PERFORMANCE OF SEED SLUDGE ACCLIMATIZED SYNTHETIC WASTEWATER IN TREATING CHICKEN SLAUGHTERHOUSE WASTEWATER USING UPFLOW ANAEROBIC SLUDGE BLANKET.

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 Master of Science.

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Chicken slaughterhouses generate wastewater rich in organic content and are considered high organic load wastewater, becoming a suitable feedstock for treatment processes that generate electricity. Improper treatment of chicken slaughterhouse wastewater (CSWW) has created severe environmental deterioration especially in surface water. Various treatments have been implemented to treat slaughterhouse wastewater such as dissolved air floatation, coagulation and flocculation processes, conventional activated sludge, lagoon and pond systems, and anaerobic digestion (AD) but meeting limitations to achieve efficiency. Thus, Upflow Anaerobic Sludge Blanket (UASB) reactor was introduced to be the best method for anaerobic treatment. The common drawback in the UASB reactor is the slow start-up process at the early stage of treatment, where the system requires well-developed microorganisms in the seed sludge to degrade the waste. In this study, two sets of UASB reactors, named UASB 1 and UASB 2 were employed to study on the effect of acclimatized seeding sludge using synthetic wastewater (SWW) on reactor process performance and energy generation in treating CSWW. In UASB 1, acclimatization process was not applied on seeding sludge for monitoring purposes, while the seed sludge in UASB 2 was acclimatized using SWW for 30 days. After the acclimatization stage reached a stable state, both bioreactors were fed with the same CSWW at the same organic loading rate (OLR) from 0.5 g/L/day to 6 g/L/day with hydraulic retention time (HRT) of 24 hours and under mesophilic condition (37°C). The Chemical Oxygen Demand (COD) removal efficiencies of UASB 2 were more than 90 % throughout the steady-state of the OLR added. This is equivalent to Specific Methane Production (SMP) of 0.27 $LCH_4/gCOD_{added}$ recorded at the optimum OLR of 5 g/L/day in UASB 2 compared to the overall performance observed in the UASB 1. Other parameters such as pH, alkalinity, total ammonia nitrogen (TAN), total suspended solid (TSS), fats, oil and grease (FOG), and colour intensity were analysed to evaluate on the system stability in both reactors. UASB 1 showed some distress in the system when the feeding reached OLR 5 and 6 g/L/day compared to UASB 2, showing stable condition throughout the study. The reactor which contains the acclimatized seed sludge successfully produced a significant methane yield and sufficient removal of COD in the

effluent, which met the standard addressed by the Department of Environment Malaysia. The acclimatized seed sludge has fastened the start-up process for the bioreactor with only 30 days compared to other studies as it developed an adequate microorganism to degrade the CSWW. Energy generation for laboratory scale (LS) bioreactor and commercial scale (CS) bioreactor were calculated at 0.0186 kWh and 181.78 kWh per day respectively, using data from optimum performance in UASB 2. This shows that the UASB reactor in CS treating CSWW with acclimatized seed sludge is able to cover the electrical energy required for the chicken slaughterhouse operation of 44 kWh.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PRESTASI ENAP CEMAR DIAKLIMATISASI OLEH AIR SISA SINTETIK DALAM MERAWAT AIR SISA RUMAH SEMBELIHAN AYAM MENGGUNAKAN LAPISAN ENAP CEMAR ANAEROBIK ALIRAN NAIK.

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Rumah penyembelihan ayam menghasilkan air sisa kaya dengan bahan cemar organik dan nutrien dianggap sebagai air sisa berkekuatan tinggi dan berpotensi untuk proses rawatan yang memulihkan tenaga. Kurangnya amalan pengurusan air sisa penyembelihan ayam (CSWW) yang baik menyebabkan pencemaran ke dalam sumber air. Berbagai rawatan telah dilaksanakan untuk mengolah air buangan penyembelih seperti enapcemar aktif konvensional, pengapungan udara terlarut, sistem lagun dan kolam, proses pembekuan dan flokulasi dan pencernaan anaerobik (AD) tetapi berhadapan dengan beberapa batasan untuk mencapai kecekapan. Oleh itu, reaktor Lapisan Enap Cemar Anaerobik Aliran Naik diperkenalkan sebagai metod yang terbaik dalam rawatan anaerbik, namun kelemahan yang biasa ditemui dalam UASB reaktor ini adalah proses permulaan rawatan yang lama dimana ia memerlukan sisa enap cemar yang mempunyai kandungan mikroorganisma yang cukup bagi merawat sisa. Dalam kajian ini, dua set reaktor UASB, dinamakan sebagai UASB 1 dan UASB 2 digunakan untuk mengkaji kesan aklimatisasi enapcemar menggunakan air sisa sintetik (SWW) terhadap prestasi bioreaktor dan pemulihan tenaga dalam merawat CSWW. Dalam UASB 1, tiada proses aklimatisasi yang diterapkan pada enapcemar bagi tujuan perbandingan, manakala enapcemar di UASB 2 diaklimatasi menggunakan SWW selama 30 hari. . Setelah tahap aklimatisasi mencapai kestabilan, kedua-dua reaktor diberikan CSWW yang sama dengan kadar muatan organik (OLR) 0.5 hingga 6 g/L/sehari dengan masa tahanan hidraulik (HRT) 24 jam dan keadaan mesofilik (37°C). Penurunan COD UASB 2 melebihi 90% sepanjang keadaan stabil OLR ditambah. Ini setara dengan pengeluaran metana tetap (SMP) 0.27 LCH_4/gCOD direkodkan pada OLR optimum 5 g/L/sehari di UASB 2 dimana penurunan ketara dalam prestasi keseluruhan diperhatikan di UASB 1. Parameter lain seperti pH, kealkalian, jumlah nitrogen ammonia (TAN), pepejal terampai (TSS), lemak, minyak dan gris (FOG) dan intensiti warna dianalisis untuk menilai kestabilan sistem di kedua-dua reaktor. UASB 1 menunjukkan beberapa komplikasi dalam sistem ketika penambahan influen mencapai OLR 5 dan 6 g/L/sehari berbanding UASB 2 yang menunjukkan keadaan stabil sepanjang kajian. Reaktor yang mengandungi enap cemar diaklimatasi berjaya

menghasilkan hasil metana yang ketara dan penyingkiran COD dalam efluen, dan mematuhi piawai pembuangan air yang ditetapkan oleh Jabatan Alam Sekitar (DOE) Malaysia. Enapcemar yang diaklimatasi telah mempercepatkan proses permulaan untuk bioreaktor dengan hanya 30 hari berbanding kajian lain dimana ia menggalakkan pertumbuhan mikroorganisma yang mencukupi untuk merawat CSWW. Pemulihan tenaga untuk bioreaktor skala makmal dan yang diunjurkan untuk bioreaktor skala komersial masing-masing memperoleh 0.0186 kWh dan 181.78 kWh sehari, menggunakan data dari prestasi yang baik di UASB 2. Ini menunjukkan reaktor UASB dalam skala komersial yang merawat CSWW dengan enapcemar yang diaklimatisasi mampu menjana tenaga elektrik yang diperlukan untuk operasi penyembelihan ayam sebanyak 44 kWh.

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All praises to Allah, Lord of the Universe, the Merciful for granting me the ability, knowledge, and strength to undertake this study and complete it successfully.

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Thank you, may Allah SWT return all the good deeds with the ultimate reward.

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

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CH_4	Methane
CS	Commercial Scale
CSWW	Chicken Slaughterhouse Wastewater
FOG	Fats, Oil and Grease
HRT	Hydraulic Retention Time
IA/PA ratio	Alkalinity ratio
IA	Intermediate Alkalinity
LCFA	Long Chain Fatty Acid
LS	Laboratory Scale
OLR	Organic Loading Rate
PA	Partial Alkalinity
PSW	Poultry Slaughterhouse Wastewater
SMP	Specific Methane Production
SWW	Synthetic Wastewater
TAN	Total Ammonia Nitrogen
TSS	Total Suspended Solid
UASB	Upflow Anaerobic Sludge Blanket
VFA	Volatile Fatty Acid
VSS	Volatile Suspended Solid

CHAPTER 1

INTRODUCTION

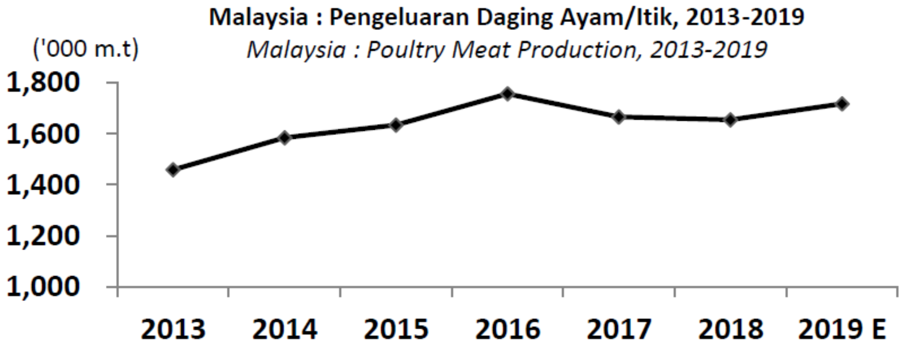
1.1 Research background

The domestic slaughtering industry in Malaysia has been around since before the war, where it was first introduced into the Malay Peninsular by the early immigrants in their journey from South China to the Malay Archipelago. There are chances that early Malays initially only brought poultry, pigs, goats, and sheep, then later the buffalo and cows. At least six slaughterhouses were built during this time and the number is growing rapidly in parallel with the population throughout the years (Babjee, 1994). Now, Malaysia has a variety of livestock and breed species. These include native breeds, adapted breeds and breeds continuously imported from other countries (Department of Veterinary Services, 2016). Production from the slaughtering focuses on two major industries: the ruminant (cattle, buffalo, goat, sheep, camel and deer) and non-ruminant (chicken, duck, geese, turkey, pigeons and pig). A ruminant is an animal with four stomach cavities. They throw out their undigested food and regurgitate it for better digestion. Non-ruminant mainly refers to 'birds' of any age or sex with a simple single-chambered stomach (Department of Islamic Development Malaysia, 2011).

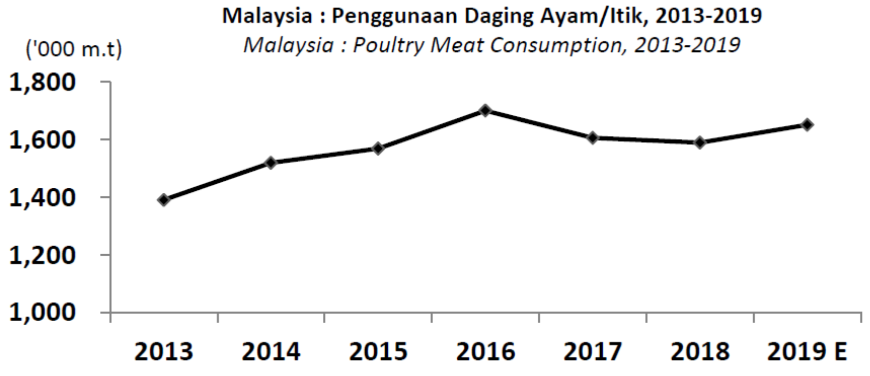
The ruminant industry is mostly run on a small scale. They only target the surrounding consumer market, compared to the non-ruminant, especially poultry, whose products were advertised in several local markets and neighbouring countries (M. Mazuan & Zalina, 2018). The non-ruminant industry is quite progressive as it dominates with large scale production and contributes more than 80% of the livestock in the country. The production of poultry meat in 1960 was recorded at only 21,273 metric tons and increased to 944,840 metric tons in 2006, with the percentage of 82.9% of production compared to other livestock such as beef, mutton and pork with the percentage of 2.3%, 0.1% and 14.8% respectively (Mohamed et al., 2013).

The growth of population in Malaysia bring about the massive production of poultry meat to meet the market demand. According to the Department of Veterinary Services of Malaysia, in 2019, the livestock population specifically for poultry reached more than 270 million in total, with output from the product about 1,716,700 metric tons of poultry meat. It is estimated that the consumption of the poultry meat product is around 1,651,600 metric tons in total, which on average of 58.6 kg were consumed per capita.

Figure 1.1 (a) and (b) below illustrate the increment of poultry meat production and consumption from 2013 to 2019 in Malaysia. Therefore, since 1984, this industry itself has reached to a stage where it is self-sufficient and internationally competitive as about RM 4.0 billion was contributed by the sub-sector, roughly 76.8% (55.7% of poultry and 21.1% eggs) of the output of the livestock industry listed in Table 1.1 (Loh, 2002). In 2017, there was approximately 124 poultry slaughterhouse registered with the Department of Islamic Affairs Malaysia (JAKIM) where the awarding of the certificate are given into three categories; small, medium, and large scale, depending on the total of slaughtering per day in the premises (Mazuan & Zalina, 2018).



(a) Increment of poultry meat production from 2013 to 2019.



(b) Increment of poultry meat consumption from 2013 to 2019.

Figure 1.1: Production and Consumption of Poultry Meat, 2013-2019.
(Source: DVS, 2016)

Table 1.1: Gross Output Value of Livestock

Livestock	Value (RM million)	Contribution (%)
Poultry meat	2 903.0	55.7
Eggs	1 105.0	21.1
Pork	906.8	17.4
Beef	248.7	4.8
Mutton	12.9	0.2
Dairy	43.5	0.8
Total	5219.9	100

(Source: Loh, 2002)

In every industry specifically in livestock, the production related with slaughtering the animal leads to waste effluent with various concentrations of organic compounds containing diluted blood, protein, fat, and suspended solids. Figure 1.2 below portrays the condition in one of the chicken processing facilities in Selangor state and the effluent produced from the slaughtering activities. The liquid and solid residues from an increasing number of slaughterhouses may be significant in the future due to the two-fold increment of global meat production in the past decades (Bustillo & Mehrvar, 2017). Chicken processing can generate about 30:1 ratio of wastewater to Biochemical Oxygen Demand (BOD) with strength of 600 mg/l (Wheatley, 1991). Table 1.2 below shows the wastewater generated by other food industries and how significant chicken processing waste is compared to other food industries in European country.

Figure 1.2: Waste Effluent of Slaughterhouse at Seri Kembangan wet market in Selangor. (Photo by: Marzuki, 2019)

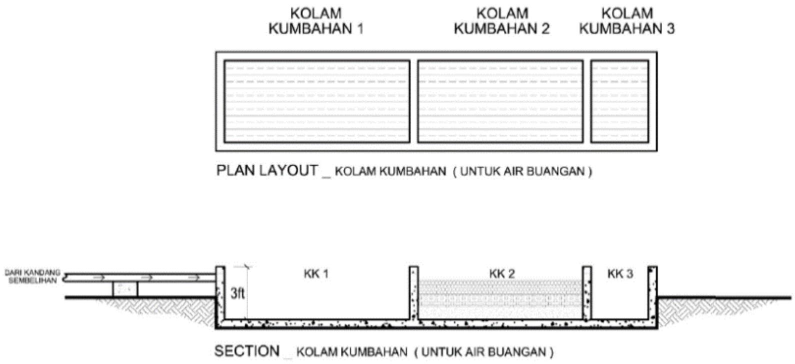
Table 1.2: Food Industry Wastewater in European Country

Industry	BOD (mg/L)	Water to 1 product ratio (L/unit)
Dairy	500 – 750	12
Butter and cheese	1500 – 2500	3.0
Distillery	1500 – 2000	20
Brewery	500 – 1500	8
Malting	2000 – 3000	15
Food canning	100 – 1300	10
Frozen peas	1000 – 2000	12
Chips and other vegetables	1000 – 1500	20
Chicken	600	30
Slaughter house (cattle)	1000 – 2000	20
Sewage	250	130 per head

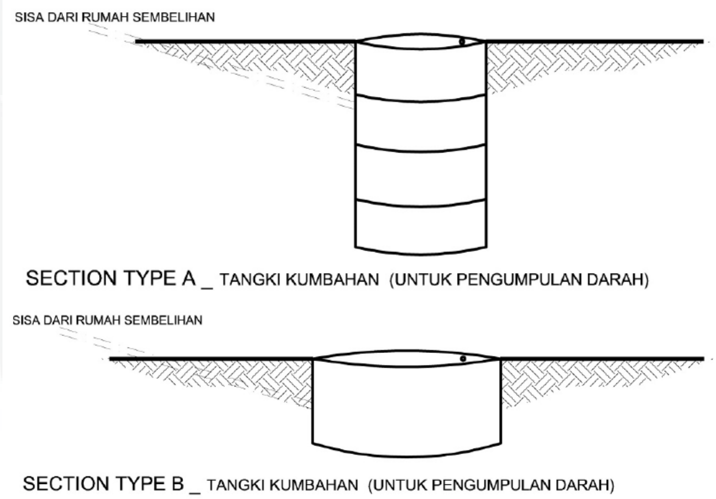
(Source: Wheatley, 1991)

Among other stream generated, slaughtering house contains the highest organic content ranging from 1500 mg/L to 16,000 mg/L and Total Suspended Solid (TSS) ranging from 300 mg/L to 11,000 mg/L depending on flow rates and composition of the effluent (Ruiz et al, 1997). Although it is described as non-toxic and non-polluting due to high oxygen demand, which is less harmful than industrial chemical effluent (Talukder & Selvakumar, 2015), the European legislation considered it as 'very contaminating' due to its medium to high concentration and partially solubilized residues that often lumped together as "flow materials" in wastewater discharge thus it may severely affect the riverbed or other water sources if it's not properly treated (Tritt & Schuchardt, 1992).

To avoid these effluents affecting the environment, the authorities and the public's attention and action is needed before it becomes worse. The Department of Veterinary Services has provided a complete manual for the local slaughterhouses. The manual includes guidelines on preparing and constructing a complete facility for waste management of slaughterhouse wastewater. Figure 1.3 below shows (a) the schematic plan of sewage pond for wastewater and (b) waste tank for collection of blood.



(a) Sewage pond for wastewater.



(b) Waste tank for collection of bloods

Figure 1.3: Guidelines on waste management facility for slaughterhouses.
(Source: Department of Veterinary Services, 2016)

Every country has its own way of handling waste management for their slaughterhouse effluent. For example, in Miri Sarawak, a small and simple sewage treatment plant was installed in a pig slaughterhouse facility. It is recommended by their Public Health Division, Miri City Council to ensure its environmental cleanliness and conservation (Utusan Borneo Online, 2016).

In developed countries, the most common wastewater treatment methods are centralized aerobic wastewater treatment plants and lagoons for domestic and industrial wastewater (Doorn et al., 2006; Musa & Idrus, 2021). For instance, some slaughterhouse industries in Ethiopia implemented lagoons to treat wastewater. Nevertheless, with limited holding capacity of the lagoons, coupled with high production and wet season, the existing lagoon was loaded with wastewater and eventually overflown into the nearby river and lands, causing more environmental problems (Amenu, 2014). In Finland, there are a few measures that have been done for recovery and disposal of solid organic by-products and wastes generated from their poultry farming and slaughterhouses. This include rendering, use for animal feed, incineration, burial and controlled landfilling, composting, and AD treatment (Salminen & Rintala, 2002).

Over the years, AD has become an established and proven technology in managing solid organic waste, contributing to material recovery and energy production (De Baere, 2000). This biological phenomenon has naturally occurred in the surrounding environment, such as in sediments, soils, and animal intestinal tracts. It is a process involving complex mixture of microorganisms that convert organic materials into biogas without the presence of oxygen (Wilkie, 2005). AD performs well than other treatments of solid slaughterhouse waste, assuming the operations are well managed and achieved their economic viability (Banks, 1994). In 1983, Brazil first used plant-scale Upflow Anaerobic Sludge Blanket (UASB) and currently operates about 228 units of the AD treatment for their liquid effluent produced from slaughterhouses and other food-based industrial activities wastes (Del Nery et al., 2001). There is also a full scale AD plant built in the slaughterhouses in the Netherlands, Belgium, and New Zealand (Johns, 1995).

1.2 Problem Statement

Poultry slaughterhouse wastewater is mainly known to contain phosphorous and nitrogenous substances other than blood, FOG, and proteins (Debik & Coskun, 2009). Production of chicken slaughterhouse wastewater (CSWW) without treatment can be assured to affect the environment. The wastewater loaded with high organic content requires treatment that is efficient and reliable.

Various approaches have been proposed to treat CSWW, but it resulted in several limitations and less achievable goals. The aerobic process is widely used for waste treatment due to its ability to deal with large biomass, thus lesser land requirement for the precipitation under a simple-applied reactor. The process that coupled Granular Aerobic Sludge with Sequencing Batch Reactor (SBR) may serve an adequate removal of parameter TSS and ammonia and efficiently meet the effluent standard. However, the concentration of BOD and Chemical Oxygen Demand (COD) in post treatment still exceed the allowable limit due to its high organic content (Septiana et al., 2019). The BOD and COD removal efficiency can only be achieved by lengthening the aeration time. Besides that, composting is also commonly applied to treat CSWW, where the process includes screening, flotation of fats trap residues, chicken manure, litter, and feather. The method minimizes the presence of pathogens thus allowing the composted waste to be reused as fertilizer and soil conditioner in a plantation. Nevertheless, composting of the waste requires some absorbing moisture capability and structural support if the waste is low in fibre content (Tritt & Schuchardt, 1992). Therefore, composting waste in a liquid form is unsuitable as it only works best on solid waste.

For Poultry Slaughterhouse Wastewater (PSW) treatment, various technologies have been developed, including physical, chemical, and biological processes (Bustillo-Lecompte et al., 2016). Due to the overall high concentration of organic matter and nutrients, anaerobic processes are an ideal biological treatment for slaughterhouse wastewater treatment among several types of treatments (Cao & Mehrvar, 2011). The anaerobic treatment of PSW has received great results since it has a smaller plant footprint, produces less sludge, uses less energy and produces biogas along with methane, which has a high calorific value (Njoya et al., 2021).
The Static Granular Bed Reactor (SGBR) which was newly developed by Ellis & Mach (2004) has demonstrated the ability to treat high-strength wastewater efficiently in a simple down-flow configuration. It allows an improved anaerobic biomass retention and a simpler influent distribution system while extracting biogas and separating anaerobic granules from treated wastewater. This is due to the counter-current flow between the gas generated and liquid phases. But according to the studies conducted by Basitere et al. (2019) treating the same PSW, due to high average OLRs between 1.97 and 4.10 gCOD/L/day, the system experienced head losses, resulting in clogging of the pea gravel in the underdrain. In addition, to resolve the operational issues, a scheduled periodic backwash need to be implemented to unclog the system. Other researchers also reported on the performances of two Upflow Anaerobic Packed-bed Filters (UPBF) filled with different packing materials, polypropylene Pall rings. They expanded polyurethane foam to treat slaughterhouse wastewater (Martinez et al., 2014). The system was based on biofilm forms where bacteria adhere to an inert support. The result shows that due to an increase in bacterial and solids retention, the two filters operating under mesophilic conditions (30°C) were more efficient than a mixed system. Drawbacks of the system revealed as the filter performances declined with OLR higher than 6 $kgCOD_{in}/m^3$/day where the COD removal efficiency was consistently above 60% but there is reduction in methane production. The pH also needed to be adjusted during the early stage of the operation. The system show an increase in pH value over 8 together with increased in alkalinity and VFA concentration due to high protein content in the slaughterhouse wastewater. Other approaches, such as advanced oxidation processes (AOPs) and membrane technologies can also be employed, but they have significant drawbacks. Due to the general usage of chemicals, high costs and toxicity, AOPs are less preferred. Membrane technology is also not recommended because of its high capital and operation costs, as well as its high tendency of membrane fouling and clogging. As a result, they are commonly adopted as a post-treatment option (Gholami et al., 2003; Salimi et al., 2017).

The UASB reactor is a promising technology for treating various industrial wastewaters due to its minimal sludge generation, low capital investment and maintenance costs, less space and energy requirements, and sufficient biogas production (Khan et al., 2011). However, due to several factors, such as the long acclimation period of seed sludge, the nutrient of hazardous chemicals, the properties of the wastewater, and liquid mixing, the system normally takes longer hydraulic retention time (HRT) to start up. Furthermore, pH and temperature are critical elements that have a major impact on the performance of the UASB reactor. As a result, it is important to consider on the seeding sludge used, bioreactor design, and operation conditions to obtain high removal of COD concentration and methane produced in the UASB bioreactor.

For CSWW treatment, previous investigations have focused on bioreactor design and organic loading rate (OLR). They have addressed on sources or types of seeding sludge in anaerobic treatment of CSWW. Debik & Coskun (2009) published a study comparing two sets of bioreactors, one with granulated and the other non-granulated mixed with granulated biomass. Gallardo et al. (2006) investigated the effect of different seeding sludge sources in batch mode. The seeding sludge came from a treatment plant producing brewery wastewater and an anaerobic lagoon. Nonetheless, no previous study has concentrated on the effect of acclimatized seeding sludge utilising synthetic wastewater (SWW), regardless of the potential of the acclimatization procedure to improve bioreactor performance. Furthermore, although most previous research focused on energy recovery during manure treatment (Wresta et al., 2015), this study calculates on the energy generation from a laboratory scale (LS) and a Commercial Scale (CS) bioreactor and estimate on the energy input to be converted into electricity for the operation of the slaughterhouse. Therefore, in this present study, a SWW was used for acclimatization of seeding sludge to fasten the start-up period at the early stage of the treatment. The study was done to study the performance of bioreactors and energy generation in the treatment of CSWW using UASB.

1.3 Objective of The Study

The aim of the study is to investigate the treatment efficiency of CSWW using UASB in term of bioreactor performance and the energy recovery. The objectives are divided into sub-objective as follow:

i. To investigate the effect of various OLR during the treatment of CSWW on COD removal and Specific Methane Production (SMP) in UASB 1 and UASB 2.
ii. To compare bioreactor stability and performance between UASB 1 and UASB 2 with different acclimatized seed sludge in treating the same CSWW.
iii. To determine energy recovery and projected energy recovery for LS and CS.

1.4 Significance of The Research

This research means to provide a systematic and adequate study on the utilization of CSWW to produce biogas as an alternative method for management of sewage in Malaysia by introducing the acclimatized seed sludge using SWW in the UASB reactor. It can fasten the start-up process of the early treatment with well-developed microorganisms in the system to degrade the waste compared to previous studies. Besides biogas, this research can also satisfy the need for clean water as the current situation has demanded a high treatment efficiency of water and wastewater management for future development. Even though the water treated from the reactor is not fully useful for everyday use, it is still sufficient to be reused in the manufacture for their product processing. The biogas produced can also be utilized for energy recovery sufficient enough to supply electrical usage for the operation of wastewater treatment.

1.5 Scope of Study

This study focuses on implementing the CSWW into the AD process using a conventional UASB Reactor to see the potential in its production of biogas from the system. The system will be operated with a certain amount of OLR from the same CSWW at HRT of 24 hours by neglecting the weekend period. Both UASB were set in a jacketed system under mesophilic conditions (37°C) where the variation of temperature was neglected due to humidity. The variations of a raw sample of CSWW were normalized by feeding the UASB using OLR basis. By investigating the SMP and the COD removal efficiency in increasing OLR, the biodegradability of the CSWW can be well observed. Furthermore, two different seed sludge will be held in two separated UASB reactors to study the performance of biodegrading the waste when the microbes are prepared differently. The seeding sludge in UASB 2 reactor (before acclimatization with SWW) and UASB 1 reactor were sampled from a sewage treatment plant located in the Faculty of Engineering, Universiti Putra Malaysia.

1.6 Thesis Outline

This thesis reported on the overall studies of the performance of acclimatized seed sludge using SWW in treating the CSWW using UASB. It comprises of 5 chapters in total, which Chapter 1 explains on the problem statement of the study, the production of untreated CSWW and its effect to the environment, the existing method for the wastewater treatment available and introduction of UASB reactor as the best option for the biological treatment of CSWW.

Chapter 2 illustrate on the background study of livestock industry wastewater, specifically in poultry production, characterization of the CSWW, the introduction of anaerobic digestion (AD) and its phases involved in degrading the waste and the industrial effluent treatment system, specifically in introduction of UASB reactor as the chosen method for the anaerobic treatment. This chapter also clarifies on previous studies that have experimented on the effect of seed sludge with different sources and the production of methane for energy recovery. Overall, this chapter has highlighted the gap of knowledge, which is the use of acclimatized seed sludge that improves the start-up process of UASB reactor.

Chapter 3 explained in detail on the methodology for the study with the research flowchart and experimental design illustrated. All of the parameters involved were listed in the chapter. The set-up process of the UASB reactor and the acclimatization stage of seed sludge in UASB 2 were explained in detail. The calculation for energy recovery and the equations required were also listed.

Chapter 4 briefed in detail on the findings of the overall study, where characterization of CSWW collected were determined. The acclimatization process in UASB 2 was then evaluated with COD removal and biogas production together with buffering capacity and pH value to see the stability of the reactor before introduced with CSWW. Further analysis was continued with COD removal and its methane yield at various OLR in both reactors UASB 1 and 2. The analysis includes COD removal efficiency, biogas production, methane concentration and SMP. The reactors were also analysed for its stability and performance comparison using parameters pH value, alkalinity ratio (IA/PA), total ammonia nitrogen (TAN), volatile fatty acids (VFA), colour, fats, oil and grease (FOG), and total suspended solids (TSS). After the experiment was completed, the analysis was continued for the determination of energy recovery in optimal condition of the best-performed reactor. In this study, it was found that the best performed reactor is UASB 2 with acclimatized seed sludge at OLR 5.0 g/L/day. The energy was analysed in LS and CS, then it was compared with the energy required for the slaughterhouse operation.

Finally, chapter 5 concluded the finding of this study and listed the recommendation that can be done to improve the drawbacks of this study for future research.

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