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

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BORANG PENGESAHAN STATUS TESIS♦

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

SESI PENGAJIAN: 2002/2003

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

NUR HIDAYAH BINTI ADNAN

This report is submitted as one of the requirement to be awarded Master Degree in Civil Engineering

Faculty of Civil Engineering
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OCTOBER 2003

"I admitted that this writing is my own efforts except the quotation and summary which each one I stated the source".

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Name : NUR HIDAYAH BINTI ADNAN

Date : OCTOBER 31, 2003

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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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).

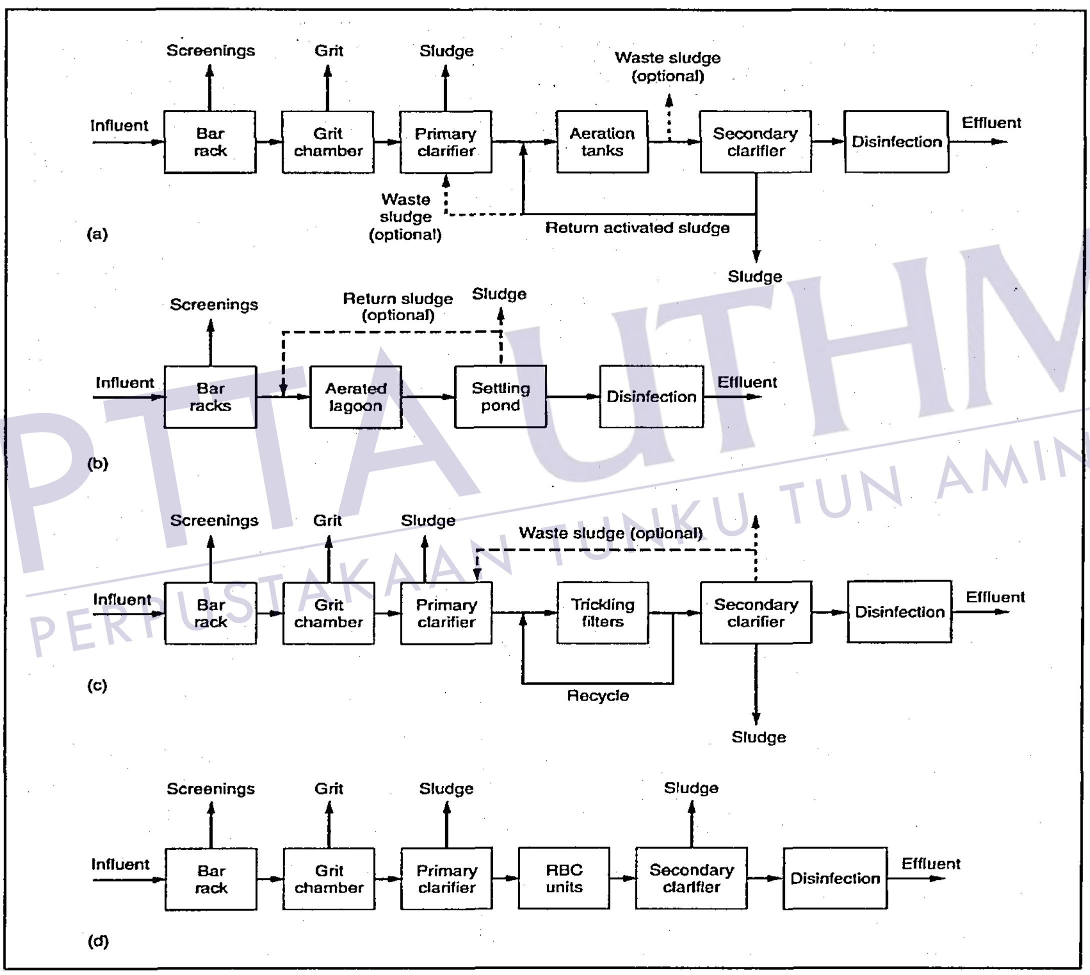

Figure 2.1 : Typical (simplified) flow diagrams for biological processes used for wastewater treatment : (a) activated sludge process, (b) aerated lagoon, (c) trickling filters, and (d) rotating biological contactor (RBC) (Source : Metcalf and Eddy, 2003).

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

Combined aerobic, anoxic and anaerobic processes		
Suspended growth	Single or multistage processes, various proprietary processes	Carbonaceous BOD removal, nitrification, denitrification, and phosphorus removal
	Single or multistage processes packing for attached growth	Carbonaceous BOD removal, nitrification denitrification, and phosphorus removal
Lagoon processes		
Aerobic lagoons	Aerobic lagoons	Carbonaceous BOD removal
Maturation (tertiary) lagoons	Maturation (tertiary) lagoons	Carbonaceous BOD removal, nitrification
Facultative lagoons	Facultative lagoons	Carbonaceous BOD removal
Anaerobic lagoons	Anaerobic lagoons	Carbonaceous BOD removal, waste stabilization

[a] adapted from Tchobanoglous and Schroeder (1985).

2.2 CHARACTERISTICS OF WASTEWATER

An understanding of the nature of wastewater is essential in the design and operation of collection, treatment, and disposal facilities and in the engineering management for environmental quality.

The physical properties and the chemical and biological constituents of wastewater and their sources are listed in Table 2.2. The important contaminants of interest in wastewater treatment are listed in Table 2.3. Wastewater characterization studies are conducted to determine the physical, biological, and chemical characteristics and the concentrations of constituents in the wastewater as the best means of reducing the pollutant concentrations.

Table 2.2 : Physical, chemical and biological characteristic of wastewater and their (Sources : Paul N. Cheremisinoff, 1995)

Characteristic	**Sources**
Physical Properties	
Color	Domestic and industrial wastes, natural decay of organic materials
Odor	Deposing wastewater, industrial wastes
Solids	Domestic water supply, domestic and industrial wastes, soil erosion, inflow infiltration
Temperature	Domestic and industrial wastes
Chemical Constituents	
Organics	
Carbohydrates	Domestic, commercial, industrial wastes
Fats, oils and grease	Domestic, commercial, industrial wastes
Pesticides	Agricultural wastes
Phenols	Industrial wastes
Proteins	Domestic and commercial wastes
Surfactants	Domestics and industrial wastes
Others	Natural decay of or organic materials
Inorganics	
Alkalinity	Domestic wastes, domestic water supply, ground water infiltration.
Chlorides	Domestic wastes, domestic water supply, ground water infiltration, water softeners.
Heavy metals	Industrial wastes
Nitrogen	Domestic and agricultural wastes
Nitrogen	Domestic and agricultural wastes
pH	Industrial wastes
Phosphorus	Domestic and industrial wastes, natural runoff
Toxic compounds	Industrial wastes
Gases	
Hydrogen sulfide	Decomposition of domestic wastes
Methane	Decomposition of domestic wastes
Oxygen	Domestic water supply, surface water infiltration
Biological Constituents	
Animals	Open watercourses and treatment plants
Plants	Open watercourses and treatment plants
Protista	Domestic wastes, treatment plants
Viruses	Domestic wastes

Table 2.3 : Important contaminants of concern in wastewater treatment (Sources : Paul N. Cheremisinoff, 1995)

Contaminants	Reason for Importance
Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated.
Biodegradable organics	Composed principally of proteins, carbohydrates and fats, biodegradable organics are measured most commonly in terms of BOD, and COD. If discharge untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions.
Pathogens	Communicable diseases can be transmitted by the pathogenic organisms in wastewaters.
Nutrients	Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of ground water.
Refractory organics	These organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols and agricultural pesticides.
Heavy metals	Heavy metals are usually added to wastewater from commercial and industrial activities and may have to be removed if the wastewater is to be reused.
Dissolved inorganic solids	Inorganic constituents such as calcium, sodium and sulfate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is to be reused.

2.3 COMPOSITION OF WASTEWATER TREATMENT

The chemical and biological composition of wastewaters from each of those sites will vary dramatically and determination of their composition is an essential task for an engineer. In addition, the effects of these are often immediate and dramatic, with the watercourse suffering severe long-term damage. Regular monitoring ensures that plant performance is maintained and that treated wastewater does not pose an unnecessary threat to receiving water quality (M. Perez *et al*, 1997).

2.3.1 : Domestic and industrial effluents

Freshly discharged domestic sewage is grey, turbid liquid with a characteristic, but (surprisingly) not unpleasant smell. However, if it is not kept fully aerated, it rapidly undergoes anaerobic biological degradation and this results in the production of such noxious compounds as hydrogen sulphide, amines and merchaptans which give it an extremely unpleasant smell. Tables 2.4 show the composition of typical domestic sewage (as reviewed by Horan,1993).

Table 2.4 : Composition of typical domestic sewage. (Source : W.J. Horan, 1993)

Determinand	Manchester (UK)	Malraq (Abu Dhabi Town)	Camping Grance (NE Brazil)	Amman (Jordan)	Nairobi (Kenya)
BOD (mgO_2/L)	240	228	240	770	520
COD (mgO_2/L)	520	600	570	1830	1120
PV (mgO_2/L)	-	75	-	-	-
SS (mg/L)	210	198	392	900	520
Ammonia (as N)(mg/L)	22	35.2	38	100	33
pH	7.4	7.6	7.8	-	7.0
Temperature (° C)	14	-	26	22	24

By comparison trade wastes comprise spent liquor from manufacturing processes, which are very strong, together with weaker water resulting from other processes such as washing, rinsing and condensing. Their final composition will obviously be dependent upon the nature of the manufacturing industries. The total pollution load resulting from industrial wastewaters is usually at least as great as that domestic sewage.

In domestic sewage there is a tendency for the peak ammonia concentration to coincide with or occur just before the peak flow. However, in industrial wastewaters it is likely that the majority of the discharges such as fertilizer manufacturing and chemical plants. In these cases the distribution of the ammonia load will be function of the operating regime practiced at the individual factories.

A factor that significantly affects the wastewater strength is the retention time in the sewers. Compositional changes will be reduced where there is a long sewer-retention time. In addition, daily variations in strength will not be as great in sewerage systems which separate storm waters from domestic and industrial wastes as compared to combined storm and wastewater sewers. Table 2.5 shows the composition of effluent from typical industrial premises (reviewed by Horan, 1993).

Table 2.5 : Composition of effluent from typical industrial premises Source : W.J. Horan, 1993)

Determinand	Pharmaceutical (India)	Textiles (India)	Beer-sugar waste (USA)	Coke-oven liquor (UK)
BOD (mgO_2/L)	15250	2000	930	1200
COD (mgO_2/L)	28540	5000	1601	3900
SS (mg/L)	5400	4000	1015	950
Ammonia (as N)(mg/L)	-	-	6.3	450
pH	9.3	12.0	7.1	5.5
Temperature (° C)	5466	-	16.4	490

2.3.2 : Leachate from landfill sites.

Unlike domestic sewage, which has characteristics within a fairly narrow range, leachates vary greatly in composition. The water present in a landfill site results from direct precipitation and groundwater movement, consequently the rate of leaching from a landfill site will be dependent upon the rate of infiltration from these two sources. In addition, seasonal and hydrologic factors also affect the composition of ensuing leachate (Pohland, 1986).

Leaching will not occur until the site is fully saturated and this process may take several years. Inside the landfill site anaerobic conditions are quickly established and a high degree of biological activity is occurring resulting in the degradation and solubilation of the site contents, thus the composition is changing constantly with the age of the site.

Consequently, leachates generally have a high organic strength, low pH and contain very high heavy metal concentrations (Horan, 1993; Kettunen and Rintala, 1997; Reinhart and Grosh, 1998). Table 2.6 and Table 2.7 have shown the composition of leachates from typical landfill sites. The wide variations observed in the composition of leachates means that treatment process, which has proved applicable at one site, may not be directly transferable to other locations In addition, due to the changes in leachate composition, which occur as the landfill ages, the treatment process initially selected may well prove inappropriate after several years of operation (Pohland and Harper, 1986; Reinhart and Grosh, 1998; Ismail, 1999).

Table 2.6 : Composition of leachate from typical landfill sites. (Source : W.J. Horan, 1993)

Determinand	Leeds (UK)	Buck County (USA)	New York (USA)
BOD (mgO_2/L)	6000	12500	10040
COD (mgO_2/L)	12000	18500	7500
SS (mg/L)	600	686	900
Ammonia (as N)(mg/L)	-	70	150
pH	6.2	6.7	4.3
Total N(mg/L)	-	748	350
Alkalinity ($CaCO_3$, mg/L)	-	5500	-

Table 2.7 : Various range in leachate composition that have been studied by different researchers (Reinhart & Grosh, 1998).

Parameter	Ehrig, 1989	Qasim and Chiang, 1994	South Florida Landfill Site*, 1987	Pohland and Harper, 1985
BOD (mg/L)	20-40,000	80-28,000	-	4-57,700
COD (mg/L)	500-60,000	400-40,000	530-3,000	31-71,700
Iron (mg/L)	3-2,100	0.6-325	1.8-22	4-2,200
Ammonia (mg/L)	30-3,000	56-482	9.4-1,340	2-1,030
Chloride (mg/L)	100-5,000	70-1,330	112-2,360	30-5,000
Zinc (mg/L)	0.03-120	0.1-30	-	0.06-220
Total P (mg/L)	0.1-30	8-35	1.5-130	0.2-120
pH (units)	4.5-9	5.2-6.4	6.1-7.5	4.7-8.8
Lead (mg/L)	0.008-1.020	0.5-1.0	BDL-0.105	0.001-1.44
Cadmium (mg/L)	<0.05-0.140	<0.05	BDL-0.05	70-3,900

BDL – below detection limits
* - South Florida Water Management District,1987.

2.4 BASIC OF ANAEROBIC TREATMENT

Anaerobic technology has been applied in sewage sludge treatment and energy production for over one hundred years. In the 1980's, anaerobic systems became increasingly common in the treatment of industrial wastewaters containing easily degradable, non-toxic compounds. The use of anaerobic systems was made possible by the development of high rate processes and the increased understanding of factors controlling the anaerobic degradation. Anaerobic wastewater treatment is usually followed by aerobic treatment to meet the effluent quality discharge standards. In many management as compared to systems based on the conventional aerobic processes. This is partially due to the resource recovery through methane gas.

Anaerobic wastewater treatment is employed in those cases where wastewater is concentrated, highly organic, ($BOD_5 > 100\text{-}1500\ g/m^3$) and has a low content of solids. In recent years it is also being applied to the treatment of municipal solid wastes. By definition, anaerobic digestion is the use of microbial organisms, in absence of oxygen, for stabilization of organic materials by conversion to methane and inorganic products including carbon dioxide:

$$\text{Organic Matter} + H_2O \xrightarrow{\text{anaerobic}} CH_4 + CO_2 + \text{New Biomass} + NH_3 + H_2S + \text{heat}$$

The process is often used for a first-stage treatment of high-strength organics wastes. The anaerobic process is also used in the treatment of sludge with a high water content (>95%), which has come from mechanical pre-treatment processes. Anaerobic processing is especially suitable for developing countries because the methane produced can be used for energy purposes and the residual material as fodder or as feed in fishponds (UNIDO, 1992).

According to UNIDO (1992), the aim of further treatment of sludge is to reduce the sludge volume by dewatering, diminish the capability of rotting and improve the hygienic condition of the sludge such as to kill any pathogenic bacteria or maggots' eggs.

The objective is to use anaerobic digestion to reduce high organic loads to magnitudes of COD that can be accommodated in conventional aerobic processes, typically activated sludge. As such anaerobic digestion is not a complete processor of wastewaters on its own. It is an addendum to existing conventional aerobic processes.

2.4.1 Microbiology of Anaerobic Digestion

There are four different trophic microbiological groups (bacteria) are recognized in anaerobic digestion, and it is the cumulative effect of all these groups that ensures process continuity and stability. The four metabolic stages required for the production of methane from organic wastes are outlined in Figure 2.2 (Sciencematrix.com, 2003).

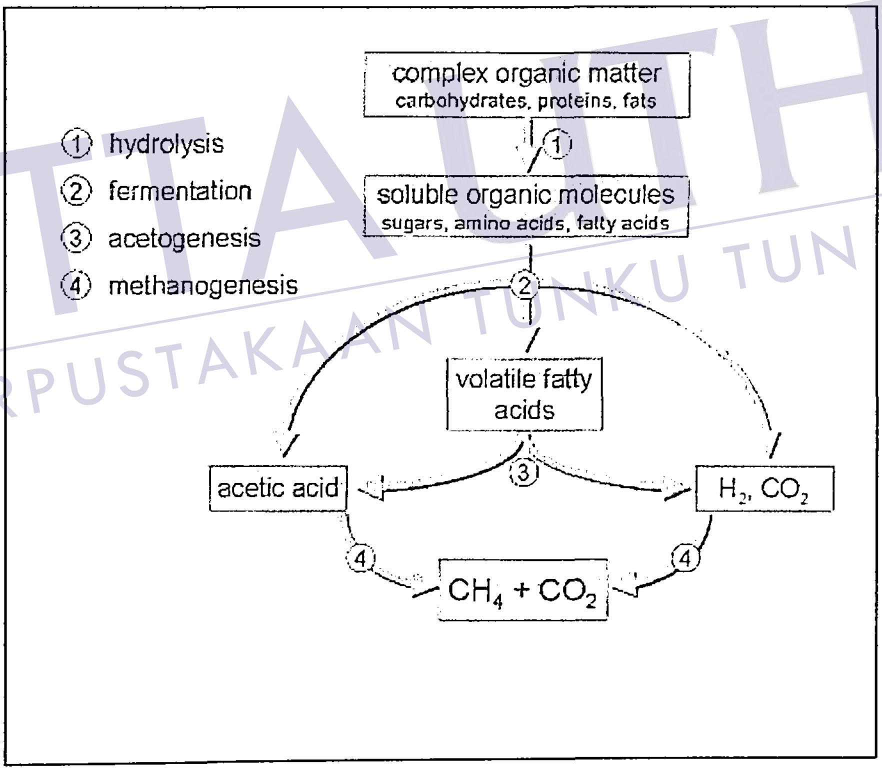

Figure 2.2 : The four metabolic stages required for the production of methane from organic wastes (Source : Sciencematrix.com, 2003).

Gujer and Zender (1983) organized by the anaerobic processes into seven sub processes as follows :

- Hydrolyses of complex particulate organic matter
- Fermentation of amino acids and sugars
- Anaerobic oxidation of long-chain fatty acids and alcohols
- Anaerobic oxidation of intermediary products
- Acetate production from CO_2 and H_2
- Conversion of acetate to methane by aceticlastic methanogens
- Methane production by hydrogenophilic methanogens using CO_2 and H_2O

The biological agents of anaerobic digestion are bacteria but fermentative and flagellate protozoa and some anaerobic fungi may play minor roles in some systems (reviewed by Gerald, 2002).

Some typical bacterial species present in the various stages and ranges of respective populations are given in Table 2.8. According to Gerald (2002), the huge range of genera and species indicates the complex nature of microbial population and in each of the stages the population densities (in sewage sludges) range from 10^5 to 10^9 per mL. The bacteria involved in anaerobic digestion have a pH range of 6 to 8 with values close to 7 for optimum activity. Volatile fatty acids depress the pH unless there is sufficient bicarbonate alkalinity present to neutralize the acids. Bicarbonate is formed when CO_2, which is soluble in water, reacts with hydroxide ions to form bicarbonate ions, HCO_3^-. It is important that sufficient alkalinity is available at all times, up to a level of ~3000 mg/L, for sufficient buffering to be maintained.

Table 2.8 : Some bacterial species in anaerobic digestion (Source : Gerald 2002)

Stage	Genera/species	Population in mesophilic sewage sludges
Hydrolytic acidogenic	*Butyvibrio, Clostridium, Ruminococus, Accetivibrio, Eubacterium, Peptococcus, Lactabacillius, Streptococcus*, etc	10^8-10^9 per mL
Acetogenic		
Homoacetogenic	*Acetobacterium, Accetogenium, Eubacterium, Pelobacter, Clostridium*, etc	≈ 10^5 per mL
Obiligate proton Reducing acetogens	*Methanobassilus omelionskii, Syntrophobacter wolinii, Syntrophomonas wolfei, Syntrophus buswelli*, etc	
Methanogenic □	*Methanobacterium(many species), Methanobrevibacter (many species), Methanococcus (many species), Methanomicrobium (many spesies), Methanospirillium hungatei, etc*	≈ 10^8 mL

□ The methanogenic bacteria are usually the limiting population.
Adapted from Wheatly, 1991, and others (reviewed by Gerald, 2002).

2.4.2 Description of the process

The decomposition of organic substances in the wastewater takes place under anaerobic (without air) conditions in two parallel stages. First, acid bacteria to organic acids, alcohols and carbon dioxide compose the organic substances of the wastewater. Second, the methane bacteria, living in symbiosis with the acid bacteria, decompose the products of the acid bacteria to methane, carbon dioxide and water.

During this process, biogas (methane) of a high caloric value is produced consisting of 70% methane and 30% carbon dioxide. A number of organic substances, such as greases, proteins, carbohydrates, ammo acids and organic acids can be decomposed on an anaerobic basis. Greases yield a high amount of gas per unit of quantity with a high percentage of hydrocarbon, proteins yield a smaller amount, while

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