UNIVERSITI PUTRA MALAYSIA

BIOLOGICAL TREATMENT OF CATTLE SLAUGHTERHOUSE WASTEWATER AND BIOGAS PRODUCTION USING UPFLOW ANAEROBIC SLUDGE BLANKET REACTORS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

February 2020

DEDICATION

This thesis is dedicated to my beloved uncle Muhammad Lawan Buba for the moral, financial support and encouragement throughout this program

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor Syazwani Idrus, PhD
Faculty : Engineering

Cattle slaughterhouses generate wastewater rich in organic contaminants and nutrients and are considered as high strength wastewater and a potential candidate for treatment processes that recover energy. Komplex Abattoir Shah Alam lack adequate and effective treatment facilities, especially for energy recovery. As a result, a large volume of extremely complex effluent with a high content of chemical oxygen demand (COD) (32,000 mg/L), biological oxygen demand (BOD) (17,158 mg/L), fats, oil and grease (FOG) (1,024 mg/L), color (16,426 Pt-Co) and turbidity (12,500 FAU) is discharged into a water body. However, the department of environment (DOE) Malaysia have set a standard limits A (COD = 120 mg/L) and B (COD = 200 mg/L) to be complied by all intending investors capable of generating waste to be discharge as wastewater. Conventionally, the treatment methods of municipal wastewater are similar to cattle slaughterhouse wastewater treatment. These includes physicochemical and biological treatment methods. Physicochemical methods includes Dissolve air floatation (DAF), coagulation-flocculation and sedimentation, electrocoagulation process and membrane technology. However, the major drawbacks of the physicochemical methods includes, energy intensive, large volume of sludge production, high investment and operation and maintenance cost, and complex infrastructure. Biological treatment methods includes anaerobic, aerobic, facultative lagoons, activated sludge process and trickling filters. Among the biological treatment methods, anaerobic digestion using conventional upflow anaerobic sludge blanket (UASB) reactor appeared to be promising. Nevertheless, its drawbacks range from the long startup period due slow growing microorganism, sludge washout at low hydraulic retention time (HRT), scum formation on the substrate surface and suspended solid accumulation at high inflow velocity. Therefore, in view of the disadvantages raised, the conventional UASB reactor was modified by introducing a synthetic grass as attached growth with large surface area for microbial attachment and a filter within the reactor to reduce sludge washout along with suspended solid to overcome the stated problems. The aim of this work was to determine the biochemical methane potential (BMP) of the cattle slaughterhouse wastewater (CSWW) and study the performance of conventional R1 and a modified R2 UASB reactors treating the CSWW in terms of water quality output at different organic loading rate (OLR). Due to the potential of the CSWW to produce energy, the work further evaluates the performance of the system at varied OLR and constant hydraulic retention time (HRT) with respect to biogas production. Studies have consistently shown that UASB reactors usually requires post treatment of the effluent in order to comply with standard discharge limits and as such, the work further examine the effect of increasing HRT on the best performing reactor in order to determine the optimum HRT to which substantial amount of organic matter will be anaerobically degraded. The BMP test result showed that ratio 1:1 produced the highest biogas with a specific methane production (SMP) of 0.25 $LCH_4/gCOD_{removed}$, while the performance of the laboratory scale conventional (R1) and a modified (R2) UASB reactors treating CSWW under mesophilic condition (35°C) revealed that both reactors achieved COD and BOD removal efficiency (> 90 %) between OLR 1.75, 3, 5 g $L^{-1}d^{-1}$, and the methane composition was found as 71, 67, and 72 % in R1, while R2 stood 88, 83, and 85 % respectively. The corresponding specific methane production (SMP) in R1 were 0.21, 0.15, 0.12 LCH_4/g COD_{added}, while R2 recorded 0.28, 0.19, and 0.18 LCH_4/g COD_{added} respectively. However, increasing OLR to 10 g $L^{-1}d^{-1}$ increases the biogas production and COD removal efficiency of R2 at 24 HRT, on the other hand an overall decrease in monitoring parameters of R1, with COD removal, biogas and methane production being 48 %, 8 L/d, and 44 %. Comparatively, the UASB reactor R2 showed high tolerance to increasing OLR and found to be more stable than reactor R1 under the same OLR. This could be due to lower VFA concentrations in R2, especially acetic, propionic and butyric acids than in the reactor R1. Scanning electron microscopy (SEM) analysis showed that R2 was dominated by *Methanosarcina* bacterial species, while R1 revealed a sludge with insufficient microbial biomass. Moreover, increasing HRT in R2 consistently removed over 90 % COD, with a biogas and methane production reaching 38 L/d and 85 % after 48 h. Coccoidal shaped *Methanosarcina* microbial population were predominant at the end of performance study of the R2. Furthermore, a steady-state mathematical model developed based on the Monod and modified Stover-Kincannon for bacterial growth, were describe the data obtained from the modified UASB reactor R2. The best fit values was found with the Modified Stover-Kincannon model with a high correlation coefficient (R2 > 0.99). The present study revealed that the UASB reactor R2 has excellent removal efficiency compared to conventional UASB reactor R1, in the treatment of CSWW. A comparison of conventional and a modified upflow anaerobic sludge blanket (UASB) reactors highlighted the advantage of the modified system over conventional and other comparable technologies. The anaerobic modified bioreactor achieves much better performance than would be seen if conventional anaerobic systems were used in the treatment of cattle slaughterhouse wastewaters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

BIOLOGI RAWATAN AIR SISA BUANGAN RUMAH SEMBELIHAN LEMBU DAN PENGHASILAN BIOGAS MENGGUNAKAN REAKTOR ALIRAN ANAEROBIK LIMPAHAN ENAP CEMAR (UASB)

Oleh

MOHAMMED ALI MUSA

Februari 2020

Pengerusi : Profesor Madya Syazwani Idrus, PhD
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Rumah sembelihan lembu menjana air sisa yang kaya dengan bahan pencemar organik dan nutrien serta dianggap sebagai air sisa berkepekatan tinggi yang mana mampu menjadi sumber berpotensi untuk proses rawatan perolehan tenaga. Kompleks penyembelihan di Shah Alam tidak mempunyai kemudahan rawatan air sisa yang lengkap dan berkesan, terutamanya untuk perolehan tenaga. Kesannya, sejumlah besar efluen yang sangat sulit dengan kandungan Keperluan Oksigen Kimia (*Chemical Oxygen Demand*, COD) (32,000 mg/L), Keperluan Oksigen Biokimia (*Biochemical Oxygen Demand*, BOD) (17,158 mg/L), kandungan lemak, minyak dan gris (Fats, Oil and Grease) (1,024 mg/L), kadar keamatan warna (Colour) (16,426 Pt-Co) dan kekeruhan (12,500 FAU) dibebaskan ke dalam permukaan air. Walau bagaimanapun, Jabatan Alam Sekitar Malaysia (DOE) telah menetapkan had piawai bagi standard jenis A (COD = 120 mg/L) dan B (COD = 200 mg/L) untuk dipatuhi oleh setiap pengguna yang menghasilkan sisa buangan sebelum dilepaskan sebagai air sisa. Secara konvensional, kaedah rawatan air kumbahan bagi kawasan perbandaran adalah sama dengan rawatan air sisa dari pusat penyembelihan haiwan ternakan lembu. Ini termasuk kaedah rawatan Fizikokimia dan Biologi. Kaedah Fizikokimia merangkumi pengapungan larutan udara (*Dissolve Air Floatation*, DAF), pengumpalan-pengelompokan dan pemendapan, proses elektrokoagulasi dan teknologi membran. Walau bagaimanapun, kelemahan utama kaedah fizikokimia termasuk penggunaan tenaga yang intensif, isipadu pengeluaran enapcemar yang besar, pelaburan, kos operasi dan kos penyelenggaraan yang tinggi serta infrastruktur yang kompleks. Kaedah rawatan biologi merangkumi anaerobik, aerobik, kolam fakultatif, proses pengaktifan enapcemar dan pengaliran penapis. Di antara kaedah rawatan biologi, pencernaan anaerobik dengan menggunakan reaktor Aliran Anaerobik Limpahan Enap Cemar (UASB) merupakan aliran konvensional yang lebih menyakinkan. Walau bagaimanapun, kelemahannya yang berpunca daripada tempoh penyesuaian yang lama disebabkan oleh pertumbuhan mikroorganisma yang perlahan, pengaliran keluar enapcemar ketika tempoh tahanan hidraulik (*Hydraulic Retention Time*, HRT) pada kadar yang rendah, pembentukan

kekam pada permukaan substrat dan pengumpulan pepejal terampai pada halaju aliran masuk yang tinggi. Oleh itu, dengan mengambil kira segala kelemahan yang telah dinyatakan, reaktor UASB konvensional telah diubahsuai untuk mengatasi masalah tersebut. Matlamat kajian ini adalah untuk mengenalpasti akan potensi metana biokimia (BMP) daripada air sisa sembelihan lembu (CSWW) dan mengkaji prestasi reaktor UASB konvensional R1 dan reaktor UASB yang diubahsuai R2 bagi merawat CSWW dari segi kualiti air pada kadar muatan organik (Organic Loading Rate, OLR) yang berbeza. Disebabkan air kumbahan ini berpotensi untuk menghasilkan tenaga, kajian diteruskan dengan menilai prestasi sistem pada kadar muatan organik (OLR) pada pelbagai tempoh tahanan hydraulik (HRT) yang tetap berdasarkan kepada penghasilan biogas. Hasil daripada kajian mendapati efluen yang telah dirawat dari reaktor UASB masih memerlukan rawatan lanjutan bagi mematuhi had piawai pembebasan sisa yang telah ditetapkan dan oleh itu, penyelidikan diteruskan lagi dengan mengkaji kesan peningkatan HRT ke atas prestasi reaktor yang lebih baik bagi menentukan HRT yang optimum di mana bahan organik terurai dengan lebih baik. Keputusan ujian BMP menunjukkan pada nisbah 1:1 menjana biogas dengan penghasilan khusus metana (SMP) tertinggi 0.25 $LCH_4/gCOD_{removed}$, sementara prestasi reaktor konvensional berskala makmal (R1) dan reaktor UASB diubahsuai (R2) merawat CSWW dalam persekitaran suhu mesophilic (35 °C) menunjukkan bahawa kedua-dua reaktor mencapai kecekapan penyingkiran COD dan BOD (> 90%) antara OLR 1.75, 3 dan 5 g $L^{-1}d^{-1}$ dengan komposisi gas metana masing-masing sebanyak 71%, 67% dan 72% dalam R1, manakala R2 berjumlah 88%, 83% dan 85%. Penghasilan khusus metana (SMP) pada R1 adalah 0.21, 0.15 dan 0.12 LCH_4 /g COD_{added}, manakala R2 mencatatkan 0.28, 0.19, dan 0.18 LCH_4 /$gCOD_{added}$. Walau bagaimanapun, peningkatan OLR kepada 10 g $L^{-1}d^{-1}$ meningkatkan penghasilan biogas dan kecekapan penyingkiran COD dari reaktor R2 dalam 24 jam HRT, tetapi penurunan keseluruhan parameter bagi reaktor R1, masing-masing dengan peratusan penyingkiran COD, isipadu biogas dan penghasilan metana menjadi 48%, 8 L/d, dan 44%. Jika dibandingkan, reaktor UASB R2 menunjukkan toleransi yang tinggi dalam peningkatan OLR dan didapati lebih stabil daripada reaktor R1 di bawah OLR yang sama. Ini terbukti dengan kandungan VFA yang lebih rendah dalam R2, terutamanya asid asetat, propionik dan butyric berbanding dalam reaktor R1. Analisis pengimbasan mikroskopi elektron (SEM) menunjukkan bahawa R2 dikuasai oleh spesies bakteria Methanosarcina, sementara R1 mendedahkan enapcemar dengan biomassa mikrob yang tidak mencukupi. Lebih-lebih lagi, peningkatan HRT di R2 secara konsisten mengeluarkan lebih daripada 90% penyingkiran COD, dengan pengeluaran biogas dan metana mencapai 38 L/d dan 85% selepas 48 jam. Coccoidal berbentuk Methanosarcina sp. adalah populasi mikroorganisme utama pada akhir kajian prestasi R2. Tambahan pula, model matematik tetap telah dicipta berdasarkan model yang dibangunkan oleh Monod dan Stover-Kincannon yang diubahsuai dan digunakan untuk menerangkan data yang diperoleh dari R2. Nilai fit terbaik dibuktikan dengan model Stover-Kincannon yang diubah suai dengan koefisien korelasi yang tinggi (R2> 0.99). Kajian ini menunjukkan bahawa reaktor UASB R2 mempunyai kecekapan penyingkiran yang sangat baik berbanding reaktor UASB R1 konvensional dalam rawatan CSWW.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AD	Anaerobic digestion
BMP	Biochemical methane potential
COD	Chemical oxygen demand
BOD	Biochemical oxygen demand
TSS	Total suspended solid
VSS	Volatile suspended solid
FOG	Fats, oil, and grease
TN	Total nitrogen
SG	Synthetic grass
CSWW	Cattle slaughterhouse wastewater
SWW	Slaughterhouse wastewater
SMP	Specific methane production
SEM	Scanning electron microscopy
OLR	Organic loading rate
HRT	Hydraulic retention time
VFA	Volatile fatty acid
TA	Total alkalinity
PA	Partial alkalinity
IA	Intermediate alkalinity
EDX	Energy-dispersive X-ray
UASB	Upflow anaerobic sludge blanket
AL	Anaerobic lagoons
DOE	Department of Environment
SRT	Solid retention time
UF	Ultrafiltration
MF	Membrane filtration
NF	Nanofiltration

RO	Reverse Osmosis
FBR	Fluidizing bed reactor
AFBR	Anaerobic fluidizing bed bioreactor
MBBR	Moving bed bioreactor
SGBR	Static granular bed reactor
SASBR	Static anaerobic sludge bed reactor

CHAPTER I

INTRODUCTION

1.1 Background

The demand for effective treatment of high-strength industrial wastewater has increased over time, due to the effects related to environmental pollution. Cattle slaughterhouses are among the food industries that utilizes considerable amount of freshwater and produce a large volume of wastewater that is rich in organic contaminants and nutrients (Jensen et al., 2014). Wastewater produced during slaughter and cleaning processes usually consists of the animal fats, blood, urine, feces, soil from hides, soft tissue removed during trimming, and cleaning and sanitizing compounds (U.S. EPA., 2004). According to Abdeshahian et al. (2016), data recorded in the year 2012 showed that cattle slaughterhouse blood generated in peninsular, Sabah, and Sarawak Malaysia stood at 270.17, 2.43 and 1.97 million m^3 yr^{-1} with a high potential for biogas production.

Discharge of untreated slaughterhouse wastewater (SWW), constitutes a severe threat to public health and the environment (Barrera et al., 2012). Although rivers have the natural cleansing capacity, the frequent release of such effluent without being adequately treated might overburden the receiving water body. The volume of water consumption per animal slaughtered varies according to the type of animals and the process used. Ahmadian et al. (2012) and Claudia et al. (2002) have reported values between 1.0 to 8.3 m^3 and 0.4 to 3.1 m^3, respectively. Furthermore, SWW usually contains high chemical oxygen demand (COD), biological oxygen demand (BOD_5), suspended solids (SS), nitrogen, and phosphorus (Bustillo-Lecompte et al., 2013). For instance, the research of Jensen et al. (2014) have reported a contaminant concentration from two different sites (A and E). These include the chemical oxygen demand (COD) (12,893 ± 6052 and 12,460 ± 2874 mg/L), total solid (TS) (8396 ± 4160 and 7400 ± 1330 mg/L), fats, oil and grease (FOG) (2332 ± 416 and 1200 ± 510 mg/L), total nitrogen (TN) (245 ± 44 and 272 ± 39 mg/L) and total phosphorus (TP) 53 ± 12 and 47 ± 8 mg/L). However, the strength could differ from one industry to another, owing to the number and type of animals slaughtered. Moreover, the high concentration of color and nitrogen in the SWW could also impede light penetration and encourage an algal boom that could lead to eutrophication (Kundu et al., 2013). Discharge of improperly treated high-strength wastewater has mandated stakeholders at both national and international levels to intervene. Most of the interventions yielded standard rules and regulatory discharge limit requirements. Table 1.1 presents the prominent characteristics of meat processing wastewater effluent and its limits from various jurisdictions worldwide.

Table 1.1 : Comparison of standard limits for slaughterhouse wastewater discharge from different jurisdictions worldwide (Bustillo-Lecompte and Mehrvar, 2017)

Parameter	World Bank	EU	USA	Canada	Colombia	China	India	Australia
BOD (mg/L)	30	25	16-26	5-30	50	20-100	30-100	5-20
COD (mg/L)	125	125	n.a	na	150	100-300	250	40
TN (mg/L)	10	10-15	4-8	1.25	10	15-20	10-50	10-20
TOC (mg/L)	n.a	n.a	n.a	n.a	n.a	20-60	n.a	10
TP (mg/L)	2	1-2	n.a	1.00	n.a	0.1-1.0	5	2
TSS (mg/L)	50	35-36	20-30	5-30	50	20-30	100	5-20
pH	6-9	n.a	6-9	6-9	6-9	6-9	5.5-9	5-9
Temperature (℃ change)	n.a	n.a	n.a	< 1℃	n.a	n.a	< 5℃	< 2℃

Malaysia is not an exception to this type of regulation. For instance, 120 mg/L and 200 mg/L are the COD standard A and B acceptable limits allowed for all intending investors capable of generating wastewater that could be discharged as sewage into a receiving water body, as shown in Table 1.2.

Table 1.2 : Malaysia acceptable standard A and B of wastewater discharge limitations (Department of Environment Ministry of Natural Resources and Environment, 2010)

Parameter	Unit	Standard	
		A	B
Temperature	˚C	40	40
pH value	-	6.0-9.0	5.5-9.0
BOD_5 at 20˚C	mg/L	20	50
COD	mg/L	120	200
Suspended solids	mg/L	50	100
Oil and grease	mg/L	5.0	10.0
Ammonical-Nitrogen (enclose water body)	mg/L	5.0	5.0
Ammonical-Nitrogen (river)	mg/L	10	20
Nitrate –Nitrogen (river)	mg/L	20	50
Nitrate –Nitrogen (enclosed water body)	mg/L	10	10
Phosphorus (enclosed water body)	mg/L	5	10

Note: Standard A for the discharge of upstream of water supply intake points/sensitive areas. Standard B used for discharge of downstream of water intake points/any other areas that do not fall under Standard B.

Conventionally, slaughterhouse wastewater (SWW) treatment methods are similar to current technologies used in municipal wastewater treatment. These include lagoon and ponds systems, sedimentation and floatation, coagulation/flocculation, adsorption, membrane technology, dissolve air, and other advanced oxidation processes (Bustillo-Lecompte and Mehrvar, 2015). However, several researchers have specifically reported diff erent methods of slaughterhouse wastewater treatment that works as an entity and a combined operation. Such works include aerobic/anaerobic (Johns, 1995; Massé and Masse, 2001; Bernet et al., 2000), fixed-bed reactor (Saddoud and Sayadi, 2007) anaerobic/aerobic (An/Ar) system (comprising of an anaerobic filter (AF) coupled to anaerobic sequential batch reactor (SBR)) (López-López et al., 2010) and fixed-bed granular sludge with/without static activated sludge (Debik and Coskun, 2009). However, most of the studies have consistently shown the numerous drawbacks, ranging from a large area of space requirement, the massive volume of sludge generation, intensive use of energy for aeration, and the high overall cost of maintenance (Bustillo-Lecompte and Mehrvar, 2015; Chan et al., 2009).

Anaerobic digestion using upflow anaerobic sludge blanket reactors (UASB) has now become a promising technique for the treatment of wastewater from food processing industries (Daud et al., 2018), due to its efficiency, flexibility, smaller footprint with less maintenance, and high-quality effluent. Moreover, the condition at which the UASB reactor operates plays a vital role in the performance of the bioreactor. For instance, the study of Kwarciak-Kozłowska et al. (2011), revealed high COD and BOD5 removal efficiencies of 85% and 82% at 6-day HRT, respectively. With the shortened HRT, the removal of organic contaminants decreased, and the average production of biogas decreased with an increase in HRT. The fermentation process of the wastewater was highly characterized by high methane content (75 %). However, from the economic point of view, the hydraulic retention time (HRT) applied to the system was too long. Mittal (2006), reported a UASB reactor with an average COD removal efficiency of 80–85 % and is very much efficient when operated at an organic loading rate (OLR) of 2.7–10.8 kg COD m^{-3} day^{-1}. In another development, slaughterhouse wastewater removal efficiency of 90 % was revealed by Mijalova Nacheva (2011), at a high OLR of 15 kg COD m^{-3} day^{-1}. Most interestingly, the UASB reactor operation was carried out at ambient temperature (20.9-25.2°C). Furthermore, a comparative study between hybrid UASB and anaerobic filter (AF) was revealed by Rajakumar and Meenambal (2008), using poultry wastewater under similar conditions of loading. The result of the experiment shows a high COD and soluble chemical oxygen demand (SCOD) removal efficiencies of 80 % and 86 % in the UASB reactor as compared to 70 % COD and 79 % SCOD in the AF. However, reducing hydraulic retention time (HRT) of both reactors from an optimum of 12 h to 10 h resulted in sludge washout and lower COD removal efficiencies to less than 80 % in the UASB and 66 % in the AF. The potential of UASB reactors in the treatment of mainly liquid wastewater was reported at full, pilot, and laboratory scales. The various types of wastewater tested ranged from slaughterhouse wastewater (SWW), dairy, wine distillery, palm oil mill, and municipal wastewater (Latif et al., 2011). The use of a UASB reactor for treating wastewater is already a well-established technology. However, researchers have consistently reported problems related to high suspended solids, slow-growing bacteria, surface scum formation, and sludge washed out along with the large population of the microbial community. In addition, as the FOG builds up, it limits the free flow in the pipe and can cause untreated wastewater to return to homes and businesses, resulting in a high cost of cleaning and restoration. Therefore, there is a need to modify a conventional UASB reactor in order to overcome the stated problems. The overall aim is to examine the performance efficiency of the two UASB reactors (conventional and modified) in terms of biogas production and effluent quality and to use the most eff ective result obtained between the two to serve as the basis for UASB bioreactor design in cattle slaughterhouses.

1.2 Problem Statements

Commercial cattle slaughterhouse wastewater is considered as high strength industrial wastewater due to high chemical oxygen demand COD, biological oxygen demand BOD, fats, oil and grease (FOG), and total suspended solids (TSS). Discharge of untreated and improperly treated slaughterhouse into a receiving water body affects the quality of water mainly by introducing macronutrients (nitrogen and phosphorus). Thus, resulting in excessive growth of algae in the receiving water surface and reduction dissolve oxygen supply to the aquatic environment. Consequently, the absence of dissolved oxygen supply to the aquatic environment could result in the death of the aquatic animals as a result of eutrophication. Eutrophication effect subjects the aquatic environment to anaerobic condition leading to the release of a large amount of methane (CH_4) and carbon dioxide (CO_2) freely into the atmosphere. The release of these gases forms a large portion of the greenhouse gases.

A reasonable proportion of these greenhouse gas emissions are related to the uncontrolled degradation of organic matter contained in the increasing amount of human-produced waste (Flores-Juarez et al., 2014; Aryal and Kvist, 2018; Delre et al., 2017). Moreover, the high concentration of color in the SWW could also impede light penetration to the aquatic environment. Furthermore, the general public health related to the discharge of untreated CSWW into water bodies is the transmission of pathogenic microorganisms to humans through direct contact with people working within the slaughterhouses or indirect interaction by the community that is using the water for cleaning, swimming or irrigation purposes. Moreover, developing countries like Africa and Asia have experienced bloody diarrhea, gastrointestinal diseases, and in some cases, death is associated with the presence of viruses, protozoa, helminthic eggs, and bacteria in SWW. Komplex Abattoir shah Alam located in Selangor, Malaysia, is discharging high strength cattle slaughter wastewater with an average COD (32,000 ± 112 mg/L), BOD (17,158 ± 95 mg/L) and TSS concentration of (22,300 ± 212 mg/L). This wastewater is discharged into a receiving water body without treatment.

The most commonly applied treatment technology for SWW, especially from the economic point of view, is the upflow anaerobic sludge bed UASB reactor. In most cases, this type of reactor is employed due to its ability to generate energy in the form of biogas, less sludge production, able to handling high organic loading rate and the overall low operation and maintenance cost. However, application of UASB reactor in the treatment of wastewaters from abattoir industries is still incipient, owing to the shortcomings of insoluble organic materials, frequent biomass loss due to sludge washout at low HRT and consequently, a decline in the reactor performance. Furthermore, UASB reactor is highly characterized by slow-growing microorganisms and scum formation that hinders the free flow of biogas out the reactor. Therefore, modification of the UASB reactor is required to overcome the existing deficiencies, especially during the treatment of high strength wastewater like the cattle slaughterhouse wastewater (CSWW). In this work, a comparative study was conducted between conventional and a modified UASB reactor. The modification was carried out by coupling a round synthetic grass (SG) covering the entire sludge zone to serve as an attached growth. The SG is employed in order to provide rough and large surface area suitable for microbial growth as compared to a system without attached growth or with flat surface area. Furthermore, the application of the synthetic grass significantly encourage the multiplication of microbial population and shield them from washout during effluent discharge at short HRT. Also, a flat round plastic mesh attached with SG was introduced to stabilize the suspended solids. Therefore, the modified system is believed to provide a UASB reactor capable of overcoming the problems of the conventional UASB reactor.

1.3 Research Objectives

This study is aimed at providing an efficient alternative treatment system for high strength cattle slaughterhouse wastewater through the comparison of laboratory-scale conventional and modified UASB reactors in terms of organic loading rate and hydraulic retention time, and to study the effect of HRT on the most effective systems between the two.

The specific objectives are:

I. To determine the biochemical methane potential (BMP) of the cattle slaughterhouse wastewater and evaluate the performance of conventional (R1) and a modified (R2) upflow anaerobic sludge blanket (UASB) reactors in terms in terms of organic loading rate (OLR) and HRT with respect water quality parameters.
II. To investigate the effect of different OLR on biogas production, specific methane yield, and alkalinity ratio of the conventional R1 and the modified R2 UASB reactors at constant HRT (24 h).
III. To determine the optimum OLR of the reactors and optimize the system with the highest efficiency in term as of the biogas production and the water quality parameters by increasing the HRT.

1.4 Scope and Relevance

This work aims at examining the biodegradability of cattle slaughterhouse wastewater (CSWW) and evaluation of the performance of a laboratory scale conventional R1 and modified R2 UASB reactors treating the CSWW. The scope and relevance of the study is as follows:

I.

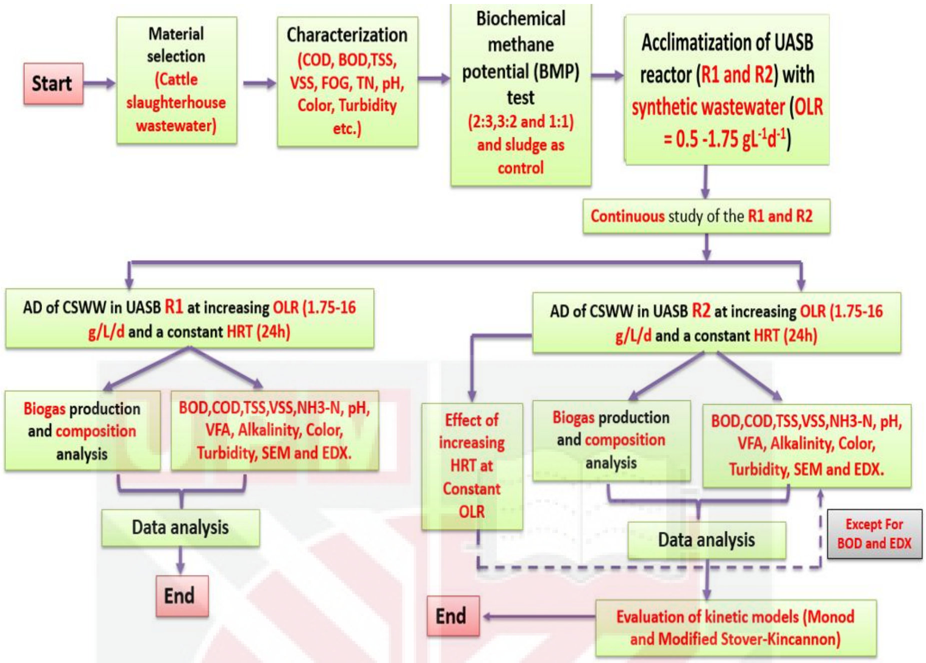

Figure 1.1 : Process flow chart of the research scope

II. Slaughterhouse wastewater (SWW) is considered as high strength industrial wastewater due to high chemical oxygen demand, biological oxygen demand, fats, oil and grease, and total suspended solids. Discharge of untreated and improperly treated slaughterhouse wastewater into water bodies may affect the quality of water and eutrophication. Several technologies are available to reduce the industry's emissions and energy costs. Among these technologies, anaerobic digestion (AD) is considered as a potential solution to reduce GHG emissions and energy costs. Anaerobic digestion is a sustainable environmental technology that is well established in Europe for organic waste management and to produce renewable energy in the form of biogas. The produced biogas can be used for cogeneration of heat and electricity (CHP), or can be upgraded into bio-CNG for transport use. In addition, the nutrient rich digestate can be used or sold as valuable organic fertilizer substitute or soil amendment.

III. The most commonly applied treatment technology for SWW, especially from the economic point of view, is the use of high rate reactor process such as UASB reactor technology. In most, cases this type of reactor is employed to generate energy in the form of biogas and to meet the standard water quality discharge limit set by the regulatory bodies. However, application of UASB reactor in the treatment of wastewater from abattoir industries is still incipient, owing to the shortcomings of insoluble organic matter coupled with biomass and sludge washout of the reactor at low HRT due to lack proper attached growth material to retained large microbial population, a decline in the biogas yield, the slow growing microorganisms and high scum formation that hinders the free flow of biogas out of the reactor. Therefore, modification of the UASB technology is required to overcome the existing deficiencies, especially during the treatment of high strength wastewater like cattle slaughterhouse wastewater (CSWW).

IV. This thesis investigates and present a comparative study carried out between conventional and a modified UASB reactor. In the modified UASB technology, synthetic grass (SG) was used as carrier material for microbial attachment. In addition a flat round plastic mesh (Filter) was attached to SG to provide a UASB reactor capable of overcoming the problems of washout of sludge along with the microbial biomass, noticed in the conventional UASB reactor.

1.5 Significance of the Study

There is incomplete or limited data on the CSWW in Malaysia and the Shah Alam abattoir in particular. Therefore, this study is significant in providing information on the characteristics of CSWW, its energy potentials, and suitable treatment for reducing the high concentration of pollutants. The study also presents a fundamental knowledge for the treatment of slaughterhouse wastewater in Malaysia in avoidance of potential risk to health and environment-related problems. Furthermore, thorough knowledge and understanding of the waste characteristic could help the concern authorities to relate between what is discharged to the environment and the standard permissible limits, like those set by the Department of Environment (DOE) in Malaysia for all intending investors capable of generating waste and discharge as sewage to the environment.

The study could also help improve the knowledge of environmentalist and plant operators', especially in the CSWW industry. UASB reactors is an established system of wastewater treatment and biogas production for many decades. However, most literature reported problems of slow-growing bacteria, scum formation, and sludge washout. Therefore, it is paramount to improve the system. Modification of convention UASB reactor was carried out by attaching an SG from the bottom of the reactor to a point little below the effluent outlet, a top flat-round perforated PVC coupled with SG was used to provide a better settling due to upflow velocity. With these, it is expected that the modified reactor is easier and simple to operate and more cost-effective with high-performance efficiency capable of overcoming the problems of convention UASB reactor. The result can be used across various strategies as benchmark evidence for future studies on successful methods of treatment for other high-strength wastewater in Malaysia. Additionally, this research might help in the decision-making processes of developing commercial-scale UASB reactors in slaughterhouses.

1.6 Thesis Organization

This thesis is structured into five (5) chapters, i.e., 'introduction,' 'literature review,' 'methodology,' 'results and discussions,' and finally 'conclusion and recommendation' with the appendices at the end. Chapter 1 covers the basic background and problems that necessitate the investigation. Also, the chapter covers the objectives, scope, and significance of the research. Chapter 2 deals with a comprehensive review of anaerobic digestion processes and the major factors affecting its operations. It also includes the previous work on slaughterhouse wastewater treatment and the different bioreactors employed for the anaerobic treatment. Chapter 3 of the thesis covers the materials and methodology used in the study. While Chapter 4 presented the findings and thorough discussion of the results. The development of anaerobic digestion model and the kinetic parameters fitted to the optimized reactor as well as the implication of the findings. Chapter 5 which is the final chapter deals with the overall summary of the findings and suggestions for further modifications and improvement.

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LIST OF PUBLICATIONS

Musa, M. A., Idrus, S., Che Man, H., Daud, N., and Norsyahariati, N. (2019). Performance comparison of conventional and modified upflow anaerobic sludge blanket (UASB) reactors treating high-strength cattle slaughterhouse wastewater. *Water*, *11*(4), 806. https://doi.org/10.3390/w11040806 (Q1)

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