Anaerobic Treatment of Wastewater Generated From Meat Processing Industry Using Batch Reactor System

By

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Submitted to the College of Engineering
in partial fulfillment of the requirements for the degree of
Bachelor degree in Environmental Technology Engineering

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Dedication

To the sake of Allah, my creator, my master, my strong pillar and sources of inspiration and knowledge;

To my great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life;

To my homeland Palestine, the warmest womb;

To the great martyrs and prisoners, the symbol of sacrifice;

To my great parents and husbands, who never stop giving of themselves in countless ways;

To my friends who encourage and support us, to all people in my life who touch our heart;

I dedicate this project.

Acknowledgment

No words can be enough to express how grateful to our university, Palestine Polytechnic University, we are.

We would like to thank the Mechanical Engineering Department and Environmental Technology Engineering teachers and assistants who were and will always be our family.

We would like to express our sincere gratitude to our advisors Dr.Yousef Subuh and Dr. Hassan Sawalha for their motivation; we could not have imagined having better advisors.

I would like to thank all the people who contributed in some way to the work described in this project.

We would not be able to be here without you

From the heart, thank you.

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Abstract

Wastewater (w.w) generated from Siniora meat processing industry contains relatively low concentrations of organic pollutants and other contaminants. The concentration of different parameters such as COD soluble, BOD, TSS, C/N ratio, pH were found to be 2,880 mg/L, 1,425 mg/L, 515 mg/L, 7/1, 6 respectively. Two anaerobic batch reactor, 1.0 L volume each were designed and used to study the treatment of this wastewater. Two experiments were conducted to study the extent of biodegradability of w.w, the amount of biogas generated and the change in pH. In the first experiment, both reactors were seeded with 400 mL of anaerobic sludge. Filtered wastewater of 400 mL (1.15 g COD) was added to one reactor and 600 mL (1.73 g COD) to the other one. The removal efficiency of soluble COD of 400 mL wastewater volume was 48% and for 600 mL was 51% after 29 days anaerobic treatment. However, a relatively small amounts of biogas released from both reactors. This may be due to low C/N ratio of such wastewater and may be as a result of leakage too / or as a result of improper water displacement system. The pH of the ww increased from 7 in raw filtered wastewater to 7.5 at the end of experiment. In the second experiment, the amount of biogas produced was 24.3 mL, 1.6 mL form 600 mL, 400 mL respectively. The removal efficiency of the soluble COD from 400 mL was 66.17% and 28.35% form 600 mL reactor after 20 days of operation.

Symbol

COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
TSS	Total Suspended Solids
TS	Total Solids
VS	Volatile Solids
VSS	Volatile Suspended Solids
TDS	Total Dissolve Solids
TN	Total Nitrogen
VFAs	Volatile Fatty Acids
TAN	Total Ammonia Nitrogen
SS	Suspended Solids
C/N	Carbon to Nitrogen
i.e	That is
OLR	Organic Loading Rate
HRT	Hydraulic Retention Time
LCFA	Long Chain Fatty Acid
VFA	Volatile Fatty Acid
EC	Electrical Conductivity

Chapter 1
Concept of the Project

1.1 Introduction

In all communities, wastewater treatment is considered as a crucial environmental issue. Scientists all over the world have been developing treatment methods for wastewater in order to avoid its adverse effects. Sound and safe handling of wastewater is a sign for civilization and social thriving and can turn out as an important resource of energy for the country if it was utilized well.

Wastewater is simply that part of water supply to the community or industry which has been used for different purposes and has been mixed with solids either suspended or dissolved. Depends on the source, wastewater may contain harmful biological and chemical pollutants, such as pathogens, microorganisms and toxic compounds. This wastewater can cause a serious pollution problem to eco-systems and threats human's life and public health if not properly treated[1].

Generally, industrial wastewater produced by manufacturing processes, can be classified into two types:

Inorganic effluent mainly produced from the coal and steel industry, from the nonmetallic minerals industry, and from commercial enterprises and industries of metal surface processing (iron picking works and electroplating plants). This type of wastewater contains heavy metals which are very hazardous and toxic. Iron(Fe), manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), and chromium (Cr) are all examples of heavy metals [2].

Organic industrial and agro-industrial wastewater effluent from chemical industries, pharmaceutical, oil refining industry, cosmetics, glue and adhesives, soaps, pesticides, herbicides, and food processing industries, is mostly biodegradable, although it may contain toxic materials. This wastewater is characterized by having high concentrations of COD and SS depending on the source of generation [3].

In Palestine, food industry has been growing fast as a result of rapid population growth which in turn has led to an increasing demand on suppliers, and thus created a challenge for manufacturers. In the meantime, it is noted there is an increase wastewater and other wastes which usually discharged to the open environment without any treatment, causing massive environmental and public health problems. Among different sources of wastewater, olive mills wastewater, dairy wastewater, potato and meat production are the most recognized.

One of the main sectors of food processing in Palestine is the meat processing industry, which results from the slaughtering of animals in order to manufacture a primary meat output like Beef Mortadella, Turkey Mortadella, Chicken Mortadella, Sausage and Hotdogs… etc. [4].

The production of the above mentioned types of meat products is accompanied by generation of wastewater. The wastewater content of the meat processing commonly includes high concentration of organic material, from body fluids, washing and cooking, and from used supplementary materials like starch and soya. Therefore, this wastewater is expected to contain high concentrations of BOD_5 and COD in addition to SS. Currently this wastewater is disposed of in an open environment without any kind of treatment causing deterioration of environment [5]. The treatment of this type and other types of wastewater should receive utmost attention.

Wastewater can be treated in three main techniques: physical, chemical and biological methods. The last method is best suited for wastewater with high organic content. For industrial wastewater treatment, both aerobic and anaerobic processes can be used. However, aerobic treatment is not efficient enough to handle the high pollutants concentration and high organic load. Unlike aerobic treatment, anaerobic treatment generates small amount of biomass (sludge). Anaerobic processes have many advantages, mainly, methane production, which can be utilized as an energy source. Also, they require less operating energy than aerobic treatment[6].

The efficiency of the anaerobic process is highly effected by environmental conditions such as pH, temperature, and nutrients, SS, (C/N) ratio).The rate of biodegradation of organics is enhanced at temperatures (mesophilic conditions (32-39ºC), optimum carbon to nitrogen ratio is in the range (20–30:1) [8],and the optimal pH value to be most favorable for Methanogenesis range, between (6.8 -7.8) [7].

C/N ratio considerably affects the TAN, and VFAs in the anaerobic digestion process. It was noted that when C/N ratio is low (i.e < 10/1), leads to high accumulation of TAN in the digester and as a toxic substance, it inhibits methanogenic activity and further accumulation could result in the failure of the whole anaerobic digestion system. One method to avoid excessive ammonia accumulation is to adjust the C/N ratios by adding high carbon content material or high carbon content wastewater, so improving the digestion performance[8].

One of the major contributors to the success of anaerobic wastewater treatment was the introduction of the so called high-rate reactor systems in which biomass retention and liquid retention are uncoupled. High reactor systems are applied to treat biodegradable compounds and even recalcitrant compounds in wastewaters. High-rate anaerobic digesters have the potential to effectively treat such wastewaters as well as enable capture of methane for use as a relatively clean energy source. Several types of high rate anaerobic reactor systems have been developed since three decades, to treat different types of industrial and agricultural wastewater. The most commonly used anaerobic digesters are the completely mixed anaerobic digester, the up flow and down flow anaerobic filter, Anaerobic fluidized and expanded bed, expanded granular sludge digester bed reactor (EGSB), anaerobic sequencing batch reactor (ASBR), up flow anaerobic sludge blanket (UASB) reactor and anaerobic batch reactor [9].

This work aims at using anaerobic batch reactor systems to study the extent of biodegradability of meat processing wastewater generated from Siniora food industries company -Al-Eizariya, Jerusalem, Palestine, and thus, get an indication of environmental factors necessary for proper anaerobic digestion to be applied to UASB reactor to treat the same wastewater.

1.2 LiteratureReview

Batch reactor has been used for treatment of wastewater with high amounts of particulate organic matter such as swine manure, landfill leachate, and dairy wastewater. It has also been applied to treat various wastewaters such as those from slaughterhouses, meat industry and olive mills plants. Some studies using low strength wastewaters have also been conducted using a batch reactor.

Anaerobic Batch reactor system was applied as a post-treatment unit to achieve anaerobic treatment for a fruit-juice industry wastewater. Temperature was adjusted to 26^{o}C in order to reduce total COD. The results showed an average effluent concentration of 50 mg/L at HRT of 11 hours and the OLR of 5.3g COD $m^{-3}d^{-1}$. Also, total BOD_5, oil and grease were 10 mg/L, 1.2 mg/L respectively[10].

In an olive mills wastewater study, it was found that the characteristics of wastewater for COD:N:P ratio has an average of about 900:5:1.7. By applying ASBR to treat olive mill wastewater, 80% of COD removal at 3days HRT and OLR of about 5.3 Kg COD/m^3.d were reached[11].

In a same manner, a batch reactor was used to treat cheese whey effluent to determine the anaerobic treatability and methane generation potential, and the influence of nutrients and trace metal supplementation was investigated. Operational parameters including HRT, COD concentration and organic loading rate were investigated[12].

Dairy wastewater is considered carbohydrate-rich that is discharged in large volumes, which is suitable for H_2production, was treated under anaerobic conditions by using a batch reactor. The optimum pH was found to be 6.5 and temperature of 55^{o}C and HRT of 6 h [13].

Similarly, a batch reactor was used for the production of hydrogen from sweet syrup; it applied a certain concentration of 25 g/L of sugar with a 1.45 g/L of $FeSO_4$and pH of 5.0 at room temperature of 30^{o}C with different HRT of 96, 48, 24, and 12 h. The results showed that by decreasing HRT, a decrease in hydrogen content took place [14].

Additional studies used batch reactor to observe the changes in methanogenic population levels by using a municipal wastewater. During an acclimation period of approximately 3 months, the batch reactor content was diluted to maintain a total ammonia-N of nearly 2000 mg/L. After this accumulation period, the volatile solids loading rate was increased with 15-day HRT, which increased the total ammonia-N in the batch to 3600 mg/L[15].

A batch reactor was used to investigate anaerobic digestion of diluted piggery wastewater mixed with 1, 2, 4 and 8 % straw. Total substrate released from straw hydrolysis, VFAs, pH, biogas production and CH_4 concentration were measured to find the optimum fermentation conditions. Results showed that the 4 % straw mixture was the most efficient followed by 2 % , 1% and 8% straw mixes had limited methane production because of high presences of the substrate[16].

In addition for treating of high strength slaughterhouse wastewater by using batch reactor operated at 30^{o}C, 25^{o}C and 20^{o}C. Where, the wastewater contains a COD between 30% and 53%. While a batch reactor easily could support volumetric loading rates of4.93, 2.94 and 2.75 Kg $m^{-3}d^{-1}$ at 30^{o}C, 25^{o}C and 20^{o}C respectively. At operating temperatures, the COD and soluble COD were reduced by over 92 % [17].

Also, a mixture of two-phase anaerobic digestion of fruit and vegetable wastes was studied by using batch reactor operated at mesophilic temperature. The result indicated that the yield of hydrolysis 81% at an organic loading rate of 7.5 g COD $L^{-1}d^{-1}$, the volatile fatty acid concentration increased when loading rate was increased, also a high methane productivity was obtained. Total COD in the final effluent below 1500 mg/L and soluble COD below 400 mg/L , the overall COD removal in the treatment system 96%. Also , the result show high process stability in a batch reactor, significant biogas productivity and better effluent quality from fruit and vegetable [18].

1.3 Problem Statement

This research project will investigate the following main and sub main questions.

- **Main Research Question**

Are anaerobic batch reactor experiments useful in providing information about the extent of biodegradability of wastewater generated from meat processing industry?

- **Sub Research Questions**

1. What are the physical and chemical characteristics of wastewater?
2. How do the operating conditions including C/N ratio, pH, and temperature, affect the treatment efficiency?

1.4 Goals and Objectives

The main objective of this study is to use anaerobic batch reactors to study the extent of the biodegradability of wastewater produced from meat processing industry.

- **Sub Goals:**

1. To characterize the wastewater from meat processing industry.
2. To design and construct a lab-scale batch anaerobic reactor to study the extent of the biodegradability of meat processing wastewater.
3. To study the effect of operating parameters including (pH , temperature).

1.5 Significance of Study

The importance of this study is to conduct experiments using ABR to get a preliminary indication of the biodegradability of meat processing wastewater and the amount of methane produced and the change in pH, as an appropriate method to facilitate the use of UASB reactor and the application of suitable organic loads.

1.6 Methodology

1. Wastewater was sampled and characterized.
2. Batch reactor apparatus were prepared.
3. The reactor was seeded with anaerobic digested sewage sludge which obtained from Al- Bireh wastewater treatment plant.
4. Since the amount of biogas was too low, a third experiments was very recently conducted to increase the C/N ratio by adding olive mills wastewater as a supplementary carbon source. Experiments are still being conducted. Results are expected by the end of December.

1.7 Budget

This project is expected to have a total cost of $ 900, as detailed in the table 1.2.

Table 1.1 The total estimated cost for project implementation.

NO.	Item	Cost$
1	**Transportation**	100
2	**Sample collection**	100
3	**Equipment (glassware, wet gas meter)**	300
4	**Samples analysis**	200
5	**Chemicals**	200
Total cost		900

1.8 Action Plan

Table 1.2 Action plan for the first semester.

TASKS	February				March				April				May
	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$
Identification of Project Idea													
Literature Review													
Field visits													
Select the required test													
Collecting samples													
Lab Tests													
Due date													

Table 1.3 Action plan for the second semester.

TASKS	September				October				November				December			
	W_1	W_2	W_3	W_4	W_1	W_2	W_3	W_4	W_1	W_2	W_3	W_4	W_1	W_2	W_3	W_4
Sample collection and characterization																
Set up and installation																
Anaerobic batch experiments																
Monitoring and reporting																

Chapter 2

Anaerobic Treatment using Batch Reactors

2.1 Introduction

Wastewater treatment is the process that removes the majority of the contaminants from wastewater and produce a liquid effluent. Wastewater produced from industrial effluents, domestic wastewater, urban run-off and agricultural wastewater. Commonly, these wastewaters contain several types of contaminants both organic and inorganic, toxic materials and pathogens [19]. The discharge of untreated wastewater into the environment causes severe environmental impacts.

1. Organic compounds are chemicals that contain carbon atoms, this includes pesticides, solvent, plastic and industrial chemicals. Some organic compounds leach from landfills into the surface and groundwater. Other, such as pesticides, seep downward through soil into the groundwater. Some industries discharge their waste water directly into the valleys [20].

2. Inorganic chemicals are which contain an element other than carbon, such as heavy metals, salts, and acids. Most of the inorganic compounds find their way into both surface and groundwater from different sources such as mines industries, irrigation, and urban runoff. Some of the inorganic pollutants are toxic to the aquatic life which makes the water unsuitable for survival, drinking and other purposes[20].

3. Pathogens: these are microorganisms such as bacteria and protozoa that cause diseases such as typhoid fever, cholera and other water-borne diseases[20].

2.2 Main Sources of Wastewater

2.2.1 Domestic Wastewater

It's simply that part of the water supply to the community which has been used for different purposes at the household level and has been mixed with solids either suspended.

The source of domestic wastewater result from black water in the toilet (faeces and urine) and less polluted grey water from showers, laundry, and kitchen. These sources should be treated separately according to their concentrations and composition [21].

2.2.2 Agricultural Wastewater

Agricultural wastewater is discharged from different types of agricultural practices such as fertilizer which runoff into water bodies causes nutrient contamination, also, chemical pesticides which may be highly toxic, can leach into the soil and then into the water and any exposure to these may adversely affect human and aquatic health [26].

2.2.3 Industrial Wastewater

Industrial wastewaters are effluents which result from human activities that are associated with raw-material processing and manufacturing. These wastewater streams come from washing, cooling, heating and other processes. Industrial wastewater can be very strong according to the concentration of pollutant which can contribute significantly to the overall pollution load imposed on the environment, and it consist of large quantities of organic compounds and heavy metals [22].

Industrial wastewaters cause significant issues of water resources quality when it released to the environment (such as toxic chemicals) [22].

Two characteristics of industrial wastewater are Physical characteristics and Chemical characteristics. Where physical characteristics of industrial wastewater vary such a solid content, color, dour and temperature. And the characteristic of chemical consists of the organic and inorganic chemical. The effluent from industrial sources contains a wide variety of pollutants which contains a typical concentration of certain parameters (BOD_5, COD, suspended solids) and pH[23].

2.3 Meat Processing

Meat processing wastewater constitutes one of the major concerns of the agro-industries. In general, meat processing wastewater contains high levels of various contaminants such as fat, SS, COD, BOD, chlorides and nitrogen. Before the food industry wastewater discharging to the environment, pollutants must be removed from this wastewater by considering the standard limit for effluents discharge. Anaerobic treatment can be applied for meat processing wastewater for its high amount of organic material and it provides to remove high COD and suspended solid by using batch reactors [24].

2.3.1 Characteristics of Meat Processing Wastewater

The meat industry has the possibility for producing large quantities of solid wastes and wastewater with BOD, COD and suspended solids level. The quantity of wastewater generated and the contaminant load relies on the type of meat being processed. The characteristics of meat processing wastewater before treatment it, except for screening of coarse solids and passing thru series of settling tanks. Table 2.1 Summary of statistical analyses of Amman slaughterhouse raw wastewater characteristics reported by water authority of Jordan for the years 2004 to 2006 at winter [24].All units are in mg/L except pH.

Table 2.1: Characteristics of meat processing wastewater [24]

Parameters	Meat processing wastewater	
	Range	Average
pH	4.59-7.8	**6.86**
Total COD (mg/L)	2186 – 17968	**7644.57**
BOD (mg/L)	751 – 3828	**1813.14**
TDS (mg/L)	846-5444	**2723.85**
TSS (mg/L)	612-3850	**1668.14**
Total solids (%)	1542-6976	**4392**

2.4 Wastewater Treatment Methods

2.4.1 Physical and Chemical Treatment

Physical treatment processes generally related to the processes which are designed to separate and concentrate different components of a waste stream without chemical modification of the form of these components. Physical treatment processes include filtration, sedimentation and adsorption [25].

Chemical treatment is a process which generate a chemical transformation of one or more components of a waste stream as the primary way of either removing a particular component or reducing its toxicity. Where oxidation, precipitation and coagulation are examples of chemical treatment processes [25].

Physical and chemical processes categorize as a primary treatment for pollutant removal. In a primary process, removal of suspended solids is by a number of physical processes that occur altogether within the tank, such as flocculation, adsorption, and sedimentation [25].

2.4.2 Biological Treatment

The biological process can be employed in the secondary treatment of wastewater after physical and chemical treatment, while the organic matter is utilized by microorganisms under aerobic or anaerobic conditions, and these processes may include, for example, aerated lagoons, activated sludge and anaerobic digestion [25].

There are two main biological wastewater treatments, aerobic and anaerobic used to decompose organic matter from wastewater, anaerobic treatment is more efficient in treating such type of wastewater, whereas aerobic is not advisable because it cannot tolerate high organic contents and needs dilution by drinking water[26].

2.5 Anaerobic Treatment

Anaerobic digestion is a power generation process, in contrast to an aerobic system that generally requires a high energy input for aeration process. It's a technically simple and comparatively cheap technology which exhaust less energy, space and produces less excess sludge in comparison to the traditional aerobic digestion technology an attractive option over another treatment process [26].

The generation of liquid industrial waste in large quantities with high organic content due to increased manufacturing trend worldwide which, if treated properly, it can lead to a significant energy source. Anaerobic digestion seems to be best suited for processing of liquid that contains high-strength organic wastes[26].

Table 2.2: The differences between aerobic and anaerobic treatment processes [26].

Aerobic treatment	**Anaerobic treatment**
• A very large fraction of the waste is converted to another type of waste(sludge)**.** • High operational costs. • Not suitable to treat industrial wastewater due to the high organic content.	• Less energy requirement as no aeration is needed. • Energy generation in the form of methane gas. • Less sludge generation. • Fewer nutrients required. • Require smaller reactor volumes. • Rapid startup. • High treatment efficacies. • Excess sludge has a market value (stabilized

There are four groups of microorganisms can be recognized in the anaerobic treatment of wastewater:

1) Hydrolysis: During anaerobic digestion, by exo-enzymes deteriorated polymer particles into smaller molecules that can cross the cell barrier. Where proteins are hydrolyzed to amino acids, a polysaccharide converted into simple sugars, and lipids to LCFA, this operation is also extremely sensitive to temperature and the change in temperature variability[26].

2) Acidogenesis: Step is to transform the fastest in the anaerobic food chain, where the product in hydrolysis step (amino acids, simple sugars, LCFA) Spread inside the bacterial cell through the cell membrane and thus oxidized anaerobically. Products include at this stage of VFAs, and alcohol, lactic acid, CO_2, H_2, NH_3, and H_2S, as well as a new cell material [26].

3) Acetogenesis: Where products, after acidogenesis, are converted into acetate, hydrogen (H_2), and CO_2 in addition to new cell material[26].

4) Methanogenesis: Organic matter is converted to methane and carbon dioxide by the bacteria. At the same time methanogenic archea group uses hydrogen and acetate for CH_4 formation resulting in CO_2 reduction. Influent COD is converted to gaseous form and leaves the system in this final stage [26].

The decomposition of organic matter under a combined action of different types of microorganisms, mainly bacteria in the absence of molecular oxygen as indicated in the Figure [2.1] [26].

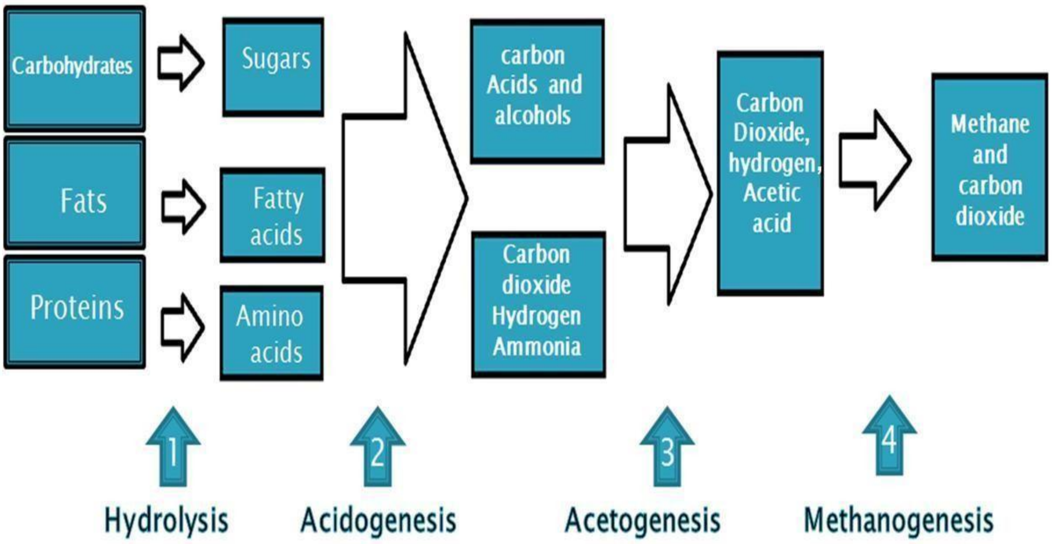

Figure 2.1:Show the microbial aspects of anaerobic treatment [27].

2.5.1 Environmental Factors Affecting Anaerobic treatment [28]

Anaerobic treatment of wastewater that generated from meat processing controlled by several parameters:

1) Temperature

Mesophilic (24-45)^{o}C and thermophilic (45-65)^{o}C anaerobic digestion are commonly available. Batch anaerobic reactor are operated at mesophilic temperature. While previous studies explained a several advantages of thermophilic digestion, including high organic removal rate, high degree of degradation. Researchers discovered that anaerobic digestion at low temperature showed reproducible microbial community structure and operational performances. However, anaerobic digestion was operated in mesophilic range (25-45)^{o}C since of heat generation through methane combustion.

2) pH

It is an important factor for continuing functional anaerobic digestion. While a typical pH is in the range of 6.5-7.6. The accumulation of intermediate acids leads to pH drop during fermentation and as a result causes a decline in methane production rate and can cause reactor souring or reactor failure.

3) Hydraulic Retention Time(HRT)

Is defined as the average length of time one reactor volume in which a an amount of substrate remains in a storage unit. The numeric definition :

$$\mathbf{HRT} = \frac{\mathbf{V}}{\mathbf{Q}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{2.1})$$

Where $HRT =$ hydraulic retention time (d)

V= volume of reactor

Q= influent flow rate

Hydraulic retention time is the time length of a substrate and particular constituents aimed to be removed from the reactor, so it is important to reactor operation and design.

4) Solid Retention Time (SRT)

Solids retention time, or mean cell residence time, is defined as the average amount of time that microorganisms are kept in the system. The numeric definition of solids retention time is :

$$\theta_c = \frac{\mathbf{V * X}}{\mathbf{Qw * Xw}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Where θ_c = solids retention time (d)

V = reactor volume (m^3)

X = cell concentration in reactor

Q_w = flow rate out of reactor

X_w = cell concentration in the flow out of the reactor

SRT is important because when SRT is too low, an organisms will be washout. If SRT is too long, then the system becomes nutrients-limited.

5) Organic Loading Rate

Is defined as " the mass of the volatile solids applied each day per reactor volume" or it's " the amount of BOD or COD added to the reactor volume per day" . The equation for organic loading rate is by the following :

$$\mathbf{OLR} = \frac{Q * COD}{Vreactor} = \frac{COD}{HRT} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where OLR = organic loading rate (m^3/d)

COD = concentration volatile solids (Kg VS/ m^3)

$V_{reactor}$ = reactor volume (m^3)

HRT = hydraulic retention time.

2.6 Reactor Types

To choose the most appropriate reactor type for a particular application, it is essential to conduct a systematic evaluation of different reactors configurations with the wastewater stream **[**29**].** It is able to retain large amounts active biomass with relatively low hydraulic retention time, solids retention time (SRT), according to the type of biomass growth in the system, which permits the slow-growing microorganisms to remain within the reactor [26].

There are many principal types which are proper in anaerobic treatment of industrial wastes and waste water. Among them, the most common types are discussed here[6].

2.6.1 Completely Mixed Anaerobic Digester

In anaerobic treatment field, the anaerobic digesters are considered the basic unit in treatment. Equal and sufficient hydraulic retention time and solids retention time ranging from 15 to 40 days provide operation and system stability.

Wastes with high solids concentrations are best treated in a completely mixed anaerobic digester Figure [2.2] with no recycle during operation. A high volumetric loading rate can only be obtained by wastes with high COD concentrations ranging between 8,000 and 50,000 mg/L, which is considered a disadvantage for this system [6].

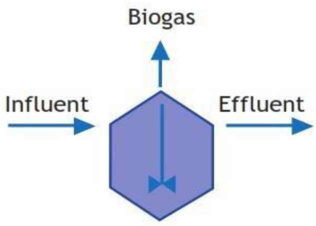

Figure 2.2: Completely mixed anaerobic digester [29].

2.6.2 Anaerobic Sludge Bed Reactor

The anaerobic sludge bed reactor is the most popular anaerobic wastewater treatment systems yet. In this reactor, the sludge retention depends on the formation of easily settling sludge aggregates, and on the application of an internal gas-liquid-solid separation system. The best known example of this concept is the upflow anaerobic sludge blanket (UASB)[26].

2.6.3 Upflow Anaerobic Sludge Blanket Reactor

The UASB Figure [2.3] reactor consists of a circular or rectangular tank in which waste flows in an upward direction through an activated anaerobic sludge bed which occupies about half the volume of the reactor and consist of highly settleable granules or flocs [26].

Solids entrapment and organic matter conversion into biogas and sludge during the treatment process that is taking place by passing it through anaerobic sludge [26].

Biogas bubbles rise up to the top of the reactor that is produced automatically by processing, these bubbles carrying water and solid particles. The solid particles drop back to the top of the sludge blanket, while the released gas are captured in an inverted cone or related structure, at the top of the reactor, biogas bubbles are directed to a gas-liquid surface at the upper part of the reactor. Water passes through the apertures is carrying solid particles which are settled in the settling area [26].

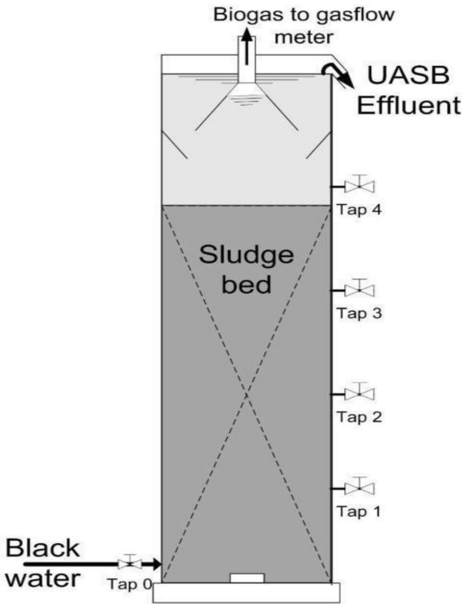

Figure 2.3: UASB reactors of the major anaerobic system manufacturers [30].

2.6.4 Anaerobic Fluidized

The anaerobic fluidized bed reactor involves small media, such as sand or granular activated carbon. Is applied a high flow rate around the particles to occur good mass transfer, it also have large pore spaces formed through bed expansion, so it less clogging and short-circuiting, and characterize with high efficiency and small size make fluidized bed reactorsmoreefficiently,andavailabilityhighspecificsurfaceareaofthecarriers[26].

2.6.5 Batch Reactor

A batch reactor (BR) is an adjustment for activated sludge, which operated by filling the reactor with slurry, letting the reactions that take a place in the reactor proceed to completion, and then removing some or all of the contents of the reactor. This procedure is repeated by stirring. The advantage of this process is easy for operation, the absence of mechanical mixing and high removal efficiency of an individual contaminant[28].

The process of batch reactor typically occurs in four steps: i. Feeding, ii. Reaction, iii. Settling, and iv. Withdrawal of treated effluent. During the feeding and reaction steps, the content of a reactant is slowly stirred to allow close contact between organics and bacteria. A biogas produced during ABR treatment of wastewater which can be utilized for cooking or heating. On the other hand, sludge by-product from the reactor can be served as soil fertilizer[22].

Chapter 3

Experimental work

3.1 Materials and Method

3.1.1 Materials

Wastewater was collected from Siniora food industries in Al-Eizariya, Jerusalem City. Anaerobic digested sewage sludge for seeding anaerobic batch reactors was obtained from anaerobic digester at a Al-Bireh wastewater treatment plant. Olive mills wastewater was blended with meat processing waste to increase the COD and most likely to increase the C/N ratio of the wastewater of meat processing.

3.1.2 Methods

3.1.2.1 Characterization of Wastewater and Sludge

Collected wastewater samples from Siniora food industries were characterized for its pH, total solids (TS), total suspended solids (TSS), COD, and nutrient content (total nitrogen) were also determined. Also sludge was characterized for its TS, VS, TSS and VSS.

3.1.2.2 Preparation of Batch Reactor Apparatus (Setup of Batch Reactor Experiment)

The Batch reactor system consists of two reactors, 1L volume each. Schematic diagram of the batch reactor is shown in Figure [3.1]. To measure the amount of biogas generated, the biogas outlet was connected to a U-tube graduated cylinder filled with gas collection solution and erlenmeyer of 1.0 L volume, thus the amount of biogas produced is determined by measuring the volume of water displaced by the biogas.

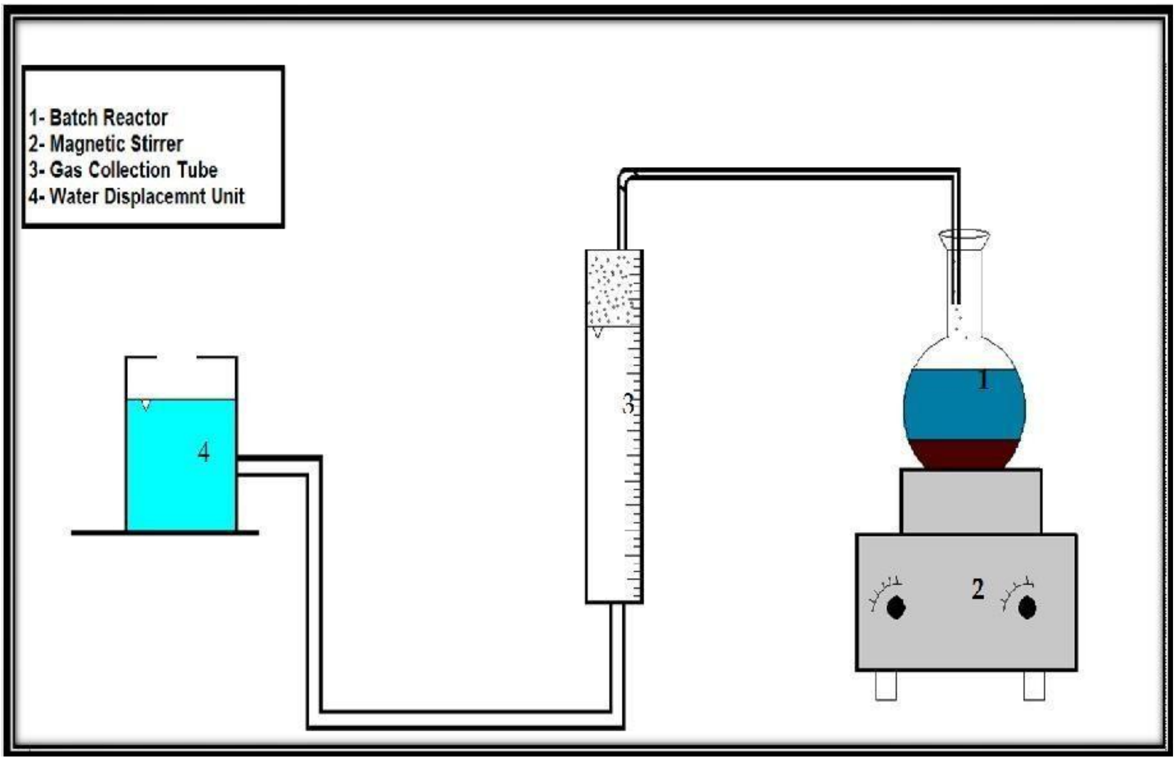

Figure 3.1 : Schematic diagram of anaerobic batch reactor.

3.1.2.3 Design of Incubator

In biology, an incubator is a device used to grow and maintain microbiological cultures. The incubator maintains optimal temperature. The incubator was constructed from a disposed off freezer and was equipped with temperature regulator and a fan to distribute the heat uniformly, using an electrical lamp as a heat source, so that the temperature inside the incubator was maintained at 32 ± 2^{o}C (mesophilic range). The photo of this incubating system is shown in Figure[3.2].

Figure 3.2 : Incubator box.

3.1.2.4 Meat Processing Wastewater Treatment Experiments

Experiments to study the treatment of meat processing wastewater were carried out using two batch reactor with a working volume of 1L. Wastewater was first filtered to remove solid particles and to have soluble COD. Before anaerobic treatment, the pH of wastewater was found 6, so it was adjusted to nearly neutral pH (6.8–7) using [0.1 M] sodium carbonate (Na_2CO_3).

3.1.2.5 Experimental Setup

Three experiments were conducted to study the extent of biodegradability of meat processing wastewater, the amount of biogas generated and the change in pH.

In the first experiment, both reactors were seeded with 400 mL of anaerobic sludge. Filtered wastewater of 400 mL (1.15 g COD) was added to one reactor and 600 mL (1.73 g COD) to the other one. The reactors were put in operation for at least 20 days with continuous stirring using magnetic stirrer at 5 RPM. The rate of biogas produced was daily monitored.

In the second experiment, reactors also are filled with the same amounts of anaerobic sludge and wastewater under the same conditions as were in the first experiments. Whereas a graduated cylinder was connected directly to the reactor as a displacement unit, to read the exact amount of biogas produced.

Since the amount of biogas was too low as it might be due to low the C/N ratio and low COD concentration in meat processing wastewater, a third experiment was conducted by blending meat processing wastewater with a portion of olive mills wastewater (16,000 mg/L) to increase the C/N ratio and also to increase the COD.

In this experiment, the first reactor was seeded with 300 mL of the same sludge as in the previous experiments. Then 525 mL of meat processing ww and 75 mL of olive mills ww (2.61 g COD) were added after filtration. In the other one, 625 mL of meat processing ww and 75 mL (3.2 g COD) were added to the same amount of sludge. ABR reaction was gently mixed at 5 rpm and carried out at temperature of 32^oC with continuous stirring.

3.1.2.6 Biogas Production

Biogas production rate was monitored daily during ABR run. Water displacement was used to quantify the amount of gas produced. Volume of gas was measured by the volume of a gas collection solution displaced from the reactor into the other container as a result of gas pressure build up inside the vessel. The gas collection solution was prepared by dissolving 100 g of table salt was added to 900 mL water, also 2-3 drops from sulfuric acid (H_2SO_4) was used to bring down the pH of gas collection solution to(1-1.5), as shown in the Figure [3.3].

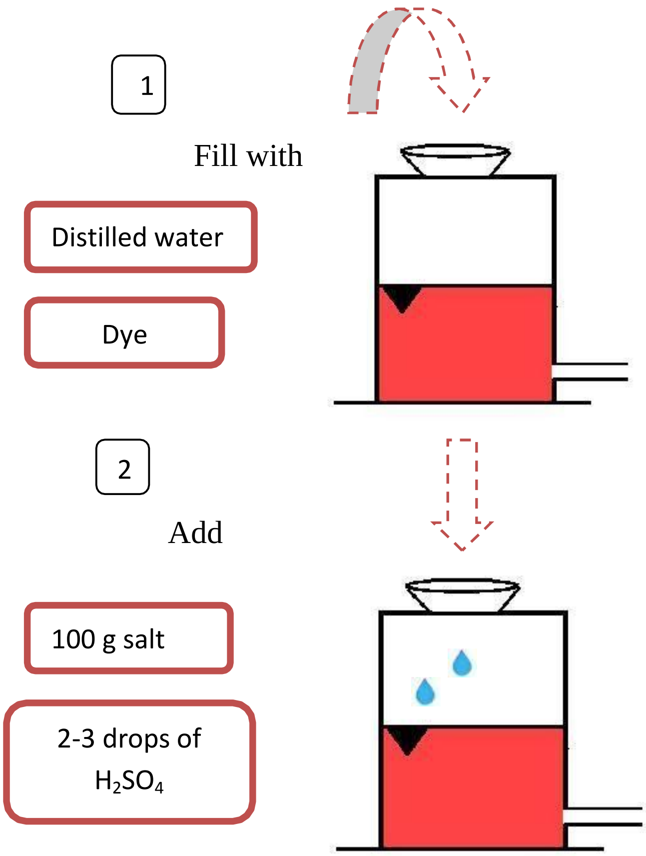

Figure 3.3 : Preparation of gas collection solutions.

3.2 Analytical Methods

Chemical oxygen demand was measured with the stipulation as per IS(Indian Standard) : 3025 (part 58) – Reaffirmed 2006. pH measurements were taken with a pH meter (model : (Mi 150), Milwaukee.) and a pH probe (MA 917). TS and VS concentrations were measured in accordance to IS: 3025 (part.16 & part 17) [32].

Chapter 4
Result and Discussion

4.1 Meat Processing Wastewater Characteristics

Wastewater from meat processing industry has a wide range of characteristics. The initial chemical analysis conducted by Birzeit University are shown in table [4.1]. The sludge were characterized and the results are shown in table[4.2].

Table 4.1: Meat processing wastewater characteristics (from discharging point).

Parameter	Result
BOD (mg/L)	1425
TSS (mg/L)	515
TN (mg/L)	81.70
pH	6
COD soluble (mg/L)	
25 MAR.	2243
22 AUG.	2320
31 OCT.	2807
14 NOV.	2880
Alkalinity HCO_3 (mg/L)	9763
Ammonia NH_3 (mg/L)	2.6
Calcium Hardness Ca as $CaCO_3$ (mg/L)	99
Total Hardness (mg/L)	155
Magnesium Hardness Mg as $CaCO_3$ (mg/L)	56
Nitrate NO_3 (mg/L)	18
Nitrite NO_2 (mg/L)	0.3
EC EcmS/cm	2.5
Turbidity NTU	101
TOC (mg/L)	411

Table 4.2: Characteristics of sludge.

Parameters	Result
TS (g/L)	26.967
VS (g/L)	23.696
TSS (g/L)	21.972
VSS (g/L)	18.73

4.2 Characterization of Olive Mill Wastewater

Olive mill wastewater (OMW) used in this study was obtained from a local olive oil mill that uses centrifugation decanter, which located in Bethlehem. The main composition of OMW is summarized in table [4.3]. OMW was used in this study as a source of carbon to increase the production of biogas.

Table 4.3:Composition of olive mill wastewater.

Parameter	Result
pH	6.35
Total COD (mg/L)	16,000
COD Soluble (mg/L)	14,720
C/N ratio [33]	50.42 ± 1.7

4.3 Anaerobic Treatment and Biogas Production Potential of Meat Processing Wastewater.

The experiments started by using a certain volume of meat processing wastewater and filled with sludge from an anaerobic sludge digester. The amount of meat processing wastewater was used about 400, 600 ml and the amount of sludge 400 ml in each reactor. This experiment was carried out to determine the anaerobic treatability of meat processing ww samples of varied COD concentrations and the associated methane production. For this purpose,twodifferentOLR,namely1.15,1.73g,wereachievedinduplicate1L erlenmeyer. The VS concentration in each bottle was adjusted to 9.5 g/L reactor volume. The rationale for selecting such values was to observe the performance of the anaerobic treatment for biodegrading meat processing ww under elevated conditions**.**

4.4 Evaluation of anaerobic treatment system performance

The destruction of organic matter (COD) was the primary indicator used for evaluating the performance of the reactors. Other major parameters analyzes for monitoring the performance of the system include pH and biogas production rate. As illustrated in the table [4.5], the removal efficiency of the soluble COD in 400 mL was 48% and for 600 mL was 51% after 29 days anaerobic treatment, which means the high removal efficiency of the organic matter content in ww. However, a less amount of biogas released from two reactors. This low production rate may be due to low COD and low C/N ratio.

The pH of the ww was measured at the end of the experiments and was found to range from 7.47 to 7.48, increased from 7 in raw wastewater to 7.5 after the course of treatment which indicates the biodegradation of fatty acids and the decomposition of organic matter to some extent.

Daily gas production was monitored in the two batch anaerobic reactor having different COD concentrations for 29 days. During the first days, a scum layer of foam was appeared in the batch reactors as shown in the Figure [4.1], also gas bubbles were observed in gas collection solution unit as shown in Figure [4.2]. These results reflected the treatment efficiency that could be gained from the anaerobic treatment used, since microorganisms were not previously acclimatized to meat processing ww.

Also, for biogas production there was no displacement for the water in the displacement unit occurred. It was noted that C/N ratio was low 7/1, that lead to high accumulation of total nitrogen in the reactors and as a toxic substance to bacteria.

Figure 4.1 : The appearance of scum layer in the ABR.

Figure 4.2 : Bubbles in the gas collection system.

Table 4.4 : pH value and COD removal efficiency after 29 days in the first experiment.

Reactors	COD (in)	COD (out) After 29 days	Removal efficiency	pH (in)	pH (out) After 29 days
400 mL	2806.67 mg/L	1370 mg/L	51.18%	7	7.47
600 mL	2806.67 mg/L	1510 mg/L	46.19%	7	7.48

In the second experiment, the removal efficiency of the soluble COD in 400 mL was 66.17 % and for 600 mL was 28.35 % after 20 days, also the pH out of the ww was found 7.25 as illustrated in table [4.5]. For the biogas production under mesophilic condition was initially assessed by means of two anaerobic batch tests using an equal amount of sludge sample. Figures [4.3], [4.4] shows the evolution of net accumulated biogas production during 20 days of operation.

For the first batch reactor (600 ml of ww), initially, the biogas production rate (indicated by the slope of the curve) up to day 10 was constant and few amount of biogas produced. However after the day 10, the biogas start to increase constantly until its reach to the 20 day where the biogas production was at maximum amount then start to decline, since nearly all the amount of fatty acid have been consumed by the anaerobic digester.

For the second reactor (400 ml of ww), initially, no biogas produced. Then after 10 days, the production rate of biogas increased in a constant manner. After 13 days, there was a slight increase in the biogas amount, indicating that most of nutrients was decomposed or an accumulation of non-biodegradable wastes.

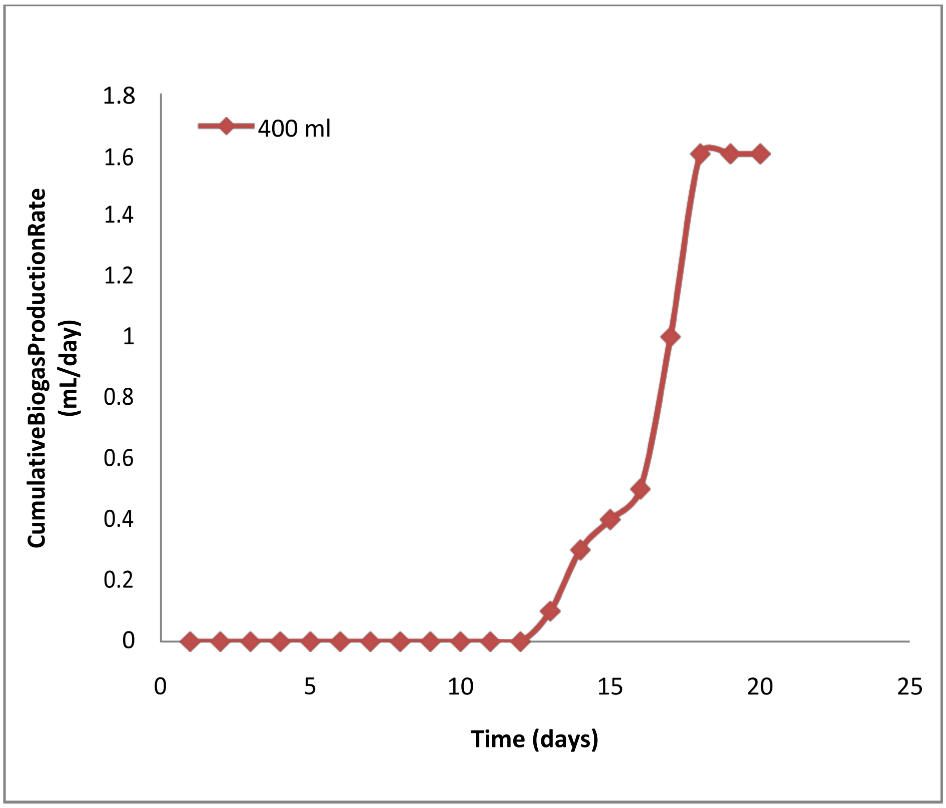

Figure [4.3] : Average cumulative biogas produced for batch 1 in second experiment.

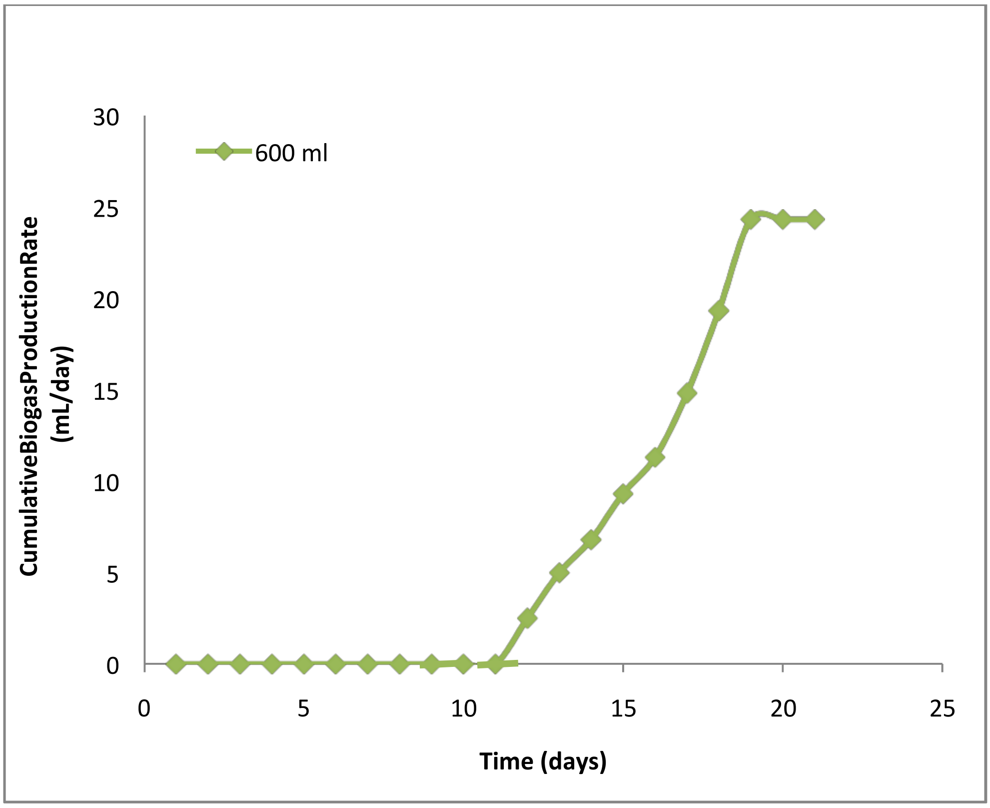

Figure [4.4] : Average cumulative biogas produced for batch 2 in second experiment .

Table 4.5: pH value and COD removal efficiency after 20 days in the second experiment.

Reactors	COD (in)	COD (out) After 20 days	Removal efficiency	pH (in)	pH (out) After 20 days
400 mL	1700 mg/L	575.1 mg/L	66.17 %	6.92	7.25
600 mL	1700 mg/L	1218 mg/L	28.35 %	6.92	7.25

In the third experiment, the removal efficiency of the soluble COD in 600 mL was 49.42 % and for 700 mL was 38.64 % after 20 days, also the pH out of the ww was found 7.26 and 7.60 respectively as illustrated in table [4.6]. Figures [4.5], [4.6] shows the evolution of net accumulated biogas production during 20 days of operation.

For the both batch reactors, initially, no biogas produced up to day 5. After the day 5, the biogas start to increase constantly until its reach to the 20 day where the biogas production was at maximum amount then start to decline, since nearly all the amount of fatty acid have been consumed by the anaerobic digester.

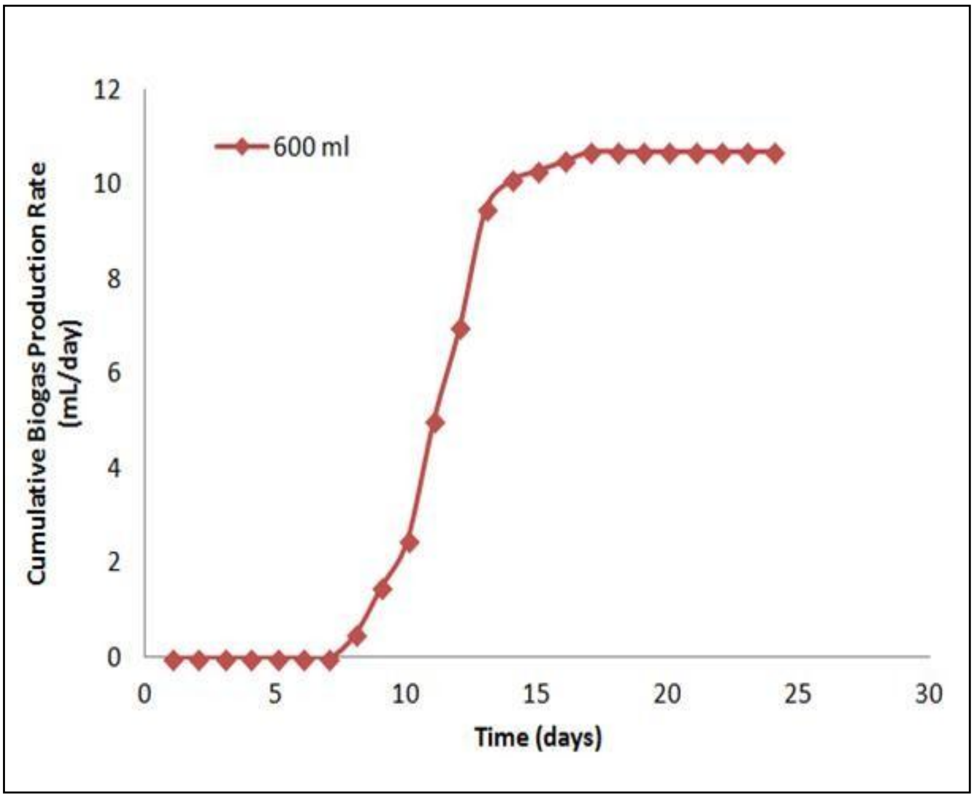

Figure [4.5] : Average cumulative biogas produced for batch 1 in third experiment.

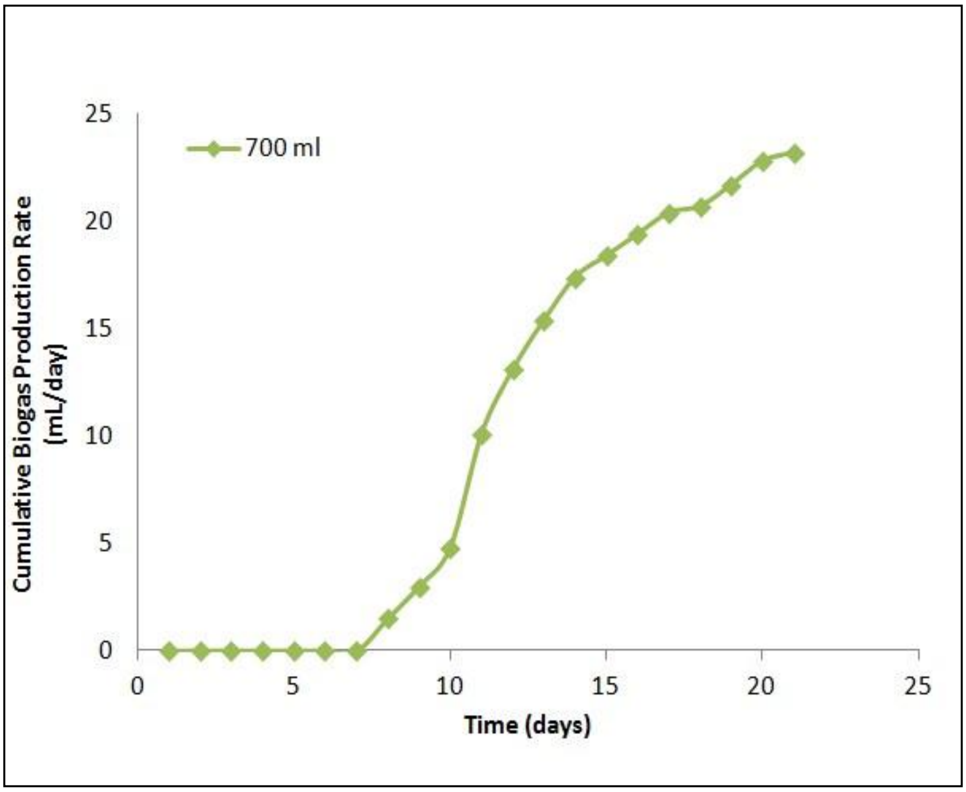

Figure [4.6] : Average cumulative biogas produced for batch 2 in third experiment .

Table 4.6 : pH value and COD removal efficiency after 20 days in the third experiment .

Reactors	COD (in)	COD (out) After 20 days	Removal efficiency	pH (in)	pH (out) After 20 days
600 mL	4350 mg/L	2200 mg/L	49.42 %	6.85	7.62
700 mL	4571.4 mg/L	2805 mg/L	38.64 %	6.94	7.60

Conclusion

Wastewater generated from meat processing industry contains relatively low concentrations of organic pollutant.

This type of wastewater is anaerobically decomposable to some extent and a small amount of biogas is accompanied due to mainly low C/N ratio of this wastewater.

Although anaerobic treatment is mostly used to treat high strength wastes, it could be used to treat low strength wastewaters like meat processing wastewater.

It was found that the biodegradability of pollutants through anaerobic treatment by using batch reactors was about 50%. This removal may be considered low and may attributed to the low C/N ratio.

Increasing C/N ratio of meat processing ww is essential to increase biogas production rate and shorten the start up time.

Recommendation

Its recommended to use a special type of wastewater which contain high amount of carbon source such as olive mills wastewater, in order to increase the amount of C/N ratio .

Also, the displacement unit not recommended for biogas collection and should be replaced with gas meters. And the tube should be made of PVC material instead of silicon tube, due to it has low permeability for biogas.

Finally, a continuous reactor (UASB) recommended to use instead of batch reactor to treat the meat processing ww, since the HRT is low and have a better performance of biogas production and removal efficiency for COD.

References:

1. Goel, P. K. *Water pollution: causes,effects and control*. New Age International, 2006 :2-3.
2. Ahluwalia, Sarabjeet Singh, and Dinesh Goyal."Microbial and plant derived biomass for removal of heavy metals from wastewater." *Bioresource technology* 98.12(2007):2243-2257.
3. Hanchang, S. H. I. "Industrial wastewater-types, amounts and effects." *Point Sources of Pollution: Local Effects and their Control-Volume II*(2009): 191.
4. Siniora Food Industries company.
5. Cristian, Oneţ."Characteristics of the untreated wastewater produced by food industry."*University of Oradea-Faculty of Environmental Protection*(2010).
6. Ersahin, Mustafa Evren, etal."Anaerobic treatment of industrial effluents: an overview of applications."*WasteWater, Treatment andReutilization*(2011):127.
7. Rajeshwari,K.V.,etal."State-of-the-art of anaerobic digestion technology for industrial wastewater treatment."Renewable and Sustainable Energy Reviews4.2 (2000):135-156.
8. Wang, Xiaojiao, et al. "Optimizing feeding composition and carbon–nitrogen ratios for improved methane yield during anaerobic co-digestion of dairy, chicken manure and wheat straw." *Bioresource Technology* 120 (2012):78-83.
9. Tauseef, S. M., Tasneem Abbasi, and S. A. Abbasi. "Energy recovery from wastewaters with high-rate anaerobic digesters." *Renewable and Sustainable Energy Reviews*19 (2013):704-741.
10. Tawfik,A., &El-Kamah, H.(2012).Treatment of fruit-juice industry wastewater in a two-stage anaerobic hybrid(AH)reactor system followed by a sequencing batch reactor (SBR). Environmental technology, 33(4),429-436
11. Ammary,B.Y.(2005).Treatment of olive mill wastewater using an anaerobic sequencing batch reactor. Desalination,177(1-3),157-165.
12. Kirankumar, Panga, et al. "Effect of operational parameters on biohydrogen production from dairy wastewater in batch and continuous reactors."Biofuels (2016):1-7.

13. Ergüder, T. H., et al. "Anaerobic biotransformation and methane generation potential of cheesewhey in batch and UASB reactors." *Waste management* 21.7 (2001):643-650.

14. Saraphirom,P.,&Reungsang,A.(2011).Biological hydrogen production from sweets orghumsyrup by mixed cultures using an anaerobic sequencing batch reactor (ASBR).International Journal of Hydrogen Energy,36(14),8765-8773.

15. Angenent, Largus T., Shihwu Sung, and Lutgarde Raskin. "Methanogenic population dynamics during start up of a full-scale anaerobic sequencing batch reactor treating wine waste." Waterresearch36.18 (2002):4648-4654.

16. Masciandaro, G., B.Ceccanti, and C.García."Anaerobic digestion of straw and piggery wastewaters: II. Optimization of the process."Agrochimica38.3(1994): 195-203.

17. Massé, DanielI., and Lucie Masse."The effect of temperature on slaughterhouse wastewater treatment in anaerobic sequencing batch reactors."Bioresource technology76.2(2001):91-98.

18. Bouallagui, H.,etal. "Two-phases anaerobic digestion of fruit and vegetable wastes: bioreactors performance."Biochemical Engineering Journal21.2(2004): 193-197.

19. Yaqoub,I. wastewater status inPalestine2004.

20. Cheremisin off, N.P., Hand book of water and wastewater treatmenttechnologies. 2001:Butterworth-Heinemann.

21. Mara, Duncan. Domestic wastewater treatment in developing countries. Routledge,2013.

22. Ng,Wun Jern ,and Kwang Wei Tjan. Industrial wastewater treatment. London: Imperial College Press,2006.

23. Munter, Rein. "Industrial wastewater characteristics."*The Baltic University Programme (BUP),Sweden*(2003).

24. Sarairah, Ameen, and Ahmad Jamrah. "Characterization and assessment of treatability of wastewater generated in Amman slaughterhouse." *Dirasat: Engineering Sciences* 35.2 (2010).

25. Washington, E. P. A.DC:“Primer for Municipal Waste water Treatment Systems.” Document no. EPA 832-R-04-001,2004.

26. SahmH. “Anaerobic wastewater treatment . “ Immobilized Biocatalysts Saccharomyces Yeasts Wastewater Treatment . Springer Berlin Heidelberg, 1984. 83-115.

27. IHE DELFT., And Wageningen Agricultural University. (1995). International Course on Anaerobic Wastewater treatment and Anaerobic Reactor Technology (July17-29).The Netherlands.

28. Rowse, Laurel Erika."Design of small scale anaerobic digesters for application in rural developingcountries."(2011).

29. Gray, Nick F. *Water technology: an introduction for environmental scientists and engineers*. Butterworth-Heinemann, 2010 :436-449.

30. De Graaff, Marthe S.,etal."Anaerobic treatment of concentrated black water in a UASB reactor at a short HRT."*Water*2.1(2010):101-119.

31. Subuh,Yousf."Anaerobic treatment of olive mills wastewater using Up-flow Anaerobic Sludge Blanket(UASB)reactor." *Unpublished M.Sc. Thesis).Water Research .An-Najah N .University, Nablus*,*Palestine*(1999).

32. APHA Standard method for the Examination of water and wastewater - 20th Edition. Method 5220C.

33. Majbar, Z., et al. "Olive mill wastewater and wine by-products valorization by co- composting."(2017).