TREATMENT OF FOOD PROCESSING INDUSTRIAL WASTEWATER USING TWO STAGES ANAEROBIC SYSTEM

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ABSTRACT

The wastewater produced by food manufacturing industry is known for its high concentration of COD and suspended solid. In wastewater treatment, anaerobic process is favorable due to its low cost, biogas production, low sludge production and more. In this study, upflow anaerobic sludge bed (UASB) and hybrid-UASB (HUASB) reactors, were combined with anaerobic filter (AF) bioreactors forming two stages system to treat food processing industry wastewater. This study was focused on the performance of UASB-AF (R1) and HUASB-AF (R2) treatment systems and the granules development. Seed sludge was deposited into HUASB column up to a third of the height. Palm oil shells were then packed into the HUASB (above seed sludge) as well as AF reactors to promote growth of microorganisms. The R1 and R2 systems were operated simultaneously, fed with raw food manufacturing wastewater taken from Azhar Food Manufacturing Factory. Parameters measured to evaluate the performance of the process were pH, COD, NH_3-N, oil and grease and total phosphorus. The highest average COD removal efficiency, at 99%, were detected in R1 and R2 systems, both at OLR 10.56 g COD/L.d. Moreover, the presence of aggregated bio particles with diameter ranges from 2.934 to 5.00 mm were observed in both UASB and HUASB reactors. The highest percentage of 2.934 to 5.00 mm diameter granules were 7.6 % and 10.7% in the UASB and HUASB respectively. In addition, the highest removal rate coefficient, k values for UASB and HUASB were 2.1981 and 3.3950, occurred at OLR 8.59 and 10.56 g COD/L.d, respectively. Overall, the k values have proved that HUASB reactor had performed better than UASB reactor.

ABSTRAK

Air sisa yang dihasilkan oleh industri pembuatan makanan terkenal dengan kandungan COD dan pepejal terampai yang tinggi. Dalam rawatan air sisa, proses anaerobik selalu digunakan kerana kos yang rendah, pengeluaran biogas, pengeluaran enapcemar yang rendah dan lain-lain. Dalam kajian ini, aliran ke atas katil enapcemar anaerobik (UASB), dan hibrid-UASB (HUASB) telah digabungkan dengan penapis anaerobik (AF) bioreaktor menjadi sistem dua fasa untuk merawat air sisa pemprosesan makanan di industri. Kajian ini memberi tumpuan kepada prestasi sistem rawatan UASB-AF (R1) dan HUASB-AF (R2) serta pembesaran granul. Benih mikrob dalam bentuk enapcemar dimasukkan ke dalam bahagian bawah reaktor HUASB sehingga sepertiga ketinggian. Cengkerang kelapa sawit pula diletakkan ke dalam HUASB (bahagian atas) dan AF reaktor untuk menggalakkan pertumbuhan mikroorganisma. Sistem R1 dan R2 beroperasi pada masa yang sama, dipam dengan air sisa pemprosesan makanan yang diambil dari Azhar Food Manufacturing Factory. Parameter yang diukur untuk menilai prestasi proses adalah pH, COD, NH_3-N, minyak dan gris dan jumlah fosforus. Purata tertinggi kecekapan penyingkiran COD, dengan 99 %, telah dikesan di sistem R1 dan R2, kedua-dua pada OLR 10.56 g COD/L.d. Selain itu, kehadiran granul bio agregat dengan diameter antara 2.934-5.000 mm ditemui dalam UASB dan HUASB reaktor. Peratusan tertinggi kumpulan granul berdiameter 2.934-5.000 mm dalam UASB dan HUASB adalah 7.6% dan 10.7 % masing-masingnya . Di samping itu, nilai pekali penyingkiran k tertinggi untuk UASB dan HUASB adalah 2.1981 dan 3.3950, berlaku pada OLR 8.59 dan 10.56 g COD/L.d masing-masingnya. Secara keseluruhan, daripada nilai k membuktikan bahawa reaktor HUASB adalah lebih baik daripada reaktor UASB.

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LIST OF ABBREVATIONS

APHA	-	American Public Health Association
USEPA	-	US Environmental Protection Agency
UASB	-	Upflow Anaerobic Sludge Blanket
HUASB	-	Hybrid-UASB
AF	-	Anaerobic Filter
OLR	-	Organic Loading Rate
HRT	-	Hydraulic Retention Time
Q	-	Flow rate
POS	-	Palm Oil Shells
COD	-	Chemical Oxygen Demand
SS	-	Suspended solids
TSS	-	Total Suspended solids
VSS	-	Volatile suspended solid
SVI	-	Sludge volume index
SMA		Specific methanogenic activity
TP	-	Total Phosphorus
$N\text{-}NH_3$	-	Ammonia-Nitrogen
O&G	-	Oil and grease
SO_4^{2-}	-	Sulphate
CH_4	-	Methane
mg	-	milligram
L	-	Liter
%	-	Percentage
mL	-	Milliliter
mm	-	Millimeter
SEM	-	Scanning Electron Micrograph

VFA	-	Volatile fatty acid
LCFA	-	Long chain fatty acid
ECP	-	Extracellular polymer

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Water is important to all living things in this world. 70.9% of the Earth's surface is covered with water. The ocean holds about 97% of surface water, the glaciers and polar ice caps holds 2.4%, while the other 0.6% of water in this world can be found at lakes, rivers and ponds. Unfortunately, the water quality has deteriorated from time to time due to human's daily routines. Making matter worse is the production of wastewater discharged by domestic residences, commercial properties, industry and agriculture that cover a broad range of potential contaminants and concentrations.

Malaysia now is a major exporter of electronic and machinery, petroleum, textiles, clothing and footwear, palm oil and wood products (Zain *et al.*, 2004). The industrial processes inevitably results in uncontrollable and high production of wastewater which if not treated properly will contaminate the environment. There are many factories contributing to industrial wastewaters such as metal industry, complex organic chemicals industry, and food industry. Industrial wastewaters are considerably diverse in their nature, toxicity and treatability, and normally require pre-treatment before being discharged to sewer. Food processing in particular is very dissimilar to other types of industrial wastewater, being readily degradable and largely free from toxicity. However, it usually has high concentrations of biological oxygen demand (BOD) and suspended solid (Gray, 1999).

Compared to other industrial sectors, the food industry uses a much greater amount of water for each ton of product (Mavrov *et al.*, 2000). One of a well-known food industry, chips industry, is also getting bigger in Malaysia throughout the years.

The most commonly used raw material in chip manufacturing industry is tapioca. Tapioca is produced from treated and dried cassava (manioc) root. Tapioca can also be used for starch-processing plants and production of pellets and chips (Chavalparit *et al.*, 2009). The process for chips or any other food processing plants normally use immense volume of water, yielding large amounts of wastewater that must be treated. Excessive water use and wastewater production results in economic and environmental burdens to the industry. The usage of water for clean-up in food processing plants flushes loose meat, blood, soluble proteins, inorganic particles, and other food waste to the drain. The wastewater produced could be treated and recycled to the process (Chen *et al.*, 1999).

The social and economic requirement for low-cost, low-technology wastewater treatment technologies has stimulated study of more advanced level wastewater treatment, including the development of new reactor designs and operating conditions (McHugh *et al.*, 2003). One of the well-known treatment methods in treating industry wastewaters is the anaerobic treatment (Moawad *et al.*, 2009). Anaerobic process has been used for the treatment of concentrated domestic and industrial wastewater for well over century. Anaerobic treatment of wastewater can be traced from the beginning of wastewater treatment itself in the form of septic tank treatment process (Seghezo *et al.*, 1998).

The interest on anaerobic systems as the main biological step (secondary treatment) in wastewater treatment was kind of inadequate, until the establishment of upflow anaerobic sludge blanket (UASB) reactor in the early 70s though a similar system called the 'biolytic tank' had been previously used in the 1910 by Winslow and Phelps (1911). Now the UASB reactor is broadly used for the treatment of several types of wastewater (Seghezo *et al.*, 1998). Other than UASB, anaerobic filter (AF) technology is also another system that applies the concept of anaerobic digestion process. AF technology has become established as a high rate process for treating industrial wastewater (Wang *et al.*, 2006). Being inspired from the UASB and AF bioreactors, the hybrid-UASB, or also known as HUASB has become popular in anaerobic bioreactor section (Oktem *et al.*, 2007). HUASB has been successfully applied as part of the treatment system in palm oil mill effluent (Habeeb *et al.*, 2011), dairy wastewater (Banu et al, 2007) and many other high strength wastewaters.

There are times where wastewater treatment would make use of support media to enhance the efficiency. Activated carbons are widely known support media that exhibits high surface area and opened pore that allows adsorption of contaminants (Haji *et al.*, 2013). However, activated carbon usually increases the cost of treatment process. This drawback has stimulated more research to utilize agricultural by-products and wastes to be used as support media (Al-Qodah and Shawabkah, 2009). One of the most acknowledged agricultural industry in Malaysia is the palm oil industry. Fibre, shell, decanter cake and empty fruit bunch makes up for 30%, 6%, 3% and 28.5% of the fresh fruit bunch respectively (Rupani *et al.*, 2010). Previous studies showed that the surface area of the resulting activated carbon prepared from the palm oil shells (POS) on a pilot plant scale without any chemical activator was 950 m^2/g (Hussein *et al.*, 1996). It was also mentioned that raw materials of palm oil shell contain high carbon and low ash (Hamad *et al.*, 2010).

1.2 Problem Statement

The food manufacturing wastewater contains high concentrations of several organic compounds including carbohydrates, starches, proteins, vitamins, pectines and sugars which are accountable for high chemical oxygen demand (COD) and suspended solids (Kobya *et al.*, 2006). The wastewater resulted from a series of processes (cleaning, cutting, slicing, washing, frying, salting, coating and packing) is one of the significant source in environmental pollution. The produced wastewater streamed with different levels of pollution load (low, medium and high contamination) are normally collected and treated in an on-site installation or in a municipal sewage treatment plant (Mavrov *et al.*, 2000). However, it is believed that more efficient treatment is required to assure the wastewater released are in compliant with the Environment Regulation 2009 (Industrial Effluent).

Nowadays, there are various treatments that can be applied to treat the industrial wastewater. The commonly preferred treatment is anaerobic treatment due to its low cost and high effectiveness. Some of the well-established anaerobic bioreactors are UASB, HUASB and AF bioreactors. Although UASB, HUASB and AF reactors are able to treat the wastewater effectively on their own, there are still flaws and disadvantages that needed to be overcome. Some of the drawbacks of UASB, HUASB and AF reactors are the slow start-up period and instability of performance. To improve on this shortcoming, studies on two stage anaerobic treatments are diligently investigated to improve on the efficiency and start-up period of the anaerobic treatment.

Ke and Fang (2005) stated that two stage anaerobic treatment is a reliable treatment system with variety of reactor designs available and can be modified or upgraded to achieve increased stability and greater efficiencies than single stage systems. Excellent performance of two stage anaerobic system had been observed in researches by Stamatelatou *et al.,* (2012), Nidal *et al.* (2003), and many more. Halalsheh *et al.* (2010) especially had done a research on two stage treatment system comprised of UASB and AF reactors in treatment of concentrated sewage which shows great efficiency, stability, and shorter start-up period. On the other hand, this study had applied the UASB-AF and HUASB-AF two stage anaerobic treatment systems to study their performance in treating food industry wastewater.

1.3 Objective of the Study

The objectives of this study are:

a) To investigate the performance of individual UASB, HUASB and AF as well as combinations of UASB-AF and HUASB-AF
b) To characterize and study the development of sludge granulation in UASB and HUASB reactors
c) To determine the removal rate constant, k of the organic pollutants in UASB and HUASB reactors.

1.4 Scope of Study

The research focuses on the laboratory scale of anaerobic treatment on food industry wastewater using UASB-AF and HUASB-AF treatment systems. The food industry wastewater was taken from the Azhar Food Manufacturing Sdn. Bhd., Food Beverage. The performance of UASB-AF and HUASB-AF were studied based on the efficiency of removing contaminants inside the wastewater with the aids from microorganism developed inside the reactors. Parameters studied were COD, total phosphorus, ammonia nitrogen, oil and grease, and total suspended solid. In addition, gas production (includes CO_2 and CH_4) and granule development were determined using a RITTER wet gas meter and PAX-it image analysis technique using light microscope respectively. A series of operational conditions, OLRs and HRTs were varied to determine the reactor's performances. The POS used was in a range size of between 5.0 mm to 10.0 mm. The role of POS as support media in this research was investigated by comparing the performance of UASB and HUASB (with palm oil shell as filter media) including the support data from the surface study of the granules and the shells using Scanning Electron Microscopy (SEM).

1.5 Significance of the Study

This study provides knowledge to the researchers, students and public on the performance of combinations of bioreactors; UASB-AF and HUASB-AF treatment systems. It is hoped that this research will generate new knowledge that will help in the development and improvement of methods to treat wastewaters produced by industries.

This research contributes in terms of improving the treatment of food manufacturing wastewater in specific. Food manufacturing wastewater has caused serious contaminations to the environment with high concentrations of COD, BOD and suspended solids (Kobya *et al.*, 2006). This would applies on slaughterhouse wastewater (Li *et al.*, 1999), dairy wastewater (Banu *et al.*, 2007), starch wastewater (Chavalparit *et al.*, 2009) and others.

This research focused on anaerobic treatments as a method to treat the food industry wastewater. One of the drawbacks of anaerobic treatment is the slow acclimatization of the anaerobes, which would improve a lot after the start-up period. Nevertheless, the two stage anaerobic systems used in this study, UASB-AF and HUASB-AF exhibit better start-up period than the UASB, HUASB and AF individually. Therefore, with low cost, high removal efficiency and shorter time consumption, this two stage anaerobic treatment system will be a good system to treat wide variety of wastewaters. Furthermore, the idea of using POS in both HUASB and AFs will hopefully generate more research on other agricultural wastes with potentials to become a great support material.

1.6 Expected Outcome

In general, the HUASB reactor was more likely to perform better than the UASB reactor overall in terms of organic removal. Moreover, the HUASB-AF system was also expected to have higher efficiency than UASB-AF system. Besides that, the amount of bigger granules inside the HUASB reactor was predicted to be higher as compared with granules inside the UASB reactor. In addition, higher value of removal rate coefficients, k were expected for HUASB reactor as compared with the UASB reactor. Furthermore, it was predicted that the HUASB reactor will be able to withstand higher OLR than the UASB reactor.

1.7 Thesis Outline

This research is investigating the anaerobic treatment of food industry wastewater using UASB-AF (R1) and HUASB-AF (R2) systems. Chapter 1 presents the general introduction, including the problem statement, objective of the study, scope of the study, significance of the study, the hypothesis and thesis layout. Chapter 2 presents a general literature review which covers some topics including food industry wastewater, wastewater treatment, environmental quality (industrial effluent) regulations 2009, biological treatment process, aerobic treatment process, anaerobic treatment process, UASB, HUASB, treatment process of UASB and HUASB, AF, design of AF bioreactor, biomass development in AF bioreactor, two stage anaerobic treatments, granule development, OLR, biogas formation, seed sludge (inoculum), support media, POS, microbiology aspect, methanogens, particle size distribution, nitrogen, nitrification, denitrification, COD, F/M ratio, phosphorus, suspended solid, and fats (oil and grease). Chapter 3 presents the methods used to treat the food industry wastewater using UASB, HUASB and AF reactors under several condition and the analysis used to monitor the reactor's performances. Chapter 4 presents the results and discussion of treatments of food industry wastewater by UASB-AF (R1) and HUASB-AF (R2) and the sludge bed development. Chapter 5 presents the general conclusion and recommendations. References and appendices are attached at the end of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Wastewater

The production of waste from human activities is unavoidable. A significant part of the waste produced will end up in the form of wastewater. The amount and type of wastewater produced can be influenced by its behaviour, lifestyle and standard of the society and as well as the technical and juridical framework by which people are surrounded. The wastewater produced from a society can be classified as domestic wastewater, industrial wastewater, leachate, stormwater, septic tank wastewater, infiltration into sewers, and wastewater from institutions. The quantity and quality of wastewater can be determined by many factors such as the chemical oxygen demand (COD), suspended solids, phosphorus, heavy metals concentration, lipid concentration and many more (Henze *et al.*, 2008)

Organic matter is the major pollutant in wastewater. One of the analysis used to determine the concentration of the organic matter in the wastewater is the determination of COD (Henze *et al.*, 2008). Yang *et al.* (2009) claims that COD is used as a measure of oxygen requirement of a sample that is subject to oxidation by strong chemical oxidant. It is a standard method for indirect measurement of the amount of pollution that cannot be oxidized biologically in a sample of water. The amount of oxygen consumed by the organic compounds and in organic matter which were oxidized in water. Basically, the higher the COD value, the higher the amount of pollution in the test sample. Belkin *et al.*, (1992) had noted that COD is significant in the control of the total content of pollution and the management of water surroundings.

COD assays are generally used for the estimation of the chemically oxidizable organic carbon of samples varying and unknown composition, such as domestic and industrial wastes and natural waters.

Phosphorus concentration in wastewater is also one of the parameter that needed to be monitored in the wastewater. Huang *et al.*, (2009) pointed out in their study that phosphorus is an essential nutrient for life on earth. It exists in soil, sediment, water and organisms. An excess of phosphorus, however, can cause eutrophication of natural waters. This issue has become one of the most worrisome environmental problems worldwide. Zhou *et al.* (2004) discussed on eutrophication as basically a problem caused by nutrient enrichment in surface water. Phosphorus; which has been identified as a nutrient limiting primary production is usually responsible for algal blooms and invasions of exotic species in most surface water ecosystems.

As discussed by Bilotta *et al.* (2008), the term SS refers to the mass (mg) or concentration (mg/L) of inorganic and organic matter held in the water column of a stream, river, lake or reservoir by turbulence. SS are usually fine particulate matter with a diameter of less than 62 um. All streams carry some SS under natural conditions. However, if the concentration of SS increases, alteration of the physical, chemical and biological properties of the water body can occur. Physical changes caused by SS include reduced penetration of light, colour, temperature changes and infilling channels and reservoirs when solids are deposited. Chemical changes include release of pollutants such as heavy metals and pesticides, nutrients into the water body. Plus, when the SS have a high organic content; resulting from factories discharge, the in-situ decomposition can cause decrease of level of dissolved oxygen in the water, resulting in oxygen shortage which will be fatal for the aquatic living.

Pollution from industrial discharges can subsequently contaminate the sediments within the surface water systems. In a study done at US east coast, 40%, 62%, 80% and 92% of the total amount of Cu, Cd, Zn and Pb are found in the suspended solids at the sediments. Suspended solids accumulate toxic components that will reach the bottom of the water. Phytoplankton and bacteria can live or adhere to the SS. This can cause increase of COD level of the water. Thus, this situation makes it critical for us to take action on it. In addition, the high surface area of the SS makes it easier for heavy metals to attach to it in high concentration; making it toxic (Mulligan *et al.*, 2009).

High lipid concentration in the wastewater can also inhibit the biodegradation process. It was found that LCFA, the intermediate products in lipid biodegradation have toxicity on cells and can cause sludge floatation effect which can cause operational failure. The LCFA toxicity is related to the adsorption onto the cell wall which affects its transport and protective functions. Floatation and washout were also one of the impacts from LCFA toxicity (Ijung *et al.*, 2006).

2.2 Food Industry Wastewater

Compared to other industries sectors, the food industry uses a much greater volume of water for each ton of product. Wastewater generated from food manufacture has distinct characteristics that distinguish it from common municipal wastewater as it is biodegradable and nontoxic. Food wastewater is widely known for its high concentration of biochemical oxygen demand (BOD) and suspended solid (SS). The constituent of food and wastewater are often complex to predict due to the differences in BOD and pH in effluents from vegetable, fruit, milk and meat products and due to the seasonal nature of food processing and post-harvesting (Onet, 2010). Table 2.1 shows some food industry wastewater and its characteristics.

Table 2.1: Food industry wastewater and its characteristics

Food industry Wastewater	pH	COD (mg/L)	BOD (mg/L)	SS (mg/L)	NH_3-N (mg/L)	Phosphate (mg/L)	Reference
Starch wastewater	4.2 ± 0.4	13941 ± 359	12776 ± 499	9130 ± 3067	-	-	Rajbhandari and Annachhatre (2004)
Chips wastewater	6.2-6.5	2200-2800	1650-2150	-	-	-	Kobya *et al.* (2006)
Dairy wastewater	7.1	5000	-	510	0.25	37.6	Banu *et al.*, (2007)
Kitchen wastewater	3.9	166.2	-	-	<10	182.5	Zhang *et al.* (2007)
Poultry slaughterhouse wastewater	7.0-7.6	3000-4800	750-1890	300-950	16-165	16-32	Rajakumar *et al.* (2011)
Dairy wastewater	7.2-8.8	1900-2700	1200-1800	500-740	-	-	Deshannavar *et al.* (2012)
Food processing wastewater	7-8	5250-5750	4000-5000	2000-2100	50-60	-	Senturk *et al.* (2013)
Slaughterhouse wastewater	6.9-7.1	27800	16680	2562	-	78	Gajender and Shanta (2013)

One of the famous food industries in Malaysia is chips manufacturing industry. The production of the chips use raw materials such as tapioca, cassava, banana and many more which contains 20-25% starch. The wastewater formed by chips industry where the raw materials are starch-containing is usually treated anaerobically. The wastewater also contains high suspended solid and COD value. Thus the wastewater needs sufficient treatment before being released to a water body (Rajbhandari *et al.* 2004).

2.3 Wastewater Treatment

Although there are many treatments available nowadays, the industries need to choose the best method to treat their wastes efficiently. Many food processing industries have been evaluating new technologies for improving wastewater treatment efficiencies, recovering valuable materials and recycling generated effluent after treatment. The motivations that drive improving of treatment system to be done are as shown in the Table 2.2

Table 2.2: Motivations for research on new technologies for improving wastewater treatment efficiencies (Chen et al, 1999).

Motivation	Notes
Cost Reduction	There are increasing costs for potable water, solid waste disposal, and effluent discharge, installing and operating treatment systems
Improved profitability	The recovery of higher value-added proteins could reduce high sludge costs from present systems
Present effluent treatment condition	The technology applied nowadays is inefficient and creates large waste disposal problems.
Regulatory	Demands continue to become more stringent
Environmental	This is particularly a concern in the communities where plants are located as well as the image with consumers.

Berardino *et al.* (2000) reported that as a support information for the motivations, anaerobic processes can favourably compete with the traditional aerobic processes for the treatment of food industry wastewater, provided that the wastewater from the industrial activity is sufficiently concentrated, availability at high temperature and characterised by high biodegradability.

2.4 Environmental Quality (Industrial Effluent) Regulations 2009

The government body of Malaysia had enforced some regulations regarding industrial effluent. Industrial effluent is a wastewater generated from manufacturing process or any other activity occurring within the industry premises. Sometimes, the industrial effluent mixes with the sewage (domestic) wastewater. Table 2.3 shows acceptable conditions for discharge of industrial effluent or mixed effluent standards A and B which represents the areas upstream of surface or above subsurface water supply intakes.

Table 2.3: Conditions for discharge of industrial effluent or mixed effluent of standards A and B (Environmental Quality Regulations 2009)

Parameter	Unit	Standard	
		A	B
Temperature	^{0}C	40	40
pH value	-	6.0-9.0	5.5-9.0
BOD_5 at 20 ^{0}C	mg/L	20	50
COD (Other industries) – industrial effluent only	mg/L	80	200
Suspended Solid	mg/L	50	100
Sulphide	mg/L	0.50	0.50
Oil and Grease	mg/L	1.0	10
Ammoniacal Nitrogen	mg/L	10	20
Phosphorus	mg/L	5.0	10.0

2.5 Biological Treatment Process

Generally, biological treatment process is a treatment that make use microbiology concept as a beneficial science for the destruction of contaminants in wastewater. The main key in removing the contaminants in the wastewater is done by the microorganisms. Microorganisms are aerobic, anaerobic or facultative in nature. If aerobic, they require oxygen to live. On the other hand, anaerobic bacteria exist and multiply in environments that lack dissolved oxygen (DO). Facultative bacteria can switch to aerobic or anaerobic growth in an aerobic or anaerobic environment. This has add to variety in biological treatment options; whether aerobically or anaerobically (Spellman 2003).

2.5.1 Aerobic Treatment Process

Aerobic treatment is a biological process which uses the application of free or dissolved oxygen by microorganisms in degradation of organic wastes. The decomposition of contaminants in wastewater using aerobic method needs aeration; which will be the oxygen source for the growth of aerobic microbes that will treat the organic matter and form sludge as the by-product of the process. Figure 2.1 below shows the aerobic decomposition:

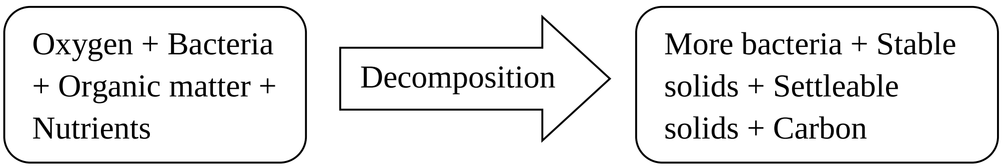

Figure 2.1: Aerobic decomposition (Spellman, 2003)

There are many aerobic treatments available to be applied in industry. Table 2.4 shows some of the many aerobic treatments applied and the performance of the treatment on the wastewater used:

Table 2.4: Aerobic treatments method and the performance

Treatment method	Performance (removal %)	Researchers
Sequence Batch reactor	COD (96-99) Total N (90-97) Total P (96-99)	Gao et al, 2011
Sequence Batch Airlift reactor	COD (91-95) NH_4-N (73-82) PO_4-P (96-98)	Bao et al, 2009
Vertically Moving Biofilm reactor	COD (94-96) Total N (77-82)	Rodgers et al, 2004

In spite of the excellent performance by the aerobic wastewater treatment, the high capital and operational costs that coincide with the aerobic treatments impose significant financial constraints. This resulted in uprising of more research to look for cost-effective, reliable and unsophisticated technology (Kassab *et al.*, 2010).

2.5.2 Anaerobic Treatment Process

The anaerobic treatment process is a process which makes use of microorganisms to break down biodegradable material in the absence of oxygen. The organic matter will be degraded to basic constituents, and later to methane gas under absence of electron acceptor (such as oxygen). The complex organic material will be hydrolysed to basic monomer by the hydrolytic enzymes. The simplified organics are then fermented into organic acids and hydrogen by the fermenting bacteria. The volatile organic acids will later on converted into acetate and hydrogen by the acetogenic bacteria. Then, the methanogens will use the hydrogen and acetic acid and transformed them into methane (Ersahin *et al.*, 2011).

Habeeb *et al.* (2011a) describes that due to the simple method of treatment, anaerobic wastewater treatment has become the most attractive method due to its low production of biomass, easy to operate, low cost effectiveness and low energy demand.

Anaerobic method has also been known as an economical process than other kind of treatment such as aerobic wastewater treatment.

Anaerobic process are commonly used to treat strong organic wastewaters and for further treatment of primary and secondary sludge from conventional wastewater treatment. Anaerobic treatment, although slow, has more advantages in the treatment of strong organic wastes. These include a high degree of purification, ability to treat high organic loads, production of small quantity of excess sludge which is normally very stable and the production of inert combustible gas (methane) as an end product. Unlike aerobic systems, complete stabilization of organic matter is not achievable anaerobically. The advantages and disadvantages of anaerobic treatment are as shown in Table 2.5:

Table 2.5: The advantages and disadvantages of anaerobic treatment compared to aerobic treatment (Gray, 1997)

Advantages	Disadvantages
Low operational costs	High capital costs Generally require heating
Low sludge production	Long retention times required (> 24 h)
Reactors sealed giving no odour or aerosols	Corrosive and malodorous compounds produced during anaerobiosis
Sludge is highly stabilized	Not as effective as aerobic stabilization for pathogen destruction
Methane gas produced as end product	Hydrogen sulphide also produced
Low nutrient requirement due to lower growth rate anaerobes	Reactor may require additional alkalinity
Can be operated seasonally	Slow growth rate of anaerobes can result in long initial start-up of reactors and recovery periods
Rapid start up possible after acclimation	Only used as pre-treatment for liquid wastes

Problems with anaerobic treatment of wastewater containing lipid can result in two phenomena: 1) adsorption of light lipid layer around biomass particles causing biomass floatation and washout, and 2) acute toxicity of long chain fatty acids (LCFA), especially unsaturated LCFA to both methanogens and acetogens (two main trophic groups involved in LCFA degradation). It was also found that the breakdown of LCFA is often the rate-limiting step in the degradation of complex substrates (Saatchi *et al.*, 2003).

2.6 Upflow Anaerobic Sludge Blanket (UASB)

The UASB reactor is a well-known treatment that can treat many types of wastewater. In the UASB system, most of the benefits of anaerobic systems are retained which includes low excess sludge production, energy production and others (Moawad *et al.*, 2009) UASB is popular with successful applications for the treatment of high strength industrial wastewater, especially those from food processing and pulp and paper industries (Das et al, 2009). The main aspect of UASB is the nature of the active biomass (Quarmby *et al.*, 1995). In a research done by Wiegant *et al.* (1985), the biomass growth will later affect the settleability of the sludge which is in the form of spherical flocs with a quite consistent structure, normally referred to as granular sludge. Figure 2.2 show an example of schematic diagram of UASB reactor.

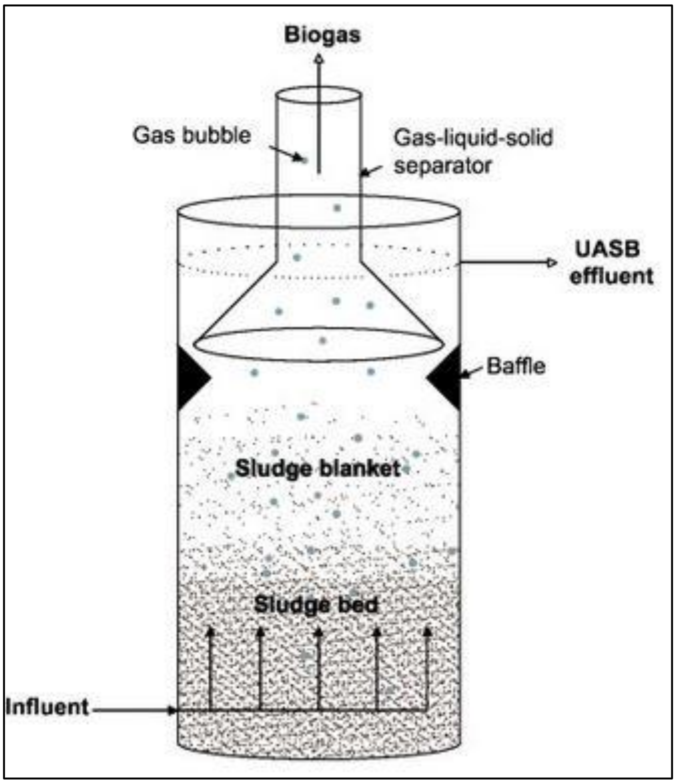

Figure 2.2: Schematic diagram of UASB reactor (Siewhui *et al.*, 2012)

In UASB process, the wastewater will flow through a sludge bed (granular or flocculent), where different physical and biochemical mechanisms act in order to retain and digest the substrates. Readily biodegradable substances will be easily acidified and then converted into methane and other gas components. Solubilisation and hydrolysis of SS and large molecules will be a slow process which will be done by the extracellular enzymes excreted by acidogenic bacteria (Ruiz *et al.*, 1998). Table 2.6 shows performance of UASB done by other researchers.

Table 2.6: Performance of UASB in treating several types of wastewaters

Sample	COD removal	Reference
Synthetic wastewater	60-90 %	Yan *et al.*, (1992)
POME	90 %	Borja *et al.*, (1996)
Domestic wastewater	79-89%	Lew *et al.*, (2004)
Synthetic wastewater	92-96%	Li *et al.*, (2008)
Distillery wastewater	76-80%	Emilia *et al.* (2011)
Brewery wastewater	96-98%	Sharda *et al.* (2013)
Fermentation wastewater	84% (maximum)	Amin and Vriens (2014)

2.6.1 Hybrid Upflow Anaerobic Sludge Blanket (HUASB)

HUASB is a modified form of an UASB reactor. This reactor makes use of the granular sludge as a key to treat wastewater is the hybrid-UASB or HUASB. Following the increase in popularity of the UASB, the HUASB reactor has also been successfully introduced to the public as a clean-efficient technology. The HUASB reactor has a presence of a filter cage which makes use of media; such as palm oil shell (Habeeb *et al.*, 2011b) to enhance contaminant removal. But still, it is reported by many researchers that both UASB and HUASB provide good treatment.

There are lots of applications of UASB and HUASB reactor in treating the wastewater resulted from the manufacturing in the industries. The performance of HUASB in studies done by other researchers are illustrated in Table 2.7.

Table 2.7: Performance of HUASB in treating several types of wastewaters

Sample	COD removal	Reference
Dairy wastewater	87%	Banu *et al.*, (2007)
Pharmaceutical wastewater	85%	Oktem *et al.*, (2007)
Palm Oil Mill Effluent	Up to 93%	Norsarafina *et al.*, 2009
Palm Oil Mill Effluent	Up to 97%	Azeera *et al.*, 2010
Palm Oil Mill Effluent	84-91%	Habeeb *et al.*, (2011b)
Poultry slaughterhouse wastewater	86-92%	Rajakumar *et al.*, (2012)
Paper and pulp wastewater	83% (maximum)	Balasubramaniam and Muthukumar (2012)

2.6.2 Treatment Process of UASB and HUASB

The UASB and HUASB bioreactor concept is based on the upflow feeding of wastewater through the sludge bed at the bottom of the reactor. For HUASB reactor, the wastewater will passes through the packing filter as an additional treatment. Rajakumar *et al.* (2012) mentioned that through their research, the maintenance of sufficient methanogenic population is important for stable performance of the treatment. To support the idea, Habeeb *et al.* (2011b) found that the start-up period of operation involves microbial communities' immobilization through continuous feeding of wastewater into seeded sludge to be developed to granules aggregations which are considered to be the key success of the process.

In spite of the importance of granules aggregation for the UASB and HUASB to operate well, the development of a dense, active sludge mass in the lower part of the reactor is also an important matter. Distinct sludge granules near the size of peas are usually formed, but in some cases the sludge blanket is flocculent. The waste is introduced at the bottom of the reactor, where upon contact with the sludge bed, the organic matter is degraded to CH_4 and CO_2. Gas formation and evolution supply sufficient mixing in the sludge bed. Some solids are buoyed up by rising gas bubbles but a quiescent settling zone is provided for their separation and return into the lower portions of the reactor. This internal recycling of solids removes the need for external solids recycle (Seghezzo *et al.*, 1998).

Lettinga *et al.* (2006) had stated that a delicate balance exists between the primary degradation (hydrolysis and acidogenesis) and the conversion of acids by acetogenic and methanogenic bacteria into methane and carbon dioxide. In addition, the effect of fluctuations in hydraulic and organic load generally depends on the applied hydraulic retention time (HRT), sludge retention time (SRT), intensity and duration of the variations, sludge properties and also the reactor design; regarding the three phase separator.

The hydraulic loading variations will affect the dynamics of the sludge bed as they expand the bed due to new equilibrium between the upflow and sludge settling velocities. Higher SS concentration can be expected due to washout of lighter biomass. However this might cause insufficient contact between the substrate and the sludge bed. As the loadings increase, organic overload can occur; which resulted in pH drop and inhibition of methanogenesis (Lettinga *et al.*, 2006).

Ghangrekar (2008) noted that, for a wastewater sample with COD concentration in the range of 2000 mg/L and 5000 mg/L, the performance of the reactor will be more dependent on the loading rate. Meanwhile, the influent substrate concentration will not give great impact on the reactor's performances. Table 2.8 shows the recommended loading range for design of UASB based on COD concentration at average flow.

Table 2.8: Recommended loading range for design of UASB based on COD concentration at average flow (Ghangrekar, 2008)

Category of wastewater	COD concentration, mg/L	OLR, kg.COD/ m^3.d	SLR, kg.COD/kg.VSS.d	HRT, hours	Liquid Upflow velocity, m/h	Expected Efficiency, %
Low strength	Up to 750	1.0 – 3.0	0.1 – 0.3	6 – 18	0.25 – 0.7	70 – 75
Medium strength	750 – 3000	2.0 – 5.0	0.2 – 0.5	6 – 24	0.15 - 0.7	75 – 85
High strength	3000 – 10000	5.0 – 10.0	0.2 – 0.6	6 – 24	0.15 – 0.7	75 – 85
Very high strength	> 10000	5.0 – 15.0	0.2 – 1.0	> 24	-	75 – 80

Claudia *et al.* (2001) had done a research on UASB treatment of slaughterhouse wastewater. It was found that the UASB treatment of wastewaters generated in meat processing plants has problems with the accumulation of suspended solids and floating fats in the reactor. This will leads to a reduction in the methanogenic activity and biomass washout, which eventually results in reactors failure. It is suggested to reduce the fats and suspended solids before pumping the substrates into the UASB system to ensure good efficiency.

Mahmoud *et al.* (2003) had concluded in his study that there are several parameters that are likely to have effects on solid removal in UASB reactor. The main parameters are the operational conditions, influent characteristics and the sludge bed characteristics. For the operational conditions, the authors mentioned temperature, OLR, HRT, SRT, and flow rate to be the main points. Meanwhile, for the influent characteristics, the author mentioned about the influents particle size and the particle charge to have effects on the reactors performance. On the other hand, for sludge bed characteristics, particle size distribution, ECP substances and charges were discussed. Table 2.9 and 2.10 show the simplified discussion on the authors study.

Table 2.9: Operational conditions affecting solids removal in UASB reactor (Mahmoud *et al.*, 2003)

Main Points	Parameters Affecting UASB Performance	Notes
Operational conditions	Temperature	The reactor performance is better at high temperature (thermophilic). This may be due to the decrease of the wastewater's viscosity at high temperature and consequently decreases the hydraulic shearing force on the particles
	OLR	High OLR, which imposes low SRT, will change the sludge bed composition (microbial, physical and chemical) and cause accumulation of floatable substances (proteins and lipids)
	HRT and SRT	HRT affects the performance due to its direct relation to upflow velocity and solids contact time in the reactor. Meanwhile, SRT can indirectly influence the solids removal as through changing of the physical-chemical and biological characteristics of the sludge bed in addition to biogas production.
	Upflow velocity	Increasing the upflow velocity can increases the rate of collisions between suspended materials and the sludge and also increases the hydraulic shearing force, which counteracts the removal mechanism through exceeding the settling velocity of more particles and detachment of captured solids. However, it was noted that the flow rate should be high enough to provide good contacts and disturb gas pockets gathered in the sludge bed.

Table 2.10: Influents and sludge bed characteristics affecting solids removal in UASB (Mahmoud *et al.*, 2003)

Main Points	Parameters	Notes
Influent characteristics	Influent concentration	Fluctuations in influent concentration can leads to better removal efficiency due to increasing collision opportunity.
	Influent particle size	Particles removal in sludge bed involves transport and attachment. The removal efficiency of particles smaller than ~ 1um increases with decreasing size and accomplished by diffusion, while for particles > ~ 1 um increases with particle size due to increase of gravitational force.
	Influent particle charge	Domestic sewage have hydrophilic and hydrophobic particles.
Sludge bed characteristics	Particle size distribution	Smaller media size gives better removal efficiency.
	ECP substances	ECP can affect several physical and chemical characteristics of activated sludge, like dewaterability, floc charge, floc structure, settleability, granulation, and flocculation
	Charges	Sludge surface charge can influence many physical-chemical characteristics of sludge, like exchange potential, sludge settleability, dewaterability, and viscosity.

A research on the effect of OLR on the performance of UASB reactor treating slaughterhouse effluent had been done by Torkian *et al.* (2003). It was observed that the slaughterhouse wastewater contains high amount of organic matter. The suspended and colloidal components in the form of fats, proteins, and cellulose can cause negative impact on the performance of UASB reactors. In the end, these components can cause deterioration of the microbial activity and washout of active biomass.

2.6.3 Seed sludge (Inoculum)

Seed sludge that is used for the UASB and HUASB reactor in start-up period to be upgraded to granules can be provided from any source containing appropriate bacterial flora. Normally, the seed sludge has to be obtained from anaerobic ponds sediments, fresh water sediments, septic tank sludge, manure, digested sewage sludge and anaerobic treatment plants (Habeeb *et al.*, 2011b). Various kind of seed sludge has been successfully used for UASB start-up. Agrawal *et al.* (1997) agreed that selection of the most suitable seed is important to successfully start-up UASB and HUASB reactor. The seed can be granular sludge or non-granular sludge; such as digested sewage sludge, cow manure and sewer slurry. Among the non-granular sludge, digested sewage sludge is widely used in UASB and HUASB reactor as seed.

2.7 Anaerobic Filter (AF)

Biological filtration is a standard treatment for wastewater. Biological filtration as the name states encourages microbial growth in filters to enhance their performance beyond solely physical filtration. Microorganisms existed will consume or digest organic matter in the wastewater which includes removal of nitrogen, phosphorus and other organic matter (Droste, 1997). There are many applications of anaerobic filter in treating various wastewaters. The examples are shown as in Table 2.11.

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