 as mentioned before.

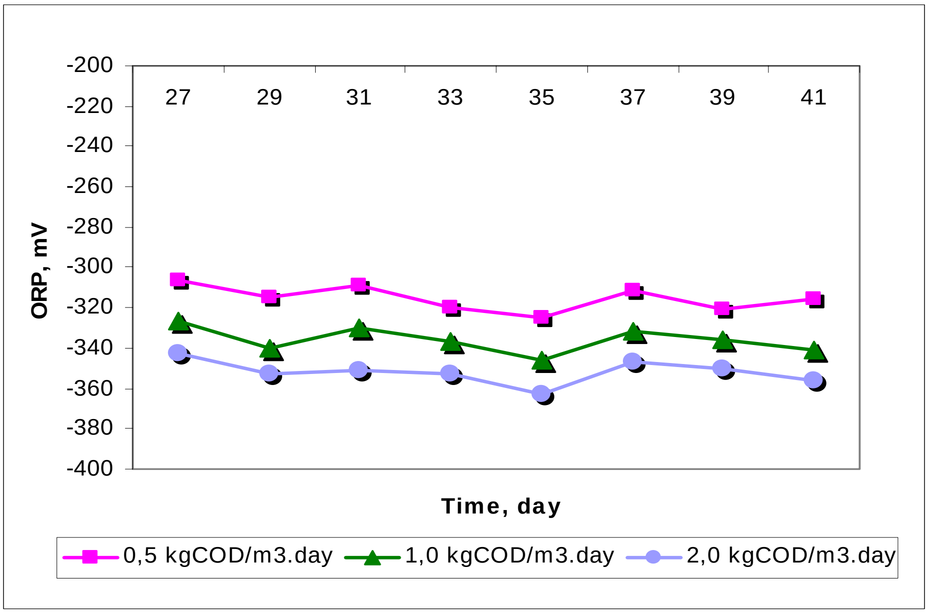


Figure 4.52 ORP values depending on organic loading rates for UAF 50 reactor in semi-continuous mode at HRT = 2 days

### *4.4.4 Results of UAF 25 Reactor in Semi-Continuous Mode*

Results of UAF 25 reactor in semi-continuous mode are given in Table 4.11.

Table 4.11 Laboratory results for the UAF 25 reactor at different organic loading rates in semi-continuous mode (average values)

| **Parameters** | **Organic Loading Rates (kg COD/m$^3$.day)** | | |
|---|---|---|---|
| | **0.5 kg COD/m$^3$.d** | **1.0 kg COD/m$^3$.d** | **2.0 kg COD/m$^3$.d** |
| $COD_{Inf}$. (mg/L) | 1015 | 2131 | 4127 |
| $COD_{Eff}$. (mg/L) | 389 | 930 | 2484 |
| COD Removal Efficiency (%) | 62 ± 1.0 | 56 ± 0.9 | 40 ± 1.4 |
| $pH_{Inf}$. | 7.50 | 7.50 | 7.50 |
| $pH_{Eff}$. | 6.92 | 6.76 | 6.62 |
| $Temperature_{Inf.}$ (°C) | 35 | 34 | 34 |
| $Temperature_{Eff}$. (°C) | 38 ± 0.7 | 37 ± 0.5 | 38 ± 0.7 |
| $Alkalinity_{Inf.}$ (mg $CaCO_3$/L) | 2017 | 1954 | 1895 |
| $Alkalinity_{Reactor}$ (mg $CaCO_3$/L) | 1622 | 1533 | 1431 |
| Total Solid $(TS)_{Inf.}$ (mg/L) | 206 | 301 | 247 |
| Total Solid $(TS)_{Eff.}$. (mg/L) | 101 | 183 | 170 |
| TS Removal Efficiency (%) | 51 ± 1.1 | 39 ± 1.0 | 31 ± 0.7 |
| Total Volatile Solid $(TVS)_{Inf}$. (mg/L) | 121 | 242 | 131 |
| Total Volatile Solid $(TVS)_{Eff.}$.(mg/L) | 68 | 157 | 96 |
| TVS Removal Efficiency (%) | 44 ± 1.1 | 35 ± 1.2 | 27 ± 0.9 |
| ORP (mV) | -292 | -318 | -342 |

62%, 56% and 40% average COD removal efficiencies were obtained in 0.5 kg COD/m$^3$.day, 1.0 kg COD/m$^3$.day and 2.0 kg COD/m$^3$.day of organic loading rates, respectively. 2.0 kg COD/m$^3$.day of organic loading rate was caused very high performance reduction in this period. Maximum COD removal efficiency was obtained with 0.5 kg COD/m$^3$.day which was the minimum tested organic loading rate and the minimum COD removal efficiency was obtained with 2.0 kg COD/m$^3$.day with the maximum organic loading rate tested. The results indicate that

while organic loading rates increased, COD removal efficiencies decreased. The results are shown in Figure 4.53. As mentioned before in this section, the reasons of reduction of COD removal efficiency are satisfactory.

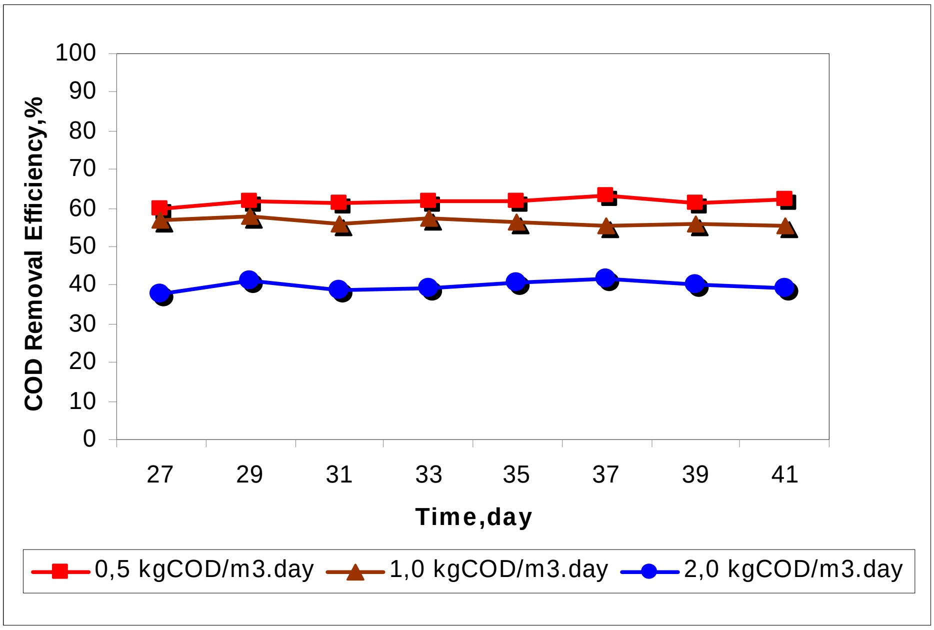


Figure 4.53 COD removal efficiency values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

The pH values were measured between 6.36 and 7.16 in this operation period. Temperature of reactors was kept at 37 ± 1°C. The results are shown in Figure 4.54 and Figure 4.55, respectively. The results are similar to study reported by Murto et. al. in 2004 as mentioned before.

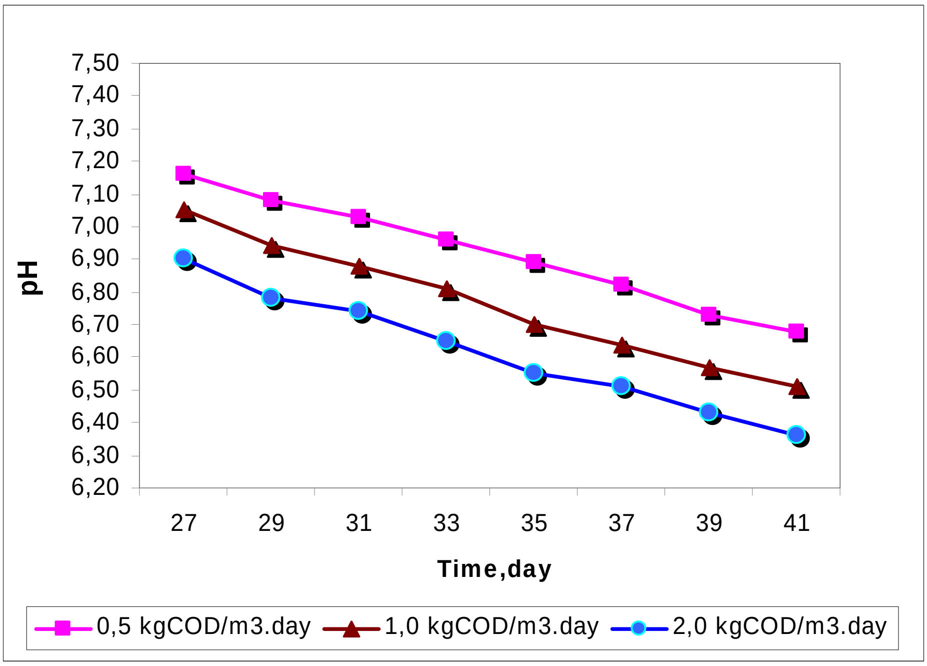


Figure 4.54 pH values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

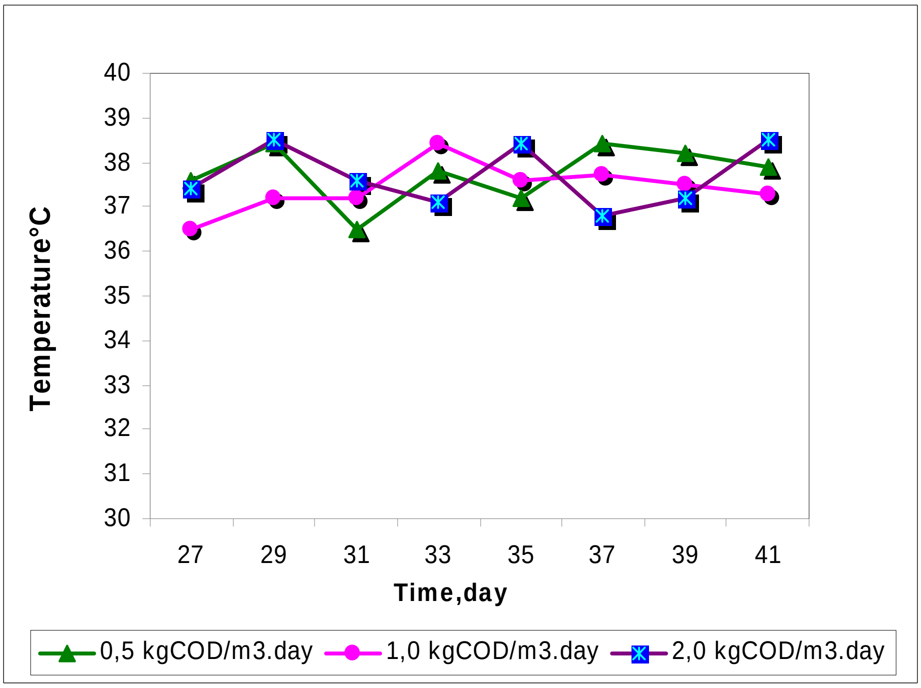


Figure 4.55 Temperature values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

The values of alkalinity were measured between 1204 and 1782 mg $CaCO_3$/L. The results are shown in Figure 4.56. The results are similar to study reported by Murto *et. al*. in 2004 as mentioned before.

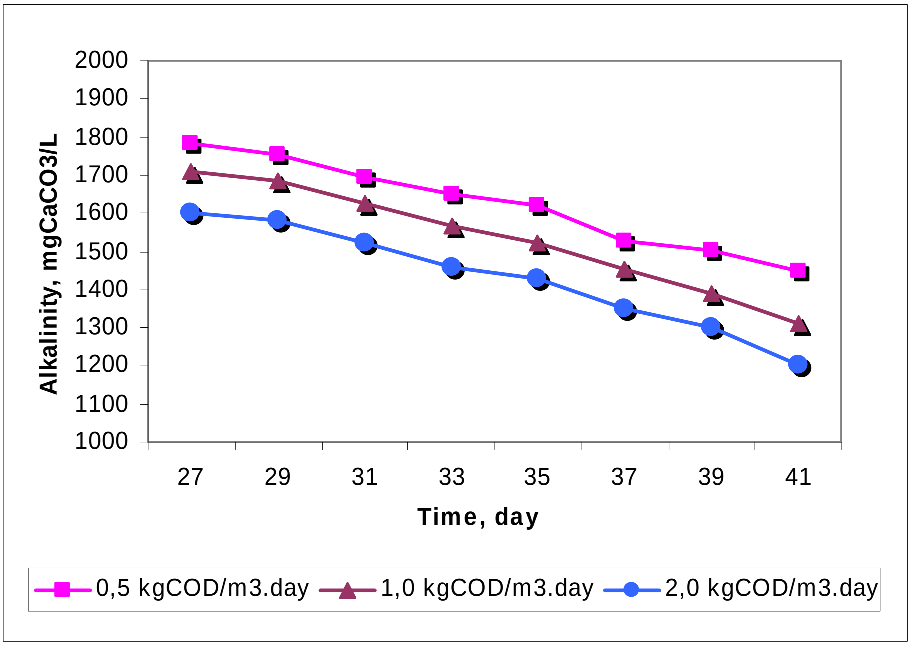


Figure 4.56 Alkalinity values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

As average, 51%, 39% and 31% total solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum TS removal efficiency was obtained with 0.5 kg COD/$m^3$.day which was the minimum tested organic loading rate and the minimum TS removal efficiency was obtained with 2.0 kg COD/$m^3$.day with the maximum organic loading rate tested. The results indicate that while OLR increased, total solid removal efficiencies decreased. Maximum removal efficiency reduction is shown at 2.0 kg COD/$m^3$.day. The results are shown in Figure 4.57. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

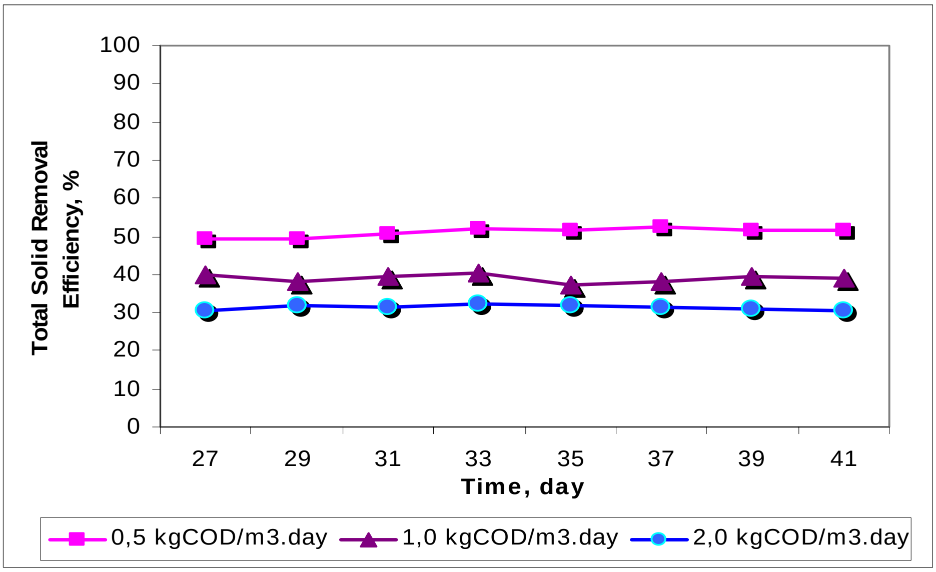


Figure 4.57 Total solid removal efficiency values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

As average, 44%, 35% and 27% total volatile solid reductions were obtained in 0.5 kg COD/$m^3$.day, 1.0 kg COD/$m^3$.day and 2.0 kg COD/$m^3$.day of organic loading rates, respectively. Maximum total volatile solid removal efficiency is shown at 0.5 kg COD/$m^3$day. Figure 4.58 shows the results. The results are similar to study reported by Show and Tay in 1999 as mentioned before.

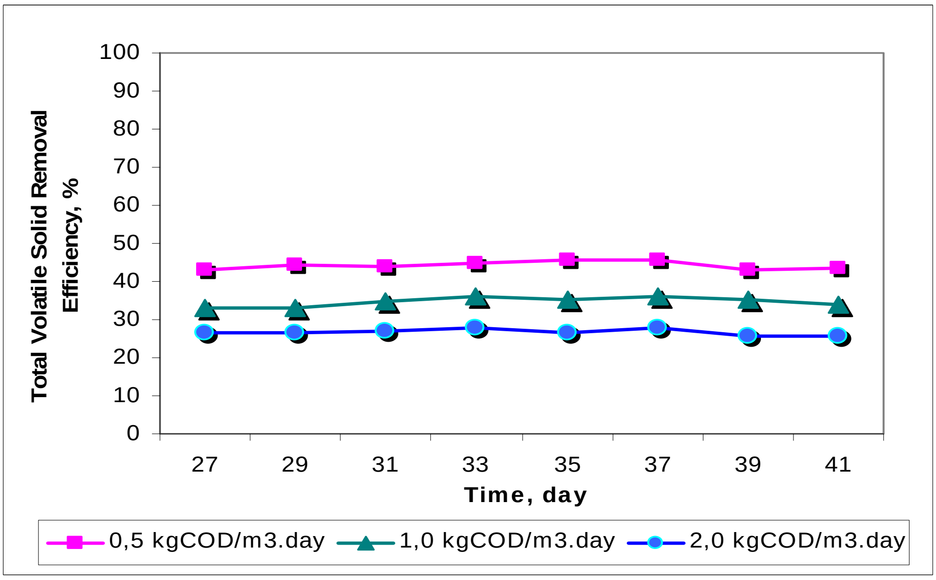


Figure 4.58 Total volatile solid removal efficiency values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

Oxidation Reduction Potential (ORP) was measured every other day. The values measured between -287 and -350. ORP values showed that the reactor was in anaerobic mode. The results are shown in Figure 4.59. The results are similar to study reported by Acharya et. al. in 2007 as mentioned before.

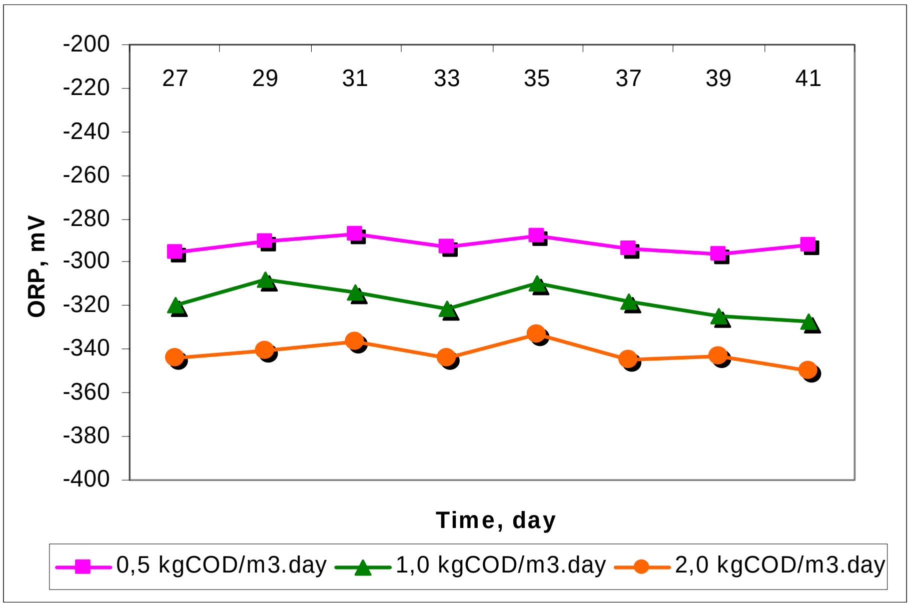


Figure 4.59 ORP values depending on organic loading rates for UAF 25 reactor in semi-continuous mode at HRT = 2 days

### *4.4.5 Comparison of Reactors in Semi-Continuous Operation Mode*

#### *4.4.5.1 Effects of Filter Material Ratio with COD Removal Efficiency at Different Organic Loading Rates*

Average COD removal efficiency values of reactors depending on organic loading rates are given in Table 4.12. The results are shown in Figure 4.60.

Table 4.12 Average COD removal efficiency values of reactors depending on organic loading rates in semi-continuous operation mode

| OLR (kg COD/$m^3$.day) | Average COD Removal Efficiency Values, % | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| 0.5 | 80 | 73 | 64 | 62 |
| 1.0 | 74 | 68 | 59 | 56 |
| 2.0 | 64 | 55 | 45 | 40 |

As seen in Figure 4.60, while OLR values increased, COD removal efficiency values decreased due to the filter material ratios. This decrease is very clear at 2.0 kg COD/$m^3$.day of organic loading rate.

Filter material reduction of reactor's affected COD removal efficiency for all organic loading rates in semi-continuous operation mode. When filter material ratio in the reactor decreased, biofilm and amounts of microorganism decreased. Because of that COD removal efficiency decreased. COD removal efficiencies decreased with reduction of filter material ratios which were averagely 10%, 23% and 28% for 25%, 50%, 75% reducing filter material ratios, respectively. Otherwise, maximum COD removal efficiency was obtained by using UAF 100 at 0.5 kg COD/$m^3$.day of organic loading rate. In addition, COD removal efficiencies of UAF 50 and UAF 25 were very similar. Because of that, UAF 25 can be used instead of UAF 50 economically.

Finally, filter material ratio of upflow anaerobic filter reactor effects COD removal efficiency significantly in semi-continuous operation mode.

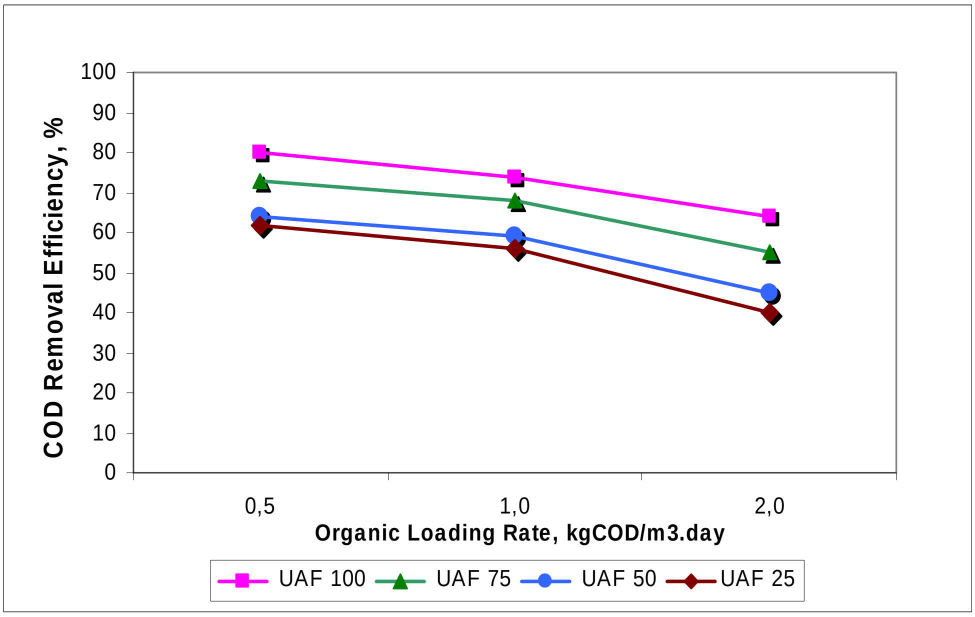


Figure 4.60 Average COD removal efficiency values of reactors depending on organic loading rates in semi-continuous mode at HRT = 2 days

*4.4.5.2 Effects of Filter Material Ratio with TS Removal Efficiency at Different Organic Loading Rates*

Average TS removal efficiency values of reactors depending on organic loading rates are given in Table 4.13. The results are shown in Figure 4.61.

Table 4.13 Average TS removal efficiency values of reactors depending on organic loading rates at semi-continuous operation mode

| OLR (kg COD/m$^3$.day) | Average TS Removal Efficiency Values, % | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| 0.5 | 70 | 63 | 58 | 51 |
| 1.0 | 66 | 59 | 50 | 39 |
| 2.0 | 60 | 51 | 39 | 31 |

As seen in Figure 4.61**,** when OLR values increased, TS removal efficiency values decreased due to the filter material ratios. Filter material reduction of reactor's affected TS removal efficiency for all organic loading rates in semi-continuous operation mode. When filter material ratio in the reactor decreased, biofilm and amounts of microorganism decreased. Because of that TS removal efficiency decreased. TS removal efficiencies decreased with reduction of filter material ratios which were averagely 12%, 25% and 39% for 25%, 50%, 75% reducing filter material ratios, respectively. Otherwise, maximum TS removal efficiencies were obtained by using UAF 100. The COD removal efficiencies at 0.5 kg COD/$m^3$.day of organic loading rate were near to each other.

Finally, it is seen that filter material ratio has a significant effect on total solid removal efficiency in upflow anaerobic filter in semi-continuous operation mode.

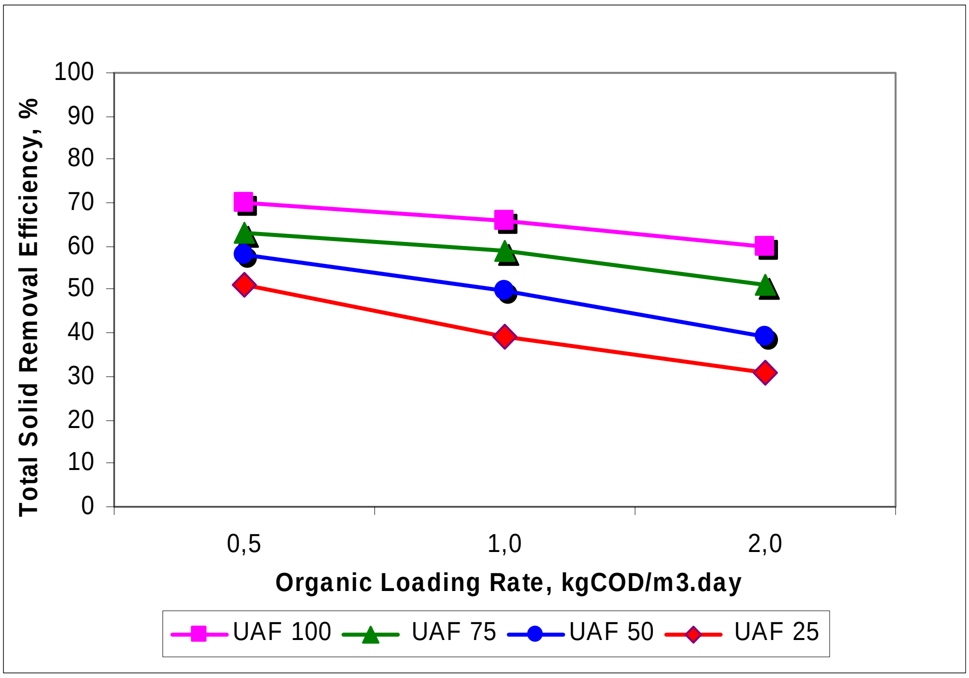


Figure 4.61 Average TS removal efficiency values of reactors depending on organic loading rates in semi-continuous mode at HRT = 2 days

*4.4.5.3 Effects of Filter Material Ratio with TVS Removal Efficiency at Different Organic Loading Rates*

Average TVS removal efficiency values of reactors depending on organic loading rates are given in Table 4.14. The results are shown in Figure 4.62.

Table 4.14 Average TVS removal efficiency values of reactors depending on organic loading rates in semi-continuous operation mode

| OLR (kg COD/m$^3$.day) | Average TVS Removal Efficiency Values, % | | | |
|---|---|---|---|---|
| | UAF 100 | UAF 75 | UAF 50 | UAF 25 |
| 0.5 | 66 | 61 | 53 | 44 |
| 1.0 | 61 | 57 | 46 | 35 |
| 2.0 | 55 | 48 | 35 | 27 |

As seen in Figure 4.62, while OLR values increased, TVS removal efficiency values decreased due to the filter material ratios. Filter material reduction of reactor's affected TVS removal efficiency for all organic loading rates in semi-continuous operation mode. When filter material ratio in the reactor decreased, biofilm and amounts of microorganism decreased. Because of that TVS removal efficiency decreased. TVS removal efficiencies decreased with reduction of filter material ratios which were averagely 9%, 27% and 42% for 25%, 50%, 75% reducing filter material ratios, respectively. Otherwise, maximum TVS removal efficiency was obtained by using UAF 100. Minimum TVS removal efficiency was obtained by using UAF 25.

Finally, it is seen that filter material ratio has a significant effect on total volatile solid removal efficiency in upflow anaerobic filter reactor in semi-continuous operation mode.

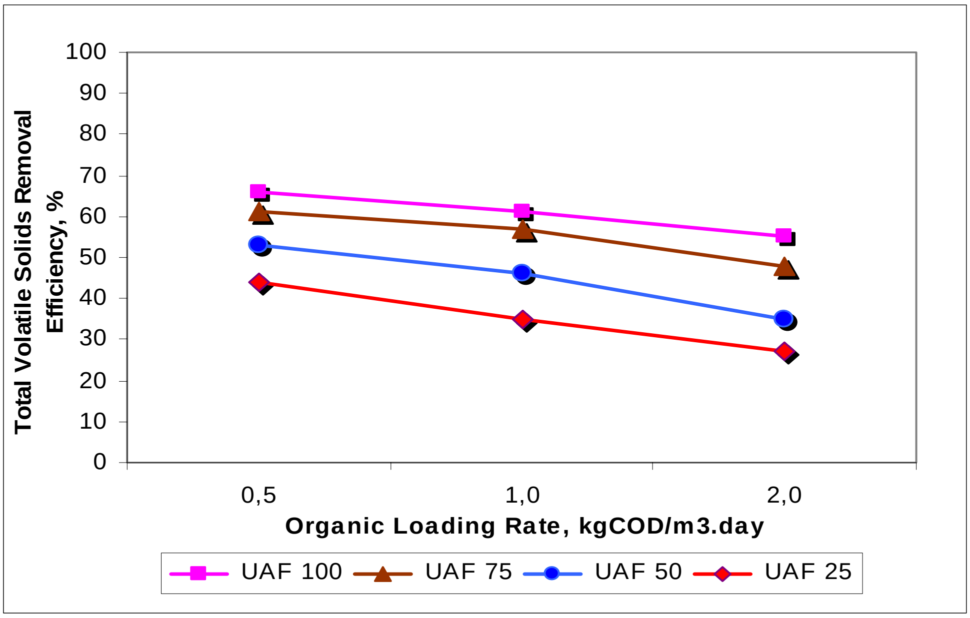


Figure 4.62 Average TVS removal efficiency values of reactors depending on organic loading rates in semi-continuous mode at HRT = 2 days

## 4.5 Comparison of Continuous and Semi -Continuous Operation Modes

### *4.5.1 Comparison of COD Removal Efficiencies*

#### *4.5.1.1 UAF 100 Reactor*

Average COD removal efficiency values of UAF 100 reactor depending on operation modes are given in Table 4.15. The results are shown in Figure 4.63.

Table 4.15 Average COD removal efficiency values of UAF 100 reactor depending on operation modes and organic loading rates

| Average COD Removal Efficiency Values, % | | |
|---|---|---|
| OLR (kg COD/$m^3$.day) | Continuous | Semi-Continuous |
| 0.5 | 85 | 80 |
| 1.0 | 81 | 74 |
| 2.0 | 73 | 64 |

As seen in Figure 4.63, while OLR values increased, COD removal efficiency values decreased. Operation mode affected COD removal efficiencies, also.

For UAF 100 reactor, when operation mode changed from continuous to semi-continuous, the COD removal efficiencies decreased due to the feeding time. Continuous feeding supplied stable conditions for microorganisms because of the long feeding period. Therefore, COD removal efficiencies in continuous mode were higher than in semi-continuous mode.

The reduction of COD removal efficiency changes in 0.5, 1.0, 2.0 kg COD/m$^3$.day of OLR's were averagely 6%, 9% and 12%, respectively. While UAF 100 was operated at 0.5 kg COD/m$^3$.day of OLR's; the operation mode did not significantly affect the reactor. However, it was affected small amounts at other OLR's.

Finally, operation mode has a little effect on COD removal efficiency in fully packed upflow anaerobic filter reactor.

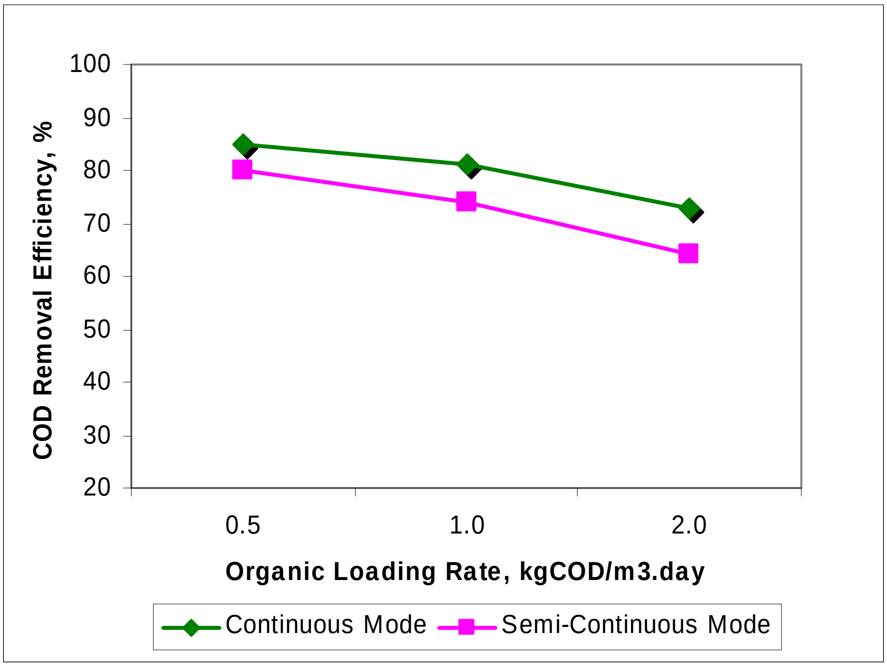


Figure 4.63 Average COD removal efficiency values for UAF 100 reactor depending on operation modes and organic loading rates, HRT = 2 days

*4.5.1.2 UAF 75 Reactor*

Average COD removal efficiency values of UAF 75 reactor depending on operation modes are given in Table 4.16. The results are shown in Figure 4.64.

Table 4.16 Average COD removal efficiency values for UAF 75 reactor depending on operation modes and organic loading rates

| **Average COD Removal Efficiency Values, %** | | |
|---|---|---|
| **OLR (kg COD/$m^3$.day)** | **Continuous** | **Semi-Continuous** |
| 0.5 | 82 | 73 |
| 1.0 | 78 | 68 |
| 2.0 | 69 | 55 |

As seen in Figure 4.64, while OLR values increased, COD removal efficiencies decreased. Operation mode affected COD removal efficiencies, also.

For UAF 75 reactor, when operation mode changed from continuous to semi-continuous, the COD removal efficiencies decreased due to the feeding time. Continuous feeding supplied stable conditions for microorganisms because of the long feeding period. Therefore, COD removal efficiencies in continuous mode were higher than in semi-continuous mode.

The reduction of COD removal efficiency changes in 0.5, 1.0, 2.0 kg COD/$m^3$.day of OLR's were averagely 11%, 13% and 20%, respectively.

Finally, operation mode has a significant effect on COD removal efficiency in 75% filled upflow anaerobic filter reactor.

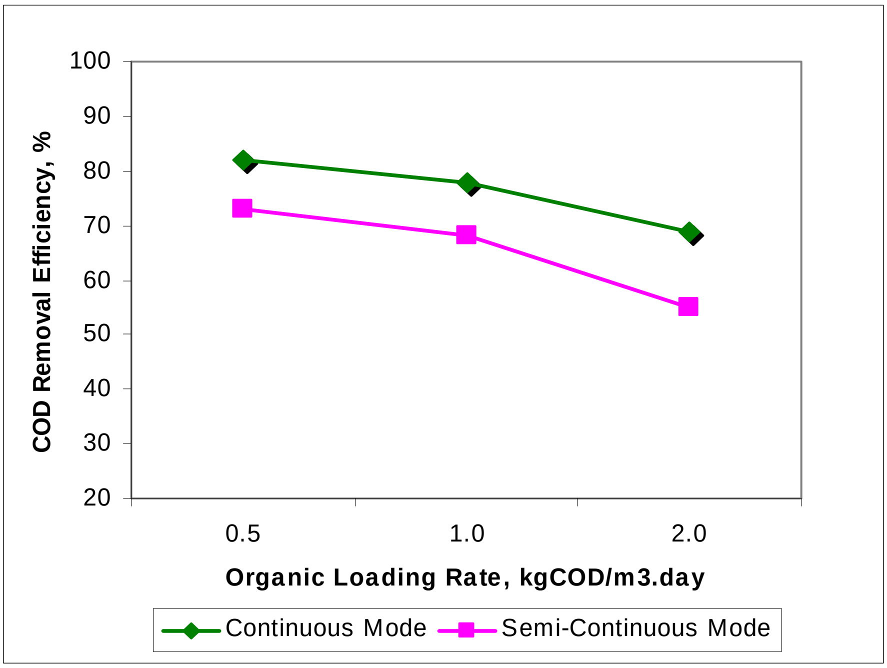


Figure 4.64 Average COD removal efficiency values for UAF 75 reactor depending on operation modes and organic loading rates, HRT = 2 days

### *4.5.1.3 UAF 50 Reactor*

Average COD removal efficiency values of UAF 50 reactor depending on operation modes are given in Table 4.17. The results are shown in Figure 4.65.

Table 4.17 Average COD removal efficiency values for UAF 50 reactor depending on operation modes and organic loading rates

| Average COD Removal Efficiency Values, % | | |
|---|---|---|
| OLR (kg COD/$m^3$.day) | Continuous | Semi-Continuous |
| 0.5 | 70 | 64 |
| 1.0 | 66 | 59 |
| 2.0 | 54 | 45 |

As seen in Figure 4.65, while OLR values increased, COD removal efficiencies decreased. Operation mode affected COD removal efficiencies, also.

For UAF 50 reactor, when operation mode changed from continuous to semi-continuous, the COD removal efficiencies decreased due to the feeding time. Continuous feeding supplied stable conditions for microorganisms because of the long feeding period. Therefore, COD removal efficiencies in continuous mode were higher than in semi-continuous mode.

The reduction of COD removal efficiency changes in 0.5, 1.0, 2.0 kg COD/$m^3$.day of OLR's were averagely 9%, 11% and 17%, respectively.

Finally, operation mode has a significant effect on COD removal efficiency in 50% filled upflow anaerobic filter reactor.

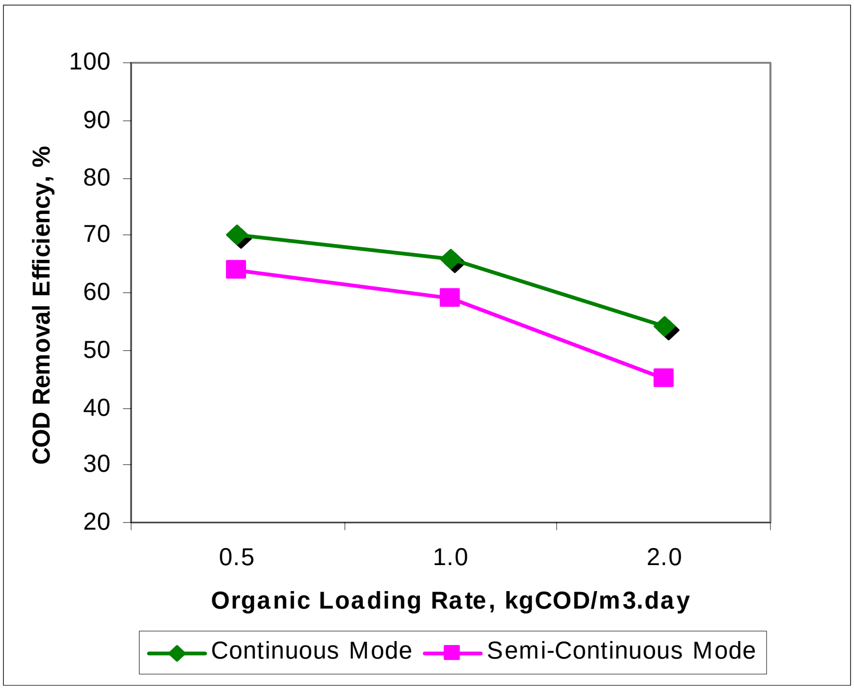


Figure 4.65 Average COD removal efficiency values for UAF 50 reactor depending on operation modes and organic loading rates, HRT = 2 days

*4.5.1.4 UAF 25 Reactor*

Average COD removal efficiency values of UAF 25 reactor depending on operation modes are given in Table 4.18. The results are shown in Figure 4.66.

Table 4.18 Average COD removal efficiency values for UAF 25 reactor depending on operation modes and organic loading rates

| Average COD Removal Efficiency Values, % | | |
|---|---|---|
| OLR (kg COD/m$^3$.day) | Continuous | Semi-Continuous |
| 0.5 | 65 | 62 |
| 1.0 | 61 | 56 |
| 2.0 | 46 | 40 |

As seen in Figure 4.66, while OLR values increased, COD removal efficiencies decreased. Operation mode affected COD removal efficiencies, also.

For UAF 25 reactor, when operation mode changed from continuous to semi-continuous, the COD removal efficiencies decreased due to the feeding time. Continuous feeding supplied stable conditions for microorganisms because of the long feeding period. Therefore, COD removal efficiencies in continuous mode were higher than in semi-continuous mode.

The reduction of COD removal efficiency changes in 0.5, 1.0, 2.0 kg COD/m$^3$.day of OLR’s were averagely 5%, 8% and 13%, respectively.

UAF 25 reactor was not significantly affected by operation mode when it was operated at 0.5 kg COD/m$^3$.day of organic loading rate. However, it was affected small amounts at other OLR’s.

Finally, operation mode has a little effect on COD removal efficiency in 25% filled upflow anaerobic filter reactor.

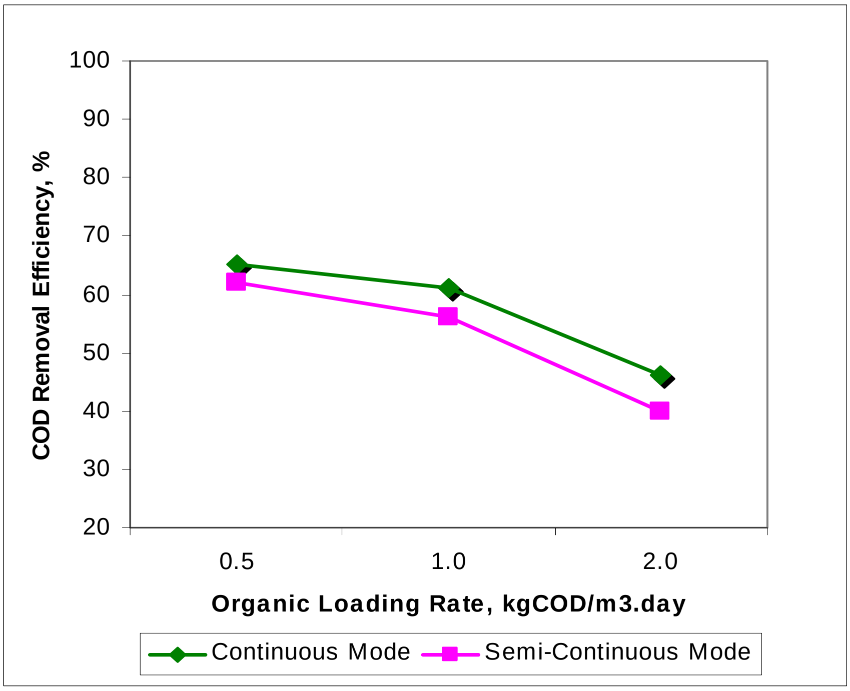


Figure 4.66 Average COD removal efficiency values for UAF 25 reactor depending on operation modes and organic loading rates, HRT = 2 days

# CHAPTER FIVE
# CONCLUSIONS

In this study, effects of filter material ratio, organic loading rate and operation mode on COD, TS and TVS removal were evaluated at four upflow anaerobic filter reactors. The four anaerobic filter reactors having different filter material ratio, UAF 100, UAF 75, UAF 50 and UAF 25 were operated at 0.5 kg COD/m3.day, 1.0 kg COD/m3.day and 2.0 kg COD/m3.day of organic loading rates for constant hydraulic retention time of 2 days, respectively. The four reactors were operated in continuous and semi-continuous mode. The results of the study are given below:

**1.** Filter material ratio affected the COD removal efficiencies of upflow anaerobic filter reactors. Removal efficiencies of filled fully anaerobic filter are more highest than the anaerobic filter having different filter material ratios in both operation mod. Depending on filter material ratio, the highest COD (85%-80%), TS (76%-70%) and TVS (71%-66%) removal efficiencies were achieved in UAF 100 at 0.5 kg COD/$m^3$.day and the lowest COD (46%-40%), TS (41%-31%) and TVS (34%-27%) removal efficiencies were achieved in UAF 25 at 2.0 kg COD/$m^3$.day of organic loading rate in both operation modes.

**2.** The filter material ratio had a significant effect and a little effect showed on the performance of upflow anaerobic filter reactors at 2.0 and 0.5 kg COD/$m^3$.day of organic loading rate, respectively in all experimental values that means of range.

**3.** Operation mode of the upflow anaerobic filter has a significant effect on COD removal efficiencies. Depending on operation mode, the highest COD removal efficiencies were achieved at continuous mode and the lowest COD removal efficiencies were achieved at semi-continuous mode.

**4.** There is a certain difference in between UAF 100-75 and UAF 50-25 in COD removal efficiencies. Filter material's 50% reduction results the decrease of the COD removal efficiencies of 15%.

**5.** TS and TVS removals performance of filters operated at continuous mode is also higher than filters operated at semi-continuous mode.

**6.** Doubling the influent concentrations while holding HRT constant, the alkalinity and pH in the reactors decreased in both operation modes.

**7.** As organic loading rates increased, COD, TS, TVS, and ORP removal efficiencies decreased in both operation modes.

**8.** Without considering filter material ratio in the filters, all experimental results are reasonable in the literature studies.

**9.** Since the COD removal efficiencies are very close, using UAF 75 instead of UAF 100 is an economic alternative. Also, using UAF 50 that is the acceptable value for anaerobic treatment as a preliminary treatment. This is also reduced the investment cost and the makes the anaerobic treatment attractive.

## REFERENCES


Acharya, B., K., Mohana, S., Madamwar, D. (2007). Anaerobic treatment of distillery spent wash - a study on upflow anaerobic fixed film bioreactor, *Biosource Technology* Vol. 99, Issue 11, pp. 4621-4626

Ahn, J. H, & Forster C. F. (2002). Kinetic analysis of mesophilic and thermophilic anaerobic upflow filters treating paper-pulp-liquors. *Process Biochemistry*; Vol. 38, No.2, pp. 257 – 262

Alicbusan, R.V. (1973). Mushroom production technology for rural development, *Global Impacts of Applied Microbiology Proceedings* No. 4, pp. 429 – 432

*Anaerobic Digestion*. (n.d.). Retrieved February 10, 2007, from http://en.wikipedia.org/wiki/Anaerobic_digestion

*Anaerobic Treatment of Industrial Wastewaters*. (n.d.). Retrieved February, 20, 2008, from http://www.etsenvironmental.com/literature.htm

Anderson, G.K., & Yang, G. (1991). Evaluation of the inhibitory effects of lithium when used as a tracer for anaerobic digester, *Water Research*, Vol. 25, Issue 7, pp. 755 – 760

APHA-AWWA, (1992). Standard methods for the examination of water and wastewater, 17th Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA

Athanasopolos, N., & Karadimitris, T. (1988). Effect of media design on the performance of cotton fabric desizing and scouring wastewater treatment in upflow anaerobic filters, *Resources, Conservation and Recycling,* Vol. 1, pp. 123 – 129

Azbar, N., Ursillo, P., Speece, R.E. (2001). Effect of process configuration and substrate complexity on the performance of anaerobic processes, *Water Research* Vol. 35, No. 3, pp. 817 – 829

Bernardo, E. C., Egashira, R., Kawasaki, J. (1997). "Decolorization of molasses' wastewater using activated carbon prepared from cane bagasse", *Carbon Materials for the Environment Workshop*, Vol. 35, No.9, pp.1217-1221, June 09, Charleston,USA

Boller, M.A. & Eugster, J. (1992). "Upflow Anaerobic Filtration of a Sugar Containing Wastewater", *Second International Symposium on Waste Management Problems in Agro-Industries*, pp. 191 – 200, 23 – 25 September, İstanbul, Turkey.

Coca, M., Pena, M., Gonzalez, G. (2007). Kinetic study of ozonation of molasses fermentation wastewater*, Journal of Hazardous Materials* Vol.149, No.2, pp. 364–370

Dahiya, J., Singh, D., Nigam, P. (2001). Decolourisation of molasses wastewater by cells of Pseudomonas fluorescens immobilised on porous cellulose carrier, *Bioresource Technology* Vol. 78, No.1, pp. 111-114

*Definition of Anaerobic Digestion*. (n.d.). Retrieved March, 25, 2008, form http://www.anaerobic-digestion.com/html/introduction_anaerobic_process.php

Demirer, G.N. (2001). "Anaerobic Treatment of Industrial Wastewaters", *Turkish-German Symposium on Recent Advances in Wastewater Treatment,* October, İzmir, pp. 45-51

Dinopolou, G., Rudd, T., Lester, J.N. (1987). Anaerobic acidogenesis of a complex wastewater, *Biotech. and Bioeng*. Vol. 31, pp. 958 – 968

*Discovering Anaerobic Digestion and Biogas.* (n.d.). Retrieved November, 8, 2007, fromhttp://www.faceonline.org.uk/index.php?option=com_content&task=blogcategory&id=129&Itemid

Dohanyos, M., Zabranska, J., Grau, P. (1988). "Anaerobic breakdown of acrylic acid". In: Hall, E. R. & Hobson, P. N. ed. *Proceedings of the International Symposium on Anaerobic Digestion*, Bologna, May 22 – 26, Pergamon Press, Oxford, pp. 287-294

Eroğlu, V., Öztürk, İ., Bircan, E. (1991). "Upgrading the anaerobic contact process capacity using polyurethane carriers", *45th Industrial Waste Conference Proceedings*, May 8-9, pp. 417-423

Filibeli, A., Büyükkamacı, N., Ayol, A. (2000). *Anaerobik Arıtma*, Dokuz Eylül Üniversitesi Mühendislik Fakültesi Yayınları, No 280, Dokuz Eylül Üniversitesi Basım Ünitesi, İzmir

Gomec, C.Y., Letsiou, I., Ozturk, I., Eroglu, V., & Wilderer, P.A. (2007). "Identification of Archaeal Population in the Granular Sludge of an UASB Reactor Treating Sewage at 13°C." Oral Presentation No. 398, IWA 2007 *Antalya Sludge Conference*, 28-30 March 2007, Antalya, Turkey.

Guiot, S. R., & van den Berg, L. (1985). Performance of an Upflow Anaerobic Reactor Combining a Sludge Blanket and a Filter Treating Sugar Wastes *Biotechnol. Bioeng*. Vol. 27, pp. 800

Jianzheng, L., Baikun, L., Gefu, Z., Nanqi, R., Lixin, B., & Junguo, H. (2007). Hydrogen production from diluted molasses by anaerobic hydrogen producing bacteria in an anaerobic baffled reactor (ABR), *International Journal of Hydrogen Energy* Vol. 32, pp. 3274 – 3283

Kanat, G. (1997). "Effect of alkalinity on volatile acid concentrations and performance of the anaerobic reactor", *International Conference on Water Problems in the Mediterranean Countries*, November 17-19, pp. 501 – 507

Kara, M. (2007). *Anaerobic filter performance at different conditions*, M.Sc. Thesis, Department of Environmental Engineering, Dokuz Eylül University, (in Turkey)

Kato, M.T., Field, J.A., Lettinga, G. (1997). The anaerobic treatment of low strength wastewaters in UASB and EGSB reactors. *Wat. Sci. Tech.,* Vol.36, No.6 – 7, pp. 375 – 382

Kobayashi,H.A., Stenstrom,M.K., Mah,R.A. (1983). Treatment of low strength domestic wastewater using the anaerobic filter, *Water Res*. Vol. 17, No. 8, pp. 903 – 909

Lettinga, G. (1981). "Anaerobic Treatment for Wastewater Treatment and Energy Production", *Inter-American Seminar on Biogas*, 22-25 November, Joao Pessoa, Brasil

Lin, C.Y., Sato, K., Noike, T., Matsumoto, J. (1986). Methanogenic digestion using mixed substrate of acetic, propionic and butyric acids, *Water Resources*, Vol. 20, No. 3, pp. 385 – 394

Martin, A.D. (July, 25, 2007). *Understanding Anaerobic Digestion, Presentation to the Environmental Services Association*, Retrieved October 22, 2007 from http://www.esauk.org/081202_ad_profile.asp

Metcalf & Eddy, (2003). *Wastewater Engineering: Treatment, Disposal, Reuse,* McGraw Book Company, New York, USA.

*Methanogens*. (n.d.). Retrieved October 24, 2007, from http://www microbewiki.kenyon.edu/index.php/MicrobeWiki

Murto, M., Bjornsson, L., Mattiasson, B. (2004). Impact of food industrial waste on anaerobic co-digestion of sewage sludge and pig manure, *Journal of Environmental Management* No. 70, pp. 101–107

Okkes, I. A. G. (1983). "Cellobic process for anaerobic treatment of industrial wastewaters" In Anaerobic Wastewater Treatment W.J. van den Brink (Ed.), AWWT Symp. Secretariat, TNO, The Hague, Neth., pp.299

Öztürk, M. (2005). Hayvan gübresinden biogaz üretimi, *Çevre Ve Orman Bakanlığı*, Ankara

Pena, M., Coca, M., Gonzalez, G., Rioja, R., & Garcia, M.T. (2003). Chemical oxidation of wastewater from molasses fermentation with ozone, *Chemosphere* Vol.51, Issue 9, pp. 893–900

Rozzi, A. (1994). Start-up and operation of anaerobic digesters with automatic bicarbonate control. *Biosource Technology*, Vol. 48, Issue 3, pp. 215 – 219

Sheridan, R. P. (1982). "The Evolution of Anaerobic Treatment of Industrial Wastewaters" Paper presented at the Am. Inst. Chem. Eng. Summer Natl. Meeting, Cleveland, Ohio

Show, K. Y., & Tay, J. H. (1999). Influence of support media on biomass growth and retention in anaerobic filters, *Wat. Res.*, Vol. 33, No. 6, pp. 1471 – 1481

Sirianuntapiboon, S., Phothilangka, P., & Ohmomo, S. (2004). Decolorization of molasses wastewater by a strain No.BP103 of acetogenic bacteria, *Bioresource Technology* Vol.92, No.1, pp.31–39

Sleat, R., & Mah, R. (1987). "Hydrolytic bacteria", In Chynoweth, D. P. and Isaacson, R. (ed.), Anaerobic digestion of biomass. Elsevier Applied Science, Netherland, p. 15–33

Song, K. H., & Yang, J. C. (1986). Media design factors for fixed-bed anaerobic filters, *Water Pollut. Control Fed.*, Vol. 58, pp. 115

Speece, R. E. (1983). Anaerobic Biotechnology for Industrial Wastewater Treatment, *Environmental Science Technology*, Vol.17, pp. 416-A

Stadlbauer, E. A, Oey, L. N., Weber, B., Jansen, K., Weidle, R., Löhr, H., Ohme, W., & Döll, G. (1994). Anaerobic purification of brewery wastewater in biofilm reactors with and without a methanation cascade, *Water Science Tech.* Vol. 30, No. 12, pp. 395 - 404

Steinbrecher, P. (1988). *Effect of Reactor Height on Anaerobic Filter Performance*, M. S. thesis, Univercity of Arkansas, Fayetteville (in USA)

Switzenbaum, M.S., Sheehan,K.C., Hickey,R.F. (1984). Anaerobic treatment of primary effluent, *Environmental Technology Letters*, Vol 5, No.5, pp.189 – 200

Tokgöz, S. (1998). *Application of anaerobic filter systems to treat concentrated organic wastes*, Ph.D. thesis, Department of Environmental Engineering, Dokuz Eylül University, (in Turkey)

Toprak, H. (1990). *Anaerobik Stabilizasyon Havuzlarının Dinamik Modellemesi*. T.C. Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü Doktora Tezi, Yöneten: Prof.Dr. O. Uslu, İzmir

Weiland, P. & Wulfert, K. (1990). "Anaerobic treatment of stillage using different pilot-scale fixed bed reactors in up and downflow mode of operation", IAWPRC, September 24 – 26, Spain, pp. 147 - 154

Wilkie, A. & Colleran, E. (1984). Start-up of anaerobic filters containing different support materials using pig slurry supernatant, *Biotechnology Letters* Vol.6, No.11, pp. 735 – 740

Wittle, T. E. (1988). “Design and Start-up of an anaerobic treatment system for food processing wastewater”, Paper presented at the 1988, *Food Process. Waste Conf.*, Georgia Tech. Res. Inst., Atlanta

Wu, M., Wilson, F., & Tay, J. H. (2000). Influence of media-packing ratio on performance of anaerobic hybrid reactors, *Bioresource Technology*, Vol 71, No.2, pp. 151-157

Young, J.C. &. Yang, B.S. (1989). Design considerations for full-scale anaerobic filters, *Journal Water Pollution Control Federation*, Vol. 61, pp 1576-1587

Young, J.C., & McCarty, P.L. (1969). The anaerobic filter for waste treatment, *Water Pollutant Control Fed*; Vol. 41, No.2, pp. 160 – 173

Yu H. Q., Wilson F, Tay, J. H. (1998). Kinetic analysis of an anaerobic filter treating soybean wastewater, *Water Research*, Vol. 32, No.11, pp. 3341–3352