PERFORMANCE OF ANAEROBIC BAFFLED REACTOR (ABR) IN TREATING DOMESTIC WASTEWATER

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Special dedication:

To my beloved Mak & Ayah,

No words could describe my love for u…

To my younger sis & bros.

(Adilah, Mohd. Hakim, Amnah, Hasan, Muhamad Kamil,

Abu Hatim, Safanah and Aniesah),

Hope all of u will be somebody someday. Amien…

To my dear,

Inni uhibbuka fillah…

Without them, I am nobody…

They really mean everything to me.

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In The Name of ALLAH, The Most Generous and The Most Merciful

Praise to ALLAH s.w.t. for every ni'mah upon us as His creatures.

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Lastly, I hope this study will contribute to the development of wastewater treatment systems in Malaysia.

May ALLAH s.w.t bless all of them. Amien Ya Rabbal 'Alamien.

Thanks.

ABSTRACT

Performance of a laboratory-scale Anaerobic Baffled Reactor (ABR) system treating chemically adjusted domestic (sewage) wastewater with variable strength of 100-500 mg/L was investigated at anaerobic condition (25-30 °C) for 81 days after reaching steady-state at different retention time of 1 d, 2 d and 3 d. The evaluation was made by assuming a series of plug flow growth reactor, so that the results did not give a realistic interpretation of the data since diffusional limitations were not considered. The experimental section shows that for all wastewater strength, maximum COD removal of 69% were obtained at loading rates of 0.102-0.306 kg. COD/m^3.day have been reported in the literature review. Removal efficiencies showed very little sensitivity to daily fluctuations in influent wastewater quality. HRT, pH and wastewater strength have a significant impact on sulfate removal, and longer retention time, lower pH and wastewater strength resulted in higher sulfate removal, contrary with nitrite where at longer retention time and lower pH and wastewater strength there would be an addition in nitrite. Overall, the ABR like other anaerobic reactors was not an efficient reactor for anions removal. The main objectives of this study was to study the ability of Anaerobic Baffled Reactor (ABR) to remove organics from domestic wastewater, as well as to investigate the possibility of ABR as an efficient, economic and lowly operation and maintenance, which do not need expertise to handle, compared to other systems. In order to enhance the commercial potential of ABR, more work still remains to be done in the following area: COD removal, solids, treatment of toxic wastewater and an improved understanding of the factors controlling bacterial ecology.

ABSTRAK

Prestasi Sistem Reaktor Sesekat Anaerobik (RSA) yang digunakan untuk merawat air sisa domestik (kumbahan) yang diubahsuai kekuatannya di antara 100-500 mg/L telah dikaji pada keadaan anaerobik (25-28 °C) selama 81 hari setelah mencapai keadaan mantap dengan masa tahanan berbeza iaitu 1 hari, 2 hari dan 3 hari. Kajian yang dijalankan telah menganggap keadaan reaktor sebagai satu siri aliran palam, maka keputusan yang diperolehi tidak memberi suatu interpretasi yang realistik, di mana had penyebaran tidak diambil kira. Kajian menunjukkan bagi semua kekuatan air sisa, penyingkiran maksimum COD ialah 69% telah dicapai pada kadar bebanan di antara 0.102-0.306 kg. COD/m^3.hari. Keupayaan penyingkiran menunjukkan sedikit kepekaan terhadap perubahan harian di dalam kualiti influen air sisa. Masa tahanan, pH dan kekuatan air sisa memberi impak yang penting terhadap penyingkiran sulfat, di mana pada masa tahanan yang panjang, pH dan kekuatan air sisa yang rendah telah memberi penyingkiran yang lebih tinggi, berbeza dengan nitrit di mana pada keadaan yang sama, terdapat penambahan dalam nitrit. Secara keseluruhan, RSA sepertimana reaktor anaerobik yang lain tidak efisien untuk menyingkirkan anion. Objektif utama kajian ini adalah untuk mengkaji kebolehan RSA terhadap penyingkiran organik yang terdapat dalam air sisa domestik, selanjutnya untuk mengkaji peluang RSA sebagai suatu sistem yang cekap, ekonomik dan pengoperasiaan yang tidak memerlukan kepakaran teknikal yang tinggi berbanding sistem yang sedia ada. Untuk tujuan mengkomersialkan potensi RSA, pelbagai usaha masih perlu dijalankan dalam beberapa bidang berikut: penyingkiran COD, pepejal, rawatan air sisa toksik dan meningkatkan kefahaman tentang faktor-faktor yang mengawal ekologi bakteria.

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SYMBOLS AND ABBREVIATIONS

t	-	retention time (day)
V	-	volume of reactor(m^3)
Q	-	flow (mL/min)
So	-	influent concentrations (mg/L)
Se	-	effluent concentrations (mg/L)
Temp.	-	temperature (°C)
COD	-	Chemical Oxygen Demand (mg/L)
TSS	-	Total Suspended Solids (=MLTSS) (mg/L)
VSS	-	Volatile Suspended Solids (=MLVSS) (mg/L)
D.O	-	Dissolved Oxygen (mg/L)
NO_2	-	nitrite (mg/L)
NO_3	-	nitrate (mg/L)
PO_4	-	phosphate (mg/L)
SO_4	-	sulfate (mg/L)

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Water is of profound importance in Islam. It is considered a blessing from God that gives and sustains life, and purifies humankind and the earth. The Arabic word for water, *ma'* occurs sixty-three times in the Quran. God's throne is described as resting on water, and Paradise is described as *"Gardens beneath which rivers flow."* As Caponera (this volume) points out, it seems that in the Quran, the most precious creation after humankind is water. The life-giving quality of water is reflected in the verse, *"And Allah has sent down the water from the sky and therewith gives life to the earth after its death."* Not only does water give life, but every life is itself made of water: *"We made from water every living thing."*

The Quran makes two clear statements regarding water that support water demand management. First, the supply of water is fixed, and second, it should not be wasted. The statement that water supply is fixed, and that therefore, at some point, demand must be managed because supplies cannot be infinitely increased is: *"And we* *send down water from the sky in fixed measure."* The Quran then tells humans that they may use God's gifts for their sustenance in moderation, provided that they commit no excess therein: "0 *Children of Adam!.... Eat and drink: But waste not by excess, for God loveth not the wasters."*

The practice of reusing domestic wastewater for irrigation can be traced back more than two thousand years to ancient Greece. Reusing wastewater is an essential component of a demand management strategy be-cause it conserves freshwater for the highest-value uses. However, treating and reusing domestic wastewater has two other advantages: first, reduced environmental effects, and second, enhanced food production and reduced artificial fertilizer use because of the nutrients contained in the wastewater.

Reusing wastewater is not without health risks or obstacles. Raw wastewater is dirty - it looks and smells bad - and, more importantly, it contains pathogens, including bacteria, viruses, and helminths (parasitic worms), that can cause illness or even death. Given the importance of cleanliness in Islam, and that many Middle East and North Africa countries have minimal wastewater treatment, it is common to hear Muslims declare that wastewater reuse is undesirable, or even *haraam* (unlawful according to Islam). However, as Abderrahman's illuminating case study of Saudi Arabia outlines, reusing wastewater is not *haraam,* provided that it will not cause harm. After a detailed study, in consultation with scientists and engineers, the Council of Leading Islamic Scholars (CLIS) in Saudi Arabia concluded in a special *fatwa* in 1978 that treated wastewater can theoretically be used even for *wudu* and drinking, provided that it presents no health risk (Naser I. Faruqui et al., 2001).

This *fatwa* demonstrates the dynamic nature and wisdom of Islamic low when confronting the changing needs of the Muslim community. It was an important step toward the reuse of wastewater effluents for different purposes depending on its degree of treatment, such as drinking, ablution removal of impurities, and restricted and non-restricted irrigation.

Millions of cubic meters of wastewater effluents used to be produced and disposed of without reuse. This was not for technical reasons, but because it was not clear if the effluents were pure according to Islamic views, even after removal of impurities by proper treatment.

Although industrial water constitutes only a small portion of total demand, certain industries require special water qualities; and the environmental effects of mismanaging industrial wastewater represent a major hazard. Industrial water demand increased from about 56 MCM per year in 1980 to 192 MCM in 1990, and is expected to grow to about 500 MCM in 2010 (Naser I. Faruqui, 2001). The growing demand is satisfied mainly by costly desalination in some industries, especially food, although groundwater satisfies other types of industries. Industrial demand varies among regions of the kingdom. In some industrial plants, part of the effluent is recycled. However, uncontrolled disposal of wastewater has had negative effects on the environment and groundwater.

In the mean time, many research and investments on treatment processes to employ depending on the nature and strength of the wastewater to be treated as well as the financial standing of the authority concerned. For the developing country, financial constraint is always the limiting factor regarding the choice of treatment facility. Treatment systems that are efficient, economic and lowly operation and maintenance, which do not need expertise to handle would be very attractive. For this reasons most of the developing country would opt for stabilization ponds as the most viable process. Stabilisation ponds offer considerable economic advantages over other forms of municipal and industrial wastewater treatment. Although ponds naturally require more space than other most methods the construction, operating and maintenance costs are lower and may even be lower than half of supplementary systems. According to Plum J. et al. (2001), wastewater produced by industries especially dye manufacturers typically comprise mixtures of the various dyes produced by the manufacturers and their intermediate precursors could not be treated using stabilization pond. Appropriate treatment of these wastewaters to remove both color and synthetic dye compounds is clearly an important issue for dye manufacturers.

It has been reported that biodegradation of dye compounds can occur in both aerobic and anaerobic environments, although certain azo dyes are known to be resistant to degradation by aerobic bacteria due to the strong electron-withdrawing property of the azo group thought to protect against attack by oxygenases. Plumb J. and coworkers (2001) proposed that biotransformation of azo dyes is a two-step process, in which the azo bond is reduced under anaerobic conditions, producing two aromatic amines, which are then mineralized by aerobic microorganisms. In contrast to this proposed process, subsequent research showed that in the presence of readily utilizable cosubstrates, two azo dyes were reduced and decolorized under methanogenic conditions, and breakdown products from one azo dye were further mineralized. Due to comparatively low operation costs, use of anaerobic digestion to treat dye wastewater is a cost-effective alternative to the physical and chemical methods commonly used to do this.

An anaerobic baffled reactor (ABR) is a high-rate reactor that contains between three and eight compartments in which the liquid flow is alternately upward and downward between compartment partitions. One of the advantages of the ABR design is the potential for spatial separation of acidogenic and methanogenic populations in the reactor compartments. This design characteristic enables separation of more sensitive anaerobic populations, such as methanogens, from the front of the reactor, where exposure to toxic or unfavorable growth conditions may occur. Successful treatment of an industrial dye waste containing potentially toxic synthetic dye compounds using an ABR has been demonstrated (Bell, J and Buckley, C.A., 2003).

1.1 PROBLEMS IDENTIFICATION

Malaysia is one of the developing countries, which is shifting rapidly from being agricultural-based to industrial-based. Along with this development trend, the industry, commercial and residential expands from fully traditional with small establishment to one of the leading industry in terms of contribution to economic development.

A review of environmental controls implemented by developing countries indicates that learning from history is as important for a country as standing alone in terms of economy and manpower. Japan is a country with a valuable history of environmental problems, and whether the solutions have been good or not, it should disclose its history and make available its pollution control technologies to foreign countries and should learn other things from those countries. The reason is that environmental problems are no longer merely domestic problems of single country, but are global and are related to energy and resource problems (Akita, 1994).

Under the current regulations and technologies, no hazardous chemicals are being discharged into environment in toxic amounts; however, they are still being discharged at low level, and these low concentrations are of major concern, because they are hazardous and can cause chronic disease.

To control such chemicals in a high technology environment, new treatment methods are needed, and more advanced treatment technology is need for complexed wastewater. This led to the development of a range of reactor designs suitable for the treatment of low, medium and high strength wastewater.

Most commonly domestic wastewater is usually treated in chemical-physical or in activated sludge especially sequencing batch reactor (SBR) plant. In order to meet more stringent legislative and effluent requirement, therefore, purification process for wastewater should be improved and upgraded.

Therefore, this project is concerned with the application of Anaerobic Baffled Reactor (ABR) for treating domestic wastewater. The laboratory-scale unit was designed to treat the wastewater.

1.2 SCOPE OF STUDY

The scope of this study was to assess domestic and synthetic wastewater from sources nearby located in KUiTTHO and was done in the Environmental Laboratory of KUiTTHO by using Anaerobic Baffled Reactor (ABR). A 36.9 L laboratory scale reactor was operated individually in the laboratory for 96 days. Chemically adjusted domestic wastewater with medium to high strength was fed into the reactor. The performance of these methods has been elucidated by three analytical parameters. They are composed of hydraulic parameters including flow and retention time, environmental control parameters including temperature, pH and dissolve oxygen concentration and organic removal parameter including influent and effluent soluble organic concentrations which are COD, TSS, VSS, nitrate, nitrite, sulfate and phosphate. Owing to the limitation of time, this study was conducted only for about 81 days after reaching steady state.

1.3 AIMS AND OBJECTIVES OF THE STUDY

The aims of these works were to study the ability of Anaerobic Baffled Reactor (ABR) to remove from domestic and synthetic wastewater, as well as to investigate the possibility of ABR as an efficient, economic and lowly operation and maintenance, which do not need expertise to handle, compare to other systems.

The objectives of this study were as follows:

i. To design and construct a prototype for the ABR

ii. To determine the removal efficiency of ABR in removing chemical and biological loading for different wastewater strength.

iii. To study the optimum retention time on the reactor.

1.4 IMPORTANCE OF THE STUDY

The importance of this study can be divided into three groups which to whom it will bring the benefits. They are the students, researchers and Department of Environment.

1.4.1 Students

Students can be well versed with the system and how the technology is applied, as well as to prepare for future career advancement.

1.4.2 Researchers

Researchers can develop new method in wastewater treatment in Malaysia to be used in local climate.

1.4.3 Kolej Universiti Teknologi Tun Hussein Onn (KUiTTHO)

The application and development of this system in the future could reduce the cost appropriate to high treatment efficiency and better process stability, in other words it will contribute to the development of wastewater treatment systems in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Wastewater is characterized in terms of its physical, chemical and biological compositions. Treatment of wastewater are concerned with the removal of biodegradable organics, total suspended solids and pathogens. Many more stringent standards have been developed recently to deal with removal of nutrients, heavy metals and priority pollutants.

Effects of pollution can be manifested by many characteristics and variations in degree when pollution enters the aquatic environment. Specific environmental and ecological responses to a pollutant will depend largely on the volume and strength of the waste and the volume of water receiving it. Within each response there can be many changes in magnitude and degree. A classic response that has often been described is the effects of organic wastes that may be discharged from sewage-treatment plants and certain industries. As these wastes enter the receiving water, they create turbidity, decrease light penetration, and may settle to the bottom in substantial quantity to form sludge beds. Wastes are attacked by bacteria and this process of decomposition consumes oxygen from the water and liberates essential nutrients that in turn stimulate the production of some forms of aquatic life.

In this study, only biological treatment processes will be discussed, but in most biological processes are accompanied by physical and chemical operations that are combined to achieve the ultimate goal of producing clean safe water.

2.1 BIOLOGICAL PROCESSES

Biological Processes are primarily designed for the removal of dissolved and suspended organic matter from wastewater. The correct environment condition are provided to encourage the growth of microorganisms that use the organic compound, often measured as biochemical oxygen demand (BOD) or chemical oxygen demand (COD), as carbon substrate. Biological wastewater treatment is also capable of removing other wastewater components, including SS, nitrogen, phosphate, heavy metals and xenabiotics. Figure 2.1 show schematic flow diagrams of various treatment processes for domestic wastewater incorporating biological processes.

One advantage of using biological processes is that they are seen as natural. The reactor system merely intensifying processes that might occur in the environment. Soluble and solid wastes are transformed, being converted to gases. Either carbon dioxide if aerobic or carbon dioxide and methane if anaerobic, invert solids and water through microorganisms can only function in relatively dilute solution, neutral pH and at ambient temperature.

Biological processes are susceptible to toxic chemical and slow compare to chemical treatment. Soluble material generates solids that need to dispose of and on produce noxious compound. The final disposition of this material in an environmentally safe manner is difficult and expensive. However, sludge that tends to pollute surface and underground water such as electroplating wastewater, a method for recovery and reuse of heavy metals from that wastewater become necessary (Zaini Ujang, 2000).

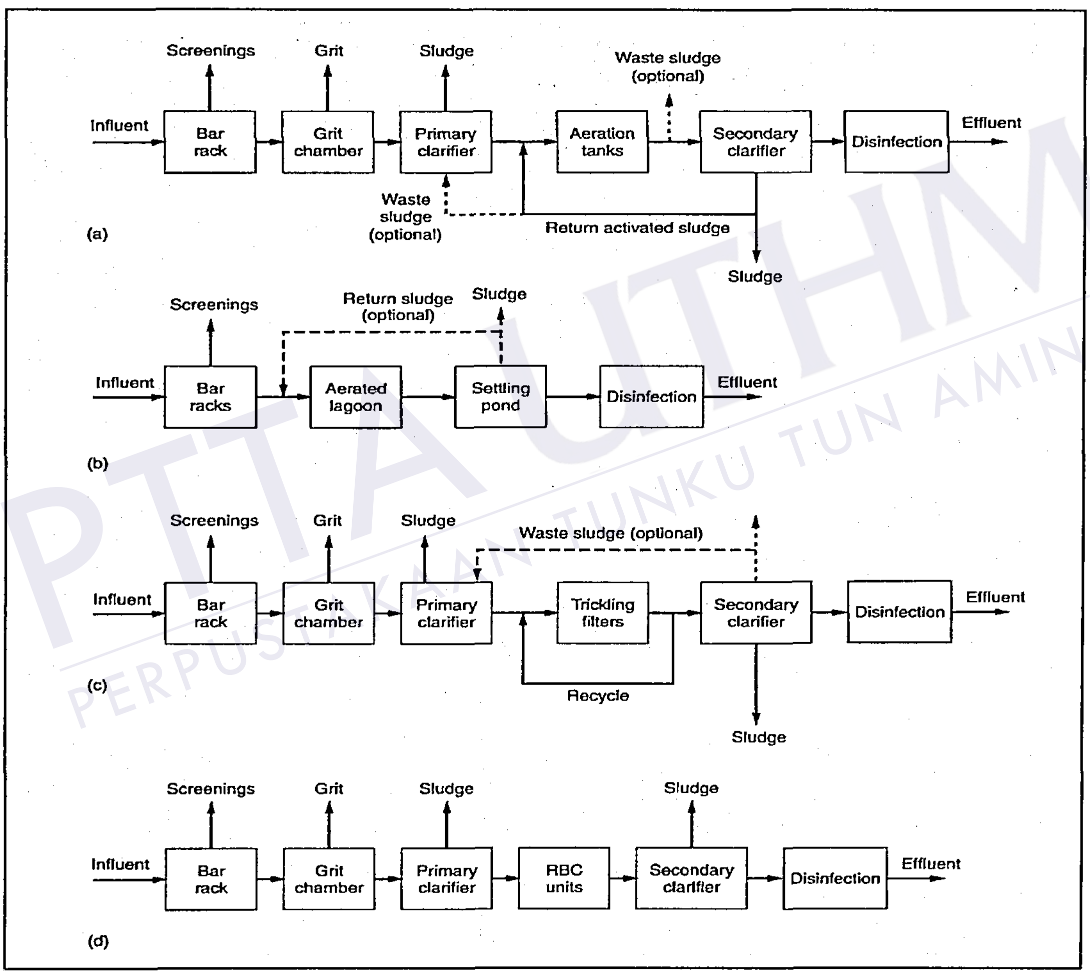

Figure 2.1 : Typical (simplified) flow diagrams for biological processes used for wastewater treatment : (a) activated sludge process, (b) aerated lagoon, (c) trickling filters, and (d) rotating biological contactor (RBC) (Source : Metcalf and Eddy, 2003).

2.1.1 Type of Biological Processes for Wastewater Treatment

The principal biological processes used for wastewater treatment can be divided into two main categories: *suspended growth and attached growth (or biofilm) processes*. Typical process applications for suspended and attached growth biological processes are listed in Table 2.1, along with other treatment processes. The successful design and operation of the processes listed require an understanding of the type of microorganisms involved, the specific reactions that they perform, the environmental factors that affect their performance, their nutritional needs, and their reaction kinetics.

Table 2.1 : Major biological treatment processes used for wastewater treatment (Source : Metcalf and Eddy, 2003)

Type	Common name	Use[a]
Aerobic processes		
Suspended growth	Activated-sludge processes	Carbonaceous BOD removal, nitrification
	Aerated lagoons	Carbonaceous BOD removal, nitrification
	Aerobic digestion	Stabilization, Carbonaceous BOD removal
Attached growth	Trickling filters	Carbonaceous BOD removal, nitrification
	Rotating biological contactors	Carbonaceous BOD removal, nitrification
	Packed-bed reactor	Carbonaceous BOD removal, nitrification
Hybrid (combined) suspended and attached growth processes	Trickling filter/activated sludge	Carbonaceous BOD removal, nitrification
Anoxic processes		
Suspended growth	Suspended growth denitrification	Denitrification
Attached growth	Attached growth denitrification	Denitrification
Anaerobic processes		
Suspended growth	Anaerobic contact processes	Carbonaceous BOD removal
	Anaerobic digestion	Stabilization, solids destruction, pathogen kill
Attached growth	Anaerobic packed and fluidized bed	Carbonaceous BOD removal, waste stabilization, denitrification
Sludge blanket	Upflow anaerobic sludge blanket	Carbonaceous BOD removal, especially high-strength wastes
Hybrid	Upflow sludge blanket/attached growth	Carbonaceous BOD removal

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