An-Najah National University

Faculty of Graduate Studies

Enhancing Biogas Production by Using Slaughterhouse Wastewater and Domestic Sludge to Cover Energy Demand for Wastewater Treatment Plant in Nablus Governorate.

by

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Dedication

To my beloved family: mother, father, brothers, and sisters

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

Enhancing Biogas Production by Using Slaughterhouse Wastewater and Domestic Sludge to Cover Energy Demand for Wastewater Treatment Plant in Nablus Governorate.

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تم الإشارة اليه حيثما ورد ، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification

Student's Name: **اسم الطالب:**

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Acc	Accumulation gas volume.
AD	Anaerobic digestion.
ALK	Alkalinity.
C:N	Carbon to nitrogen ratio.
$CaCO_3$	Calcium carbonate
CFC	Chlorofluorocarbons gas.
CH_4	Methane Gas.
cm	Centimeter.
CO_2	Carbon dioxide gas.
COD	Chemical Oxygen Demand.
d	Day.
D-CO	Digester was fed with mixture of PS and SHW.
D-PS	Digester was fed with PS.
D-SHW	Digester was fed with SHW.
EXP1	First experiment.
EXP2	Second experiment.
g	Gram.
GHG	Greenhouse gas.
H_2S	Hydrogen sulfide.
HRT	Hydraulic Retention Time.
I/S	Inoculum to Substrate ratio.
L	Liter.
LCFA	Long Chain Fatty Acids.
M	Molarity.
MCM	Million cubic meters.
mg	Milligram.
mL	Milliliter.
NH_3	Ammonia
Nml	Milliliters Normalized at 0˚C, 101.325 kPa.
O_3	Ozone gas.
OLR	Organic loading rate.
pH	Potential Hydrogen (Acidity or Alkalinity Scale).
PS	Primary sludge.
SHW	Slaughterhouse wastewater.
SS	Sewage Sludge (Mixture of primary sludge and secondary sludge).
STP	Standard temperature and pressure.
TS	Total solids.
v/v	"By volume"; used to describe the concentration of

	a substance in a mixture.
VFA	Volatile fatty acid.
VS	Volatile solids.
WN-WWTP	West Nablus - Wastewater Treatment Plant.
WWTP	Wastewater treatment plant.
°C	Degree Celsius.

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Abstract

In this study, enhancement in biogas production from using Co-digestion of slaughterhouse wastewater (SHW) mixed with primary sludge (PS) was evaluated, and compared with biogas production from digest the SHW, and PS individually. In order to carry out this evaluation, lab experiments were conducted under mesophilic condition (35±2°C) by using bench scale batch digesters at laboratories of An-Najah National University.

In all experiments, total solids (TS), total volatile solids (VS), and pH, alkalinity (ALK), also volatile fatty acids (VFA) were measured before and after digestion process. Further to these, the daily biogas and methane (CH_4) production were also measured.

Results indicated that Co-digestion system achieved the maximum biogas yield which was (499.8 Nml Biogas /g VS fed), while the biogas yield for digest each of PS, and SHW in individual digester were (411.5 Nml biogas per g VS fed, and 433.8 Nml biogas /g VS fed), respectively.

It was found that the implementation of the Co-digestion of SHW with PS has improved the biogas yield comparing with what can be achieved by digest SHW and PS separately.

Results also revealed that the CH_4 yield from the Co-digestion was the maximum value of 220.3 Nml CH_4/g VS fed, while the value of 200.1 Nml CH_4/g VS fed was produced from digest PS separately, and the lowest value of 186.9 Nml CH_4/g VS fed was achieved in case of SHW digestion separately. A result that prove along with the accumulation of VFA in the reactor the occurrence of inhibition in methanogenesis activity when the SHW was digested as individual substrate.

The biodegradability of organic matter in Co-digestion system was found greater than SHW digestion individually, since organic removal was 44.4% in case of Co- digestion system, and it was 29.1% in case of digest SHW individually, while the maximum degradation was in case of digest PS individually which was 49.0%, and this make an indication that PS sample has less complex substrate comparing with SHW and Co-digestion samples.

Results proved that implementation of anaerobic digestion to digest SHW, represents an alternative for biogas production, especially when it was applied in Co-digestion system.

This study results has given useful answers for improving the efficiency of West Nablus Wastewater Treatment Plant (WN-WWTP) and about the appropriateness of SHW treatment to enhance the waste biodegradation and enhance biogas production within anaerobic digestion stage in the treatment plant, without causing financial, operational, technical, and environmental impacts on the treatment system.

Keywords: Biogas, Methane, Anaerobic digestion, Co-digestion, Domestic Sludge, Slaughterhouse wastewater, Blood, WWTP.

Chapter One

Introduction

1.1.General

In general, the world energy consumption is exponentially increasing due to the development in technologies and the increasing in the world's population (Pandey, 2009). Energy is the main nerve of our life growth and world development, since it is a base stone of the industry and economy, so energy is an irreplaceable thing and it can't be abandoned (Nepal and Amatya, 2006).

The energy demand for global mainly is covered from utilizing fossil fuel, but use fossil fuel for energy is problematic, since such this source is finite and fast depleting, moreover the dependency on fossil fuel as primary energy source leads to emit greenhouse gases (GHG) into atmosphere, which includes methane gas (CH_4), ozone gas (O_3) and Chlorofluorocarbons gas (CFC), but mainly carbon dioxide (CO_2), and this is the most contributor in causing the global warming.

Palestine faces the same energy, environmental and economic problems and moreover, since Palestine has a special situation, because it lies under occupation for 60 years, which makes the situation more difficult.

For many years, Palestinian communities and institutions have suffered from scarcity and nonexistent of any energy sources that can be managed by Palestinian Authorities. Since Palestine is a net importer of energy, and the largest portion of Palestinian Territories energy demand is imported from Israel (Abu Hamed et al., 2012).

This dependency on Israel to cover energy demand makes the Palestinian energy sector vulnerable to political manipulation, and this situation indicates to an unsustainable situation, therefore people are trying to find an energy source that is easier and less expensive.

Also from the aspects of global warming and shortage of fossil fuel reserves, in addition to environmental concerns and military conflicts in addition to significant increase in fuel price, scientists and engineers now are looking for energy alternatives that are environmental friendly.

Renewable energy is one of the preferable solutions to the growing energy challenges, and it plays an important role in electricity supply and economic development and reduce carbon emission (OECD, 2011).

The renewable energy sources that can be exploited to produce energy in Palestine are solar energy, biomass, and wind energy. But Palestine lacks for areas that encourage to exploit the wind energy on other words Palestine has low wind speed. While there are many applications for solar energy, for example, Jericho wastewater treatment plant project, while there is a limited use for bio-energy despite the availability of raw materials (wastes) that can be used to produce biogas (Homeidan et al., 2015).

Biogas is considered a renewable fuel as it originates from organic materials, it production from organic wastes takes a special role in developing the renewable energy, since it is suitable for production the electricity and heat simultaneously (Wheeler, 2001).

Thus, biogas production has many benefits as it play roles in reducing wastes, GHG, and in producing clean energy. In addition to biogas, the residues from the digestion process can be used as fertilizer, which has a role in completing the nutrition chain in soil.

This study evaluates the feasibility of enhancing biogas production by using Co-digestion of slaughterhouse with domestic sludge as a step toward creating an alternative energy source and saving the energy cost in wastewater treatment plant (WWTP); because from the energy aspects, such of this facility is considered highly energy consuming, moreover from the environmental aspects, utilizing waste to produce biogas helps to protect the environment (water, air, and soil) from impacts and pollutions those are resulted from disposing the wastes in incorrect way.

1.2. Study Area

1.2.1. Description

As we can see from Figure 1.1, Nablus is a Palestinian city in the north of West Bank, it is the capital and the only city in Nablus Governorate, and it is classified as one of the largest cities in the West Bank, 63 kilometers far from Jerusalem city, with inhabitants of 153061, and it extends on area approximately to 32,947 dunums (PSBC, 2015).

The economy of Nablus city is based on agriculture, trade and handicrafts, in addition to industry, the most common industry in Nablus city is

manufacture the soap from olive oil, and it is considered a long-established career.

Nowadays, Nablus city is an industrial and commercial city, and is considered as Palestinian commercial and cultural center ("Nablus Guide: Culture, Society, Tourism in Nablus, West Bank, Palestine", 2017).

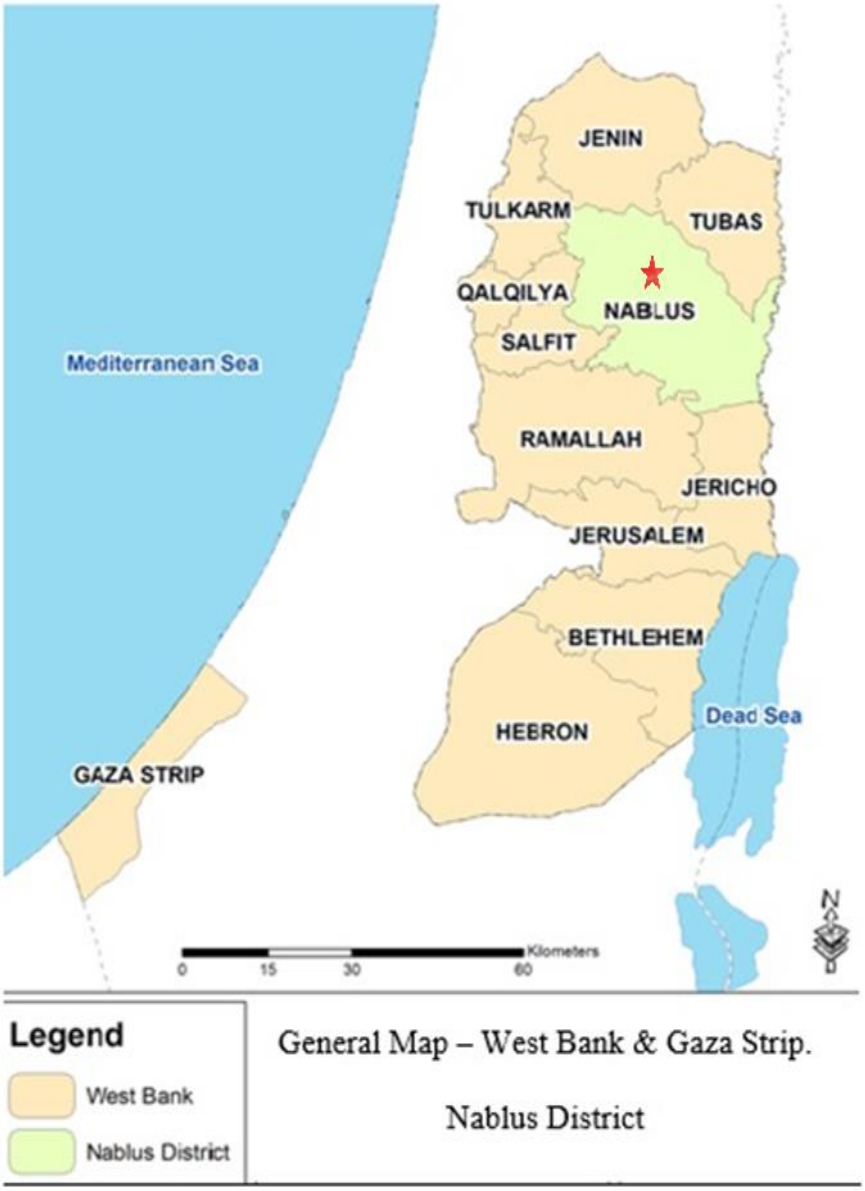

Figure 1. 1: General Map – West Bank & Gaza Strip (Nablus District).

(**Source**: Beit Iba checkpoint re-expanded and fortified despite Israeli words of “peace” and closure lifting. (2007)).

1.2.2. Wastewater Treatment Plant in Nablus City

In case of wastewater collection, Nablus city sewage system was constructed early in 1950s, it was connected with 93% of Nablus households, also it serves the refugee camps such of Balata, Askar and Ein Beit al-Ma', and residents of the remaining part (7%) use cesspits, or let their wastewater discharge into the near open valleys (Drake & Scull International PJSC, 2017).

While in case of wastewater treatment in Nablus city, there is a one WWTP in Nablus city, which is West-Nablus Wastewater Treatment Plant (WN-WWTP). WN-WWTP had been located on Deir Sharaf Village lands, 10 km north west of Nablus city, as it was shown in Figure 1.2, it serves the western parts of Nablus city and the nearby five villages, That means WN-WWTP serves around 55% of the Nablus governorate population.

The plant was operated in year 2013, and currently receives domestic wastewater, and it is processed with capacity of 15000 m^3/day (SEAP, 2017), and it treats 5.4 million cubic meters (MCM) of raw sewage (Drake & Scull International PJSC, 2017).

WN-WWTP contains two main treatment approaches, the first one is wastewater treatment path, which consist of grit chamber, primary sedimentation tank, biological tank, final sedimentation tank, filtration and disinfection, and the second path is sludge treatment which includes thickener, anaerobic digester, sludge drying basin, gas holder and flare (Abu-Ghosh, Abu-Jaffal and Homaiedan, 2014).

Figure 1. 2: Location of WN-WWTP.

(**Retrieved** from: https://www.ochaopt.org/location/west-bank)

1.2.3. Slaughterhouse Facility in Nablus City

Nablus municipality slaughterhouse, was constructed on the outskirts of the city during the 1920s, it was constructed at the east part of the city, Nablus slaughterhouse was constructed because Nablus municipality issued a special statute to organize the slaughtering services, including inspection, slaughtering and fee collection instead of dispersed slaughter in meat shops (Nablus municipality, n.d.).

There has been no expansion or major improvement in the conditions of Nablus slaughterhouse since that time. Nablus slaughterhouse provides

receiving of livestock, slaughter the animals, chilling of carcass, packaging, freezing of finished carcass in addition to rendering services.

Slaughtering activates at Nablus municipality slaughterhouse were documented in Figure 1.3. In general, the number of slaughtered animals per day is 73, on average, includes cattle as calves and sheep. Due to the cattle slaughtering and cleaning the carcasses in the Nablus municipality slaughterhouse facility, about 29,371 liters of wastewater are produced daily.

At Nablus municipality slaughterhouse, there is no available treatment unit for the waste in the site, just separation the liquid and the solid waste, then the solid waste is transferred to Zahrat Al Finjan landfill, and the wastewater is discharged to near valley not to treatment plant until now.

Figure 1. 3: Slaughtering Process at Nablus Municipality Slaughterhouse.

1.3.Research Objective

The aims of this research are:

1) Carry out the Co-digestion of organic fraction of slaughterhouse wastewater (SHW) and domestic sludge.
2) Assess of biogas generation from Co-digestion of SHW and domestic Sludge.
3) Develop an action plan for inventing safe and beneficial way of disposing SHW to WN-WWTP.

1.4.Research Questions

Our study will attempt to answer the following questions:

1) Would Mixing of SHW and domestic sludge from WN-WWTP affect on the biogas production?
2) Dose SHW in anaerobic digestion (AD) process will effect on biological activity in the digestion process?

1.5.Research Motivation

Specifically, the energy costs of the WN-WWTP are collected by Nablus municipality through the domestic water consumption bills. In addition to wastewater treatment energy costs, Nablus municipality bears the slaughterhouse solid waste disposal costs.

In addition to waste cost problem, there are environmental problem, since slaughterhouse wastewater is discharged to open area without treatment, which causing environmental problem in Nablus city.

So, after the current situation of WN-WWTP and Nablus municipality slaughterhouse was discussed, the research motivations of this study have been identified. Which are the need to reduce the wastewater treatment energy cost at WN-WWTP, in addition to treat the Nablus slaughterhouse wastewater with minimum cost.

Since entering the slaughterhouse wastewater into aeration system at WN-WWTP causes defects in its effluent, since it is a high load wastewater, therefore, more energy is required to treat that high load wastewater, which means more and more cost.

To solve the treatment cost problem, anaerobic digestion technology (AD) was proposed. AD can contribute in saving the treatment cost, by providing the biogas which can be utilized to cover energy demand for wastewater treatment plant. Also AD can help to develop a future plan to deal with the slaughterhouse wastewater.

Chapter Two

Background

2.1.Anaerobic Digestion Treatment

AD is a process of decomposition the organic materials, by which organic compounds are broken down to simple components specifically under anaerobic conditions. Simply, anaerobic microorganisms degrade the organics, in close environment without oxygen (O_2), to produce methane (CH_4) and carbon dioxide (CO_2) and other traces.

2.1.1. Stages of Anaerobic Digestion Process

To understand AD fundamentals four stages will be discussed: hydrolysis, acidogenesis, acetogenesis and methanogenesis (See Figure 2.1 and McCarty, 1982).

The hydrolysis is the beginning step and has a significant effects on methane production in AD process (Chynoweth et al., 1987). In this step lipids, proteins, carbohydrates and others, are converted into easy soluble compounds, such as amino acids, sugar, fatty acid and other, to be readily accessible for acidogenic bacteria in the next step (Henze et al., 2008).

Acidogenesis is the following step after hydrolysis, also it is called acid forming process. The biological path of acidogenesis is complementary and integral for hydrolysis, where there is further breakdown of the remaining compounds by acidogenic bacteria, in addition to turning the dissolved compounds that have been produced during the hydrolysis step into fermented products as volatile fatty acids (VFA), ethanol, lactic acid, and hydrogen, carbon dioxide (Gujer and Zehnder, 1983).

The objective of acetogenesis stage is to simplify the end products from acidogenesis step, since acidogenesis end products cannot be consumed by methane production bacteria immediately. Those products need to be broken down further into acetate, carbon dioxide (CO_2) and hydrogen (H_2) by special bacteria, which is called acetogenic bacteria to enable methanogenic bacteria to deal with them.

Methanogenesis is a final step in AD, during this step the end products of previous stages are converted to biogas. Methanogenesis stage is the most crucial one, since methanogenic microorganisms are highly sensitive to oxygen gas and to pH level.

Depending on bacteria affinity, methanogenic bacteria can be classified into two main groups: methane-forming microorganisms that are responsible to produce methane from acetic acid or methanol, and the other group that are responsible to produce methane from hydrogen and carbon dioxide. Approximately 70% of methanogenic bacteria follows the first pathway to form methane (Klass, 1984).

Because of both acetogenesis and methanogenesis occur simultaneously in AD, the products of acetogenesis are converted to methane at the same rate as their formation. So maintain balance between acetogenesis and methanogenesis is critical to maintain proper digestion system.

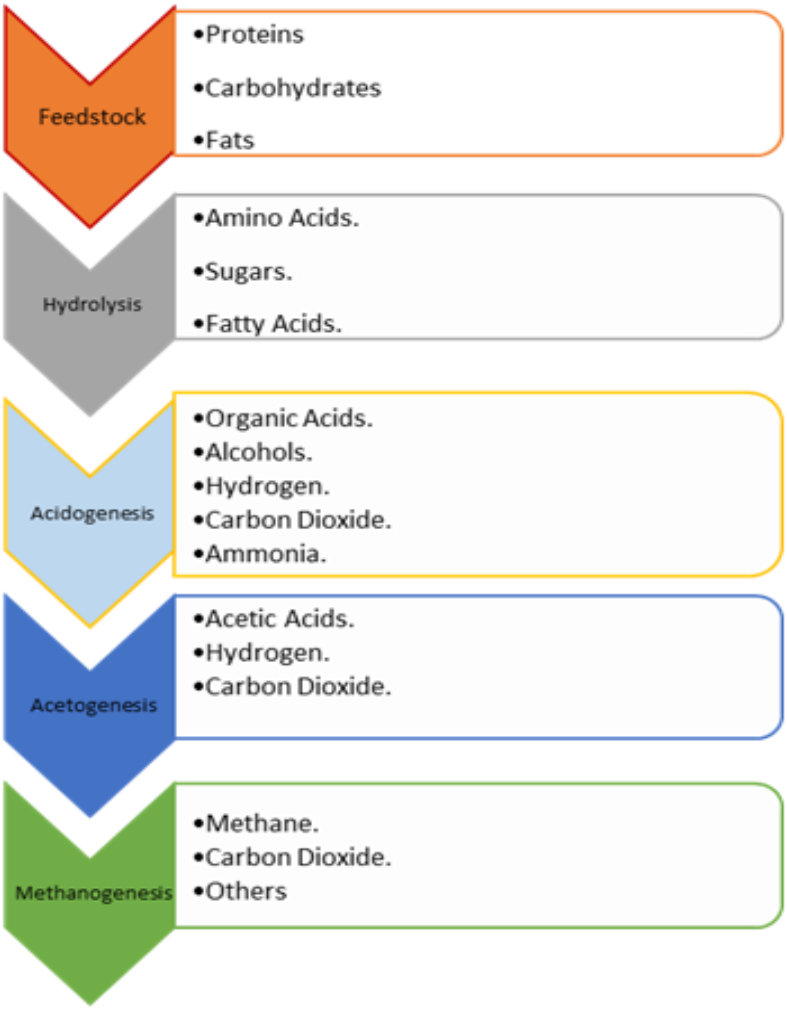

Figure 2. 1: Anaerobic Digestion Stages.

2.1.2. Operation Parameters of Anaerobic Digestion

Volatile Solids (VS): Measurement the VS during the digestion process (influent and effluent) gives an indication for the amount of waste that has been stabilized during the process, the percent of the stabilized organic matter primarily depends on the system configuration and the substrate's physical – chemical characteristics, these measurements (influent and effluent) can be used to control the digester efficiency (Lettinga et al., 1993).

Mixing: mixing improves the contact between the microorganisms and substrates and the ability of bacterial to obtain the nutrients. However, excessive mixing can disrupt the microorganisms, therefore slow mixing is preferred (Perot et al., 1988).

Temperature: temperature is essential for microbial vitality, also for rate of digestion processes and the reactions that occur during digestion processes (Boe, 2006). Commonly, most of the anaerobic digestion system are designed to operate under a mesophilic range, between 30 to 40°C, and it takes place optimally around 35°C.

Retention Time: The retention time varies vastly, and this depend on reactor geometry, intensity and substrate type in addition to operation temperature (Peyruze et al., 2009). The retention time range from few days to 40 days, depending on digester type and solids content in feedstocks.

Alkalinity (ALK) and pH: practically, in a well-operated reactor the total alkalinity must be found between 2000 and 5000 mg/L as Calcium carbonate ($CaCO_3$) (Metcalf and Eddy, 2003). Alkalinity plays an important role in the digestion process, since it maintains the pH level within the acceptable range within the digester medium.

Specifically for digestion system the optimum pH is between 6.8 and 7.4. If the pH value of slurry within digester goes out of this range the process will be subjected to failure (Seadi et al., 2008).

Volatile Fatty Acids (VFA): VFA concentration has negative impacts on anaerobic digestion system because it can cause pH drop, then as a result, the digestion process will be driven toward failure.

Carbon/Nitrogen (C:N) Ratio: The anaerobic digestion process is carried out by multi-cultural bacteria, which require sufficient nutrients to grow, and the most required nutrients are carbon and nitrogen. C:N ratio must be maintained properly, since methane production require C: N ratio around 20-35 (Ghasimi et al., 2009).

2.1.3. Types of Anaerobic Digesters

Anaerobic digestion process is occurred in air tight reactor, in batch or continuous system. In batch system, the biomass is added to the reactor at the beginning and sealed during the retention time which can be extended from 2 to 3 weeks. While, in the continuous system, the loading and withdrawal of substrate are done for several time in specific duration (Ostrem et al., 2004).

2.1.4. Co-digestion Process

Conventionally, anaerobic digestion process is operated with a single substrate, for treatment purpose. Lately, it has been recognized that anaerobic digestion turns into more stable process when it is applied for variety of substrates at the same time which called a Co-digestion process.

So Co-digestion process is defined as a digestion of a homogenous mixture of two or more substrates .

Many authors as Alvarez, and Liden, studied the Co-digestion of slaughterhouse waste, with manure, fruit and vegetable waste, and it was reported that the Co-digestion of slaughterhouse waste with various wastes had enhanced the methane generation (Alvarez and Liden, 2008). Also Weiland concluded that biogas yield could be increased, when Co-digestion principal is implemented (Weiland, 2010).

2.2.Biogas

Biogas is an energy source, it burns cleanly, and produces less carbon dioxide than fossil fuel, that is why efforts are in progress to expand the utilization of organic waste to produce biogas.

Biogas comprises mainly from methane and carbon dioxide, with traces of nitrogen, sulfuric acid, and ammonia (Kelley and Walker, 2000). Biogas is a fruitful source of energy, and there are many applications for biogas, such as generation of electricity, and as vehicle fuel (Wellinger and Lindberg, 1999).

2.3.Digestate

The remaining fraction from the digested material after degradation process is called digestate. Digestate can be used as fertilizer in agriculture, since it is rich in nutrients, as nitrogen (N), phosphorus (P), and potassium (K) will

plentifully remain within the digestate (Iacovidou et al., 2012). Thus, using of digestate has many benefits for the soil, since it can be used as a fertilizer or soil improvement in farming, and for gardens.

2.4.Benefits of Anaerobic Digestion

Righi et al., (2013), concluded that anaerobic digestion will reduce environmental impacts and it is an alternative in terms of energy production. Also Sayed 1987 reported that AD helps to remove the organic pollutants from the wastes. In addition to those, AD offers a great potential for using a renewable energy source as biogas to generate electricity, and heat. In addition to biogas, AD offers to use the digestate, since if it will be used correctly it can improve nutrient in the soil, and replace synthetic fertilizers and soil conditioners (Sayed, 1987). Thus, implementation the AD reduces waste, GHG, and produces clean energy source.

Chapter Three

Literature Review

3.1.AD of Slaughterhouse Wastewater

Several studies have been reported in many literatures for implementation the AD to treat the slaughterhouse wastes from different origins as bovine, swine and poultry, also many literatures were reported about using of these types of wastes in Co-digestion process.

Bayr et al. (2012), Studied the effect of temperature on biogas production in semi-continuous system, on Co-digestion of rendering and slaughterhouse wastes including bovine, swine and poultry wastes. In their study relation between methane yield and temperature was obtained, since in mesophilic system, the obtained methane yields was 720 mL CH_4 /g VS (added) when the organic loading rates (OLR) was 1.0 and 1.5 g VS/ L.d. While in case of thermophilic system, lowest OLR was selected, and the process faced operation problems after 1.5 hydraulic retention time (HRT), because of accumulation ammonia, and VFA in addition to long chain fatty acids (LCFA) within the digester slurry.

Alvarez and Liden. (2008), also carried out a research on Co-digestion of fruit and vegetable wastes with slaughterhouse waste in 2000 mL semi-continuous anaerobic reactor at 35°C. In their study enhancement in methane production was obtained due to mixing fruit with slaughterhouse waste, since it was reported that a higher methane production was obtained from Co-digestion system than the methane production from digest each substrate separately.

Moreover it was reported that it is possible to reach up to 50% and 65% reduction in volatile solid contents. Also it was found that the methane yield is affected by OLR, since the relation between them concluded that methane yield increased when the OLR increased up to 0.34 g VS/ L.d, and then any additional increasing in OLR led to decline in biogas production and reduced the methane content in the produced biogas.

Also Co-digestion of solid slaughterhouse waste with municipal solid waste was conducted by Cuetos et al. (2008), the study was carried out on in a semi-continuous process at mesophilic conditions, with hydraulic retention time (HRT) equal to 25 days. As a result an inhibition in slaughterhouse waste digestion was observed, since digestion the solid slaughterhouse waste without adding organic fraction municipal solid waste (OFMSW) failed at OLR equal to 1.7 g VS/ L.d. While the biogas production in case of Co-digestion system was double when comparing it with biogas production from digestion slaughterhouse waste separately.

Palatsi et al. (2011), studied the main limiting factors in digestion of slaughterhouse wastes, so digestion experiment was carried out on mixtures from pig and cattle slaughterhouse waste, and it was founded that the methane production was within 270 - 300 mL CH_4 / g COD. Moreover, an inhibition was reported at higher waste concentration. So it was concluded that slaughterhouse waste is suitable feedstock for digestion process but inhibition problem could be at a high OLR.

Also, it was observed that lipid rich substrate had a slower degradation kinetic than protein rich substrate, therefore it was justified as that the high

lipid concentration caused a LCFA inhibition, which led to long lag phase in CH_4 formation and uncompleted substrate degradation.

Batch and semi-continuous experiments for Co-digestion the pig slaughterhouse waste with sewage sludge was carried out by Borowski and Kubacki (2015), the experiment was carried out at temperature 35°C, and in their results, it was reported that the highest methane yield was observed from digest pig slaughterhouse waste in average 901 mL CH_4 /g VS, while the lower methane yield 370 mL CH_4 /g VS was shown in case of sewage sludge digestion, and mid value which was about 600 mL CH_4 /g VS, was obtained from Co-digestion the pig slaughterhouse waste with sewage sludge (50% weight basis), so it was reported as an enhancement in methane production from digest sewage sludge alone. Moreover an inhibition in methanogenesis step was reported, when the OLR was more than 4 g VS/L.d.

Also, Luste and Luostarinen (2010), carried out digestion experiment on mixture of meat-processing by-products and sewage sludge at ratio of 1:3 (based on volume) at mesophilic temperature. It was reported that the 20-days as solid retention time (SRT) with organic loading rates (OLR) within 1.8 to 4.0 g VS/ L.d, were the most suitable to obtain the highest methane yield, since 410 mL methane per g of added VS was recorded.

Pitk et al. (2013), studied the Co-digestion of sewage sludge with sterilized solid slaughterhouse waste from cattle and bovine, in Batch and semi-continuous systems. In their results it was reported that the highest methane production was achieved from the mixture that contained the lowest solid

slaughterhouse waste proportion, since 645 mL CH_4 / g VS was reported from the mixture that contained only 5% from solid slaughterhouse waste (w/w), and it was stated that an additional fraction from the sterilized solid slaughterhouse waste up to %7.5 (w/w) caused production the free ammonia within the digester slurry, which led to inhibition in methanogenesis bacteria in the digestion system. Moreover foaming and Long chain fatty acids (LCFA) problems were reported, when proportion of the sterilized solid slaughterhouse waste was %10 (w/w).

Hejnfelt and Angelidaki (2009), carried out a study on anaerobic digestion of slaughterhouse waste (animal by-products), their study was executed in batch and semi-continuously systems, at 55°C also at 37°C. In the results of their study it was reported that the methane potential for batch test of slaughterhouse by-products achieved 50 - 100% of the theoretical methane potential. And it was reported that the mixing of by-products with other type of waste improved the methane yield. Also it was reported that there was no enhancement in methane production when pretreatment (pasteurization the by-products on 70°C, and sterilization at 133°C, in addition to use NaOH) was utilized.

Finally it was concluded that the mesophilic process was the best in digestion process stability, and higher methane yield can be obtained at high waste concentrations. In contrast to thermophilic since lower yield was obtained at high concentration, because of ammonia inhibition.

Ware and Power (2016), executed a study in order to evaluate the energy recovery from the organic waste at cattle slaughterhouse. Their study was

conducted in a full scale cattle slaughterhouse. In their study, sludge from dissolved air flotation unit, paunch, and soft offal were used to conduct the biochemical methane potential test at mesophilic conditions. And their study data shown the methane yield of the tested wastes varied between 49.5 to 650.9 mL CH_4 / g VS. Moreover, 100% of the energy demand for the intended slaughterhouse facility was covered, also 1.63% from the energy demands for industrial sector in Ireland was covered.

Labatut et al. (2012), in their report about monitoring the AD system, it was recommended to use pH, TS, VS, VFA, and ALK in order to evaluate the AD process, and to optimize the process performance and minimize the possibility of occurrence the failure in the system. Also Teame et al., (2014) stated that the assessment of VS for AD system is a useful parameter to give an indication about AD stability and efficiency. Also Foley (2010), state in his thesis that percentage of volatile solid reduction are usually used to determine the biogas production from sludge, and its production can vastly vary.

3.2.AD of Domestic Sludge

Several studies have been reported in many literatures for the anaerobic digestion of domestic sludge, in addition to that, the use of domestic sludge in Co-digestion process in order to enhance the digestion of complex waste was also reported in literatures.

Arthur et al. (2010), studied the possibility of biogas production from primary sludge from treatment plant at Kwame Nkrumah University of

science and technology (KNUST), for that lab experiment was executed to investigate the biogas potential for KNUST primary sludge, and it was reported in their results, that biogas potential was around 525 ml /g VS.

Serrano et al. (2013), studied the biogas production from Co-digestion sewage sludge with orange peel, in mesophilic range at 35°C, and it was found that methane production was enhanced when Co-digestion was used comparing with methane production from digest sewage and peel separately, since the methane production was recorded around 165 ml CH_4 / g VS, moreover an improvement in solid reduction was observed in Co-digestion system comparing with the archived reduction in solo digestion system, since it was recorded about 76% reduction in VS in case Co-digestion while it was recorded around 53% in case of digest sewage sludge. In addition to that, it was reported that digestion the peel with sewage boosted the nutrients comparing with case of digestion sewage sludge.

Pastor et al. (2013), assessed the feasibility of treatment oil and landfill leachates by digest them with sewage sludge, so biochemical methane potential test (BMP) was executed at lab in mesophilic range at 38°C to, and from their results, it was observed that fresh sludge produced 6.1 ml CH_4/ g VS at STP condition, and fresh leachates produced lower methane volume.

Moreover, Co-digestion sewage with oil was also carried out in their study, and it was reported that the reduction in VS was improved by

implementing the Co-digestion system (since it was increased around 11%, also biogas production was enhanced by 23.5%).

Budych-Gorzna et al. (2016), investigated the possibility of entering the poultry waste into full scale digester that is operated at WWTP, so lab experiment was conducted for that purpose. From the lab experiment results, it was concluded that poultry waste able to produce 390 to 880 ml CH_4/g VS, and it varied according to the added amount of the waste, while in full scale case it produced about 810 ml CH_4/ g VS, so as a conclusion, it was reported that an enhancement in biogas production was achieved through poultry Co-digestion.

Xie et al. (2017), tried to evaluate the effects from Co-digestion the primary sludge with other organic wastes like food, paper pulp wastes, therefore lab scale experiment at 35°C was conducted, and it was found that Co-digestion of primary sludge with food waste or paper pulp waste played a role in enhancing the methane production, and in avoiding occurrence the inhibition event within process.

3.3.Summary

There are many treatment methods available today to treat slaughterhouse wastewater in developing countries, such as rendering, incineration, AD, and alkaline hydrolysis (Franke-Whittle and Insam, 2012). While in Palestine there is no application for any type of these methods in slaughterhouse facilities, so in this study it was suggested to use AD to

treat the slaughterhouse wastewater, because AD is simple installation method with low energy and small area requirements.

AD represents an alternative method for dealing with the wastes, that are produced from slaughterhouses, since slaughterhouse wastes are rich in proteins and nitrogen, ,thus slaughterhouse wastes are perfect substrates for the AD process. By this, dual benefits will be gathered from AD implementation, since it has a role in eliminating the waste material and producing a renewable energy source.

In case of treatment the slaughterhouse wastewater, digestion system could face many problems, such those have been discussed in the previous studies. failures that occur in anaerobic digester are commonly reported due to the accumulation of inhibitors like LCFA and VFA and free ammonia, since their accumulation cause low methane production from the system. So, first of all, the appropriate digestion conditions must be provided in order to make the process work in stable and successful situation. Mainly, OLR and HRT are limiting parameters that play a major role to run a stable digester in continuous system.

In many researches it was recommended to utilize of Co-digestion of slaughterhouse wastes with other type of waste like sewage waste, food and manure. Since the implementation of the Co-digestion will help to avoid the LCFA accumulation and will enhance the ammonia function that promote microbial growth instead of inhibiting it.

In this study, it was decided to use domestic sludge as digester feed substrate, since domestic sludge has been known as one of the most

preferable substrate for the anaerobic digestion, since it is rich with nutrients as carbohydrates, in addition to that, it has low heavy metal concentrations.

Also after the previous studies have been discussed, it was found that many researchers propose to use mesophilic range instead of thermophilic; because the occurrence of ammonia inhibition in digestion system will be higher, for that this study was carried at 35 °C.

Washout is another limitation factor, that anaerobic digestion system could face it, especially in continuous digestion system, in case of happening the washout, bacteria that responsible to execute acidogenesis and methanogenesis stages will be lost from the digester. Also researchers reported that Digester washout occurs due to high OLR.

Furthermore; because of the continuous reactor requires a peristaltic pump and other tools which it was difficult to get them, it was decided to use batch system.

Volatile solid (VS) term is defined as organic material within the substrate composition. It is a simple, direct and inexpensive method to determine the organic fractions.

Moreover as it can be seen in discussion the listed previous studies, VS degradation is considered as a main assessment parameter that is usually used to evaluate the efficiency of digestion process. Importance of VS term is came from its direct relation with amount of biogas and methane that can be produced from the examined substrate, because VS is converted into biogas during digestion process. Therefor it was decided to use term of VS

reduction to assess the efficiency of anaerobic digestion process, in addition to biogas and methane yield.

Many studies have been reported in literatures, but making comparisons between their results are somehow difficult due to the differences between the experiments that have been carried out to obtain those studies results, those differences are type of substrates, characteristics of tested substrates, inoculum sources, size and concentration, in addition to operation and process conditions, further to the available techniques that can be used in experiments. This state was also supported by many bio-technologist researchers such as Wilson Parawira, Marika Murto, and R Zvauya (Parawira et al., 2004).

Moreover, after the previous studies that concerned on digestion the slaughterhouse wastes were reviewed, it was found that those studies were conducted on different waste sources as Cattle, pig and poultry wastes, and they were conducted on different types such as solid waste and liquid waste, many studies were conducted on slaughterhouse wastewater, but after recovery the blood or after it was subjected to pretreatment phase.

Moreover, based on my literature review and knowledge there was no study that has been previously done in Palestine on digestion of the fresh slaughterhouse wastewater, SHW, in combination with PS.

Chapter Four

Method and Material

4.1. General

The experimental methods, which have been adopted in this research, will be discussed in details in the following sections, along with reactor design, sample collection, and parametric analysis in addition to assumptions which have been used to carry out the experiments. The working steps for the research were illustrated below in Figure 4.1.

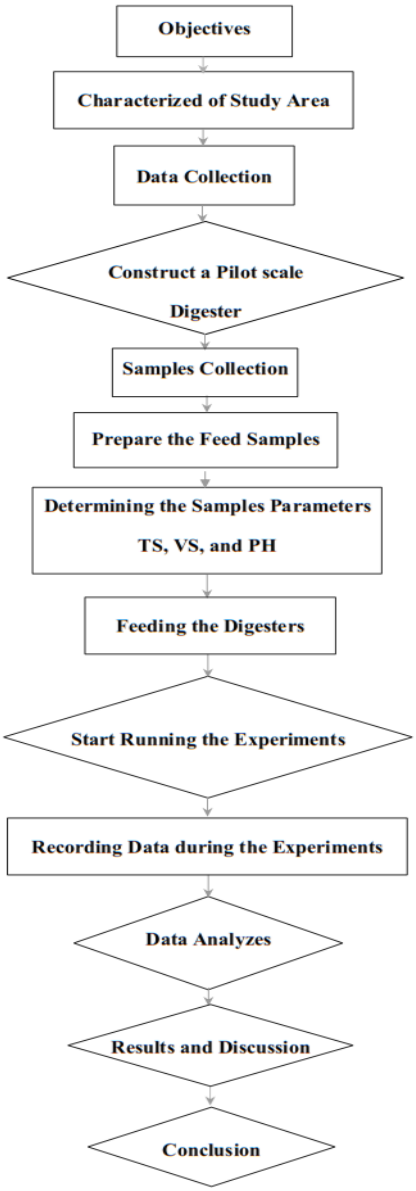

Figure 4. 1: Working Steps for the Research.

4.2.Experimental Setup

4.2.1. Laboratory Experiments

For this study, the laboratory experiments included running of bench-scale anaerobic digestion systems under controlled conditions, two main experiments were executed, the first experiment (EXP 1) has been carried out at Environmental lab – Faculty of Engineering and the second experiment (EXP 2) has been conducted at wastewater lab at Water and Environmental Studies Institute (WESI) at An-Najah national University. These experiments have been carried out during January to March in 2017.

At the beginning, concern must be paid that both experiments have been conducted during winter season, and this was one of reasons for many problems in experiments also in collection the tested substrates.

Reactor Design and Preliminary Trials

To measure the produced biogas through anaerobic digestion process, it was found that the best investigation method was to create a small digester reactor that remains enclosed for specific duration as batch system. Therefore, two batch Lab-scale reactors were operated in this study.

Reactor design: Multi trials were conducted in laboratories before the final design option was approved. During these trials observations were made on quality of the system in order to improve the final design of reactors that would be used in experiments. The design details will be described in the next section, see section 4.2.3.

Equipments and accessories: because of there is not any bio-reactor in the university laboratories available to use in this study, it was proposed to design a new simple reactor, that can help to carry out the research easily and correctly. The reactor that was proposed to design must be suitable for this study objectives and can meet all specifications, also it must be applicable and financially feasible, so immediately looking for available equipments has been started. Most of materials and equipments those have been used in thesis experiments, are listed in the following Table:

Table 4. 1: Materials and Equipments:

Material and equipments	
1. Epoxy.	2. Needles.
3. Hybex™ Glass Bottle (2000 mL).	4. Glass Rods with Diameter Of 6" And 8".
5. Polypropylene Cap (140°C).	6. Tygon Pipe PTTE.
7. IV Set Medical Pipe.	8. Tubing Connectors-Adapters (T Pattern).
9. Silicon.	10. Syringes.
11. Tape.	12. Serum Bottles (600 ml).
13. Magnetic Stirrers.	14. Sieve.
15. Shaker.	16. Funnel.
17. Stands.	18. Incubator.
19. Graduated Cylinders.	20. Water Bath.
21. Beakers.	22. Thermometer.

Testing the digestion system: before carrying out the experiment and bringing the samples for the laboratories, necessary tests need to be done on the designed reactors, in order to ensure their effectiveness and to check that there are no leaks and problems between the connections and joints, in addition to those tests, calibration was also done for all electronic equipments which have been used in study, for example the incubator was calibrated to work at temperature 35 ± 2 °C.

Checking the gas leakage: before initiating the experiments, each digester was subjected to leakage test, to see whether or not gas can easily escape from the reactor as it can be seen in Figure 4.2 and 4.3. In this test, vacuum pump was used in addition to detergent foam that was added on connections, cap ports, and serum septa rubbers to check if whether there any bubbles can be formed. Moreover the pipes of IV set pipe also were subjected to this test.

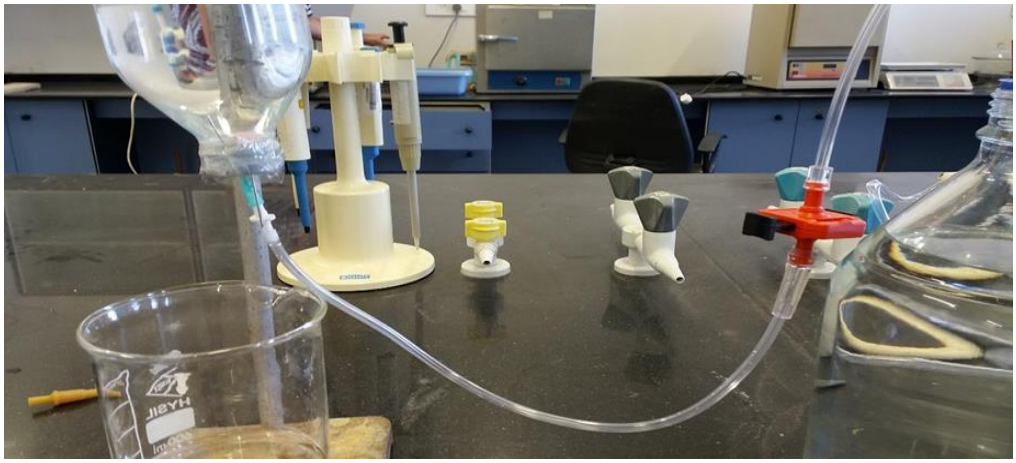

Figure 4. 2: Check the Leakage in Water Displacement Unit.

Figure 4. 3: Check the Leakage in Serum Bottles.

Workability and Performance: each reactor was compiled for check of its workability and performance, easiness of feeding the substrates and taking the samples from reactor content, and possibility for occurrence the clogging was also checked.

Also the workability of gas transforming from reactor headspace to water displacement unit was checked, and the elevation of gas measuring unit that allows gas to escape from headspace was adjusted.

Check the measurability of Multi Gas Detectors device: gas sample from cooking gas cylinder was brought and injected it into detector device by syringe and check the maximum range of device in addition to time required to response.

Preliminary trials: A lot of trials have been conducted in order to find the best way to keep the inoculum active without effecting on its microbial population.

Several times, inoculum was brought from WN-WWTP in different ways and insert it into serum bottles and then pure nitrogen gas (N_2) gas was used to flush the bottle headspace, and finally gloves were put on the top of the bottle In order to see, if the glove will be inflated as a result of gas formation, then the bottle was kept in incubator at 35 ± 2 °C for few days to see if there any gas production, as it can be seen in Figure 4.4. Actually several trials have been made to define the suitable method to deal with inoculum.

Figure 4. 4: Preliminary Investigation for Inoculum Activity.

4.2.2. Reactor Installation and Equipment Setup

Lab-scale experiments were performed by using batch system, in total 12 batch reactors have been used to carry out the experiments, the first 5 reactors have volume of 2000 mL, and the rest have volume of 600 ml.

In the final reactor design for EXP 1, the batch reactor was made from a autoclave glass bottle with capacity of 2000 mL, with working volume of 1400 mL, in addition to keep 600 mL as headspace. The reactor diameter was 23.7 cm and height was 34.5 cm. Each reactor was equipped with a 3-ports screw cap, three house connections, first one was used as reactor inlet, to feed reactor with substrates, and it was extended down to 25 cm below the upper level of the reactor to avoid gas losses. The second one was implemented as samples port, to take samples from digester, and it was drawn down to 20 cm from reactor top, the last port was used as gas outlet which was connected with valve and PTFE pipe that connects the reactor with gas measuring unit. For more details about EXP 1 reactor design see Figure 4.5.

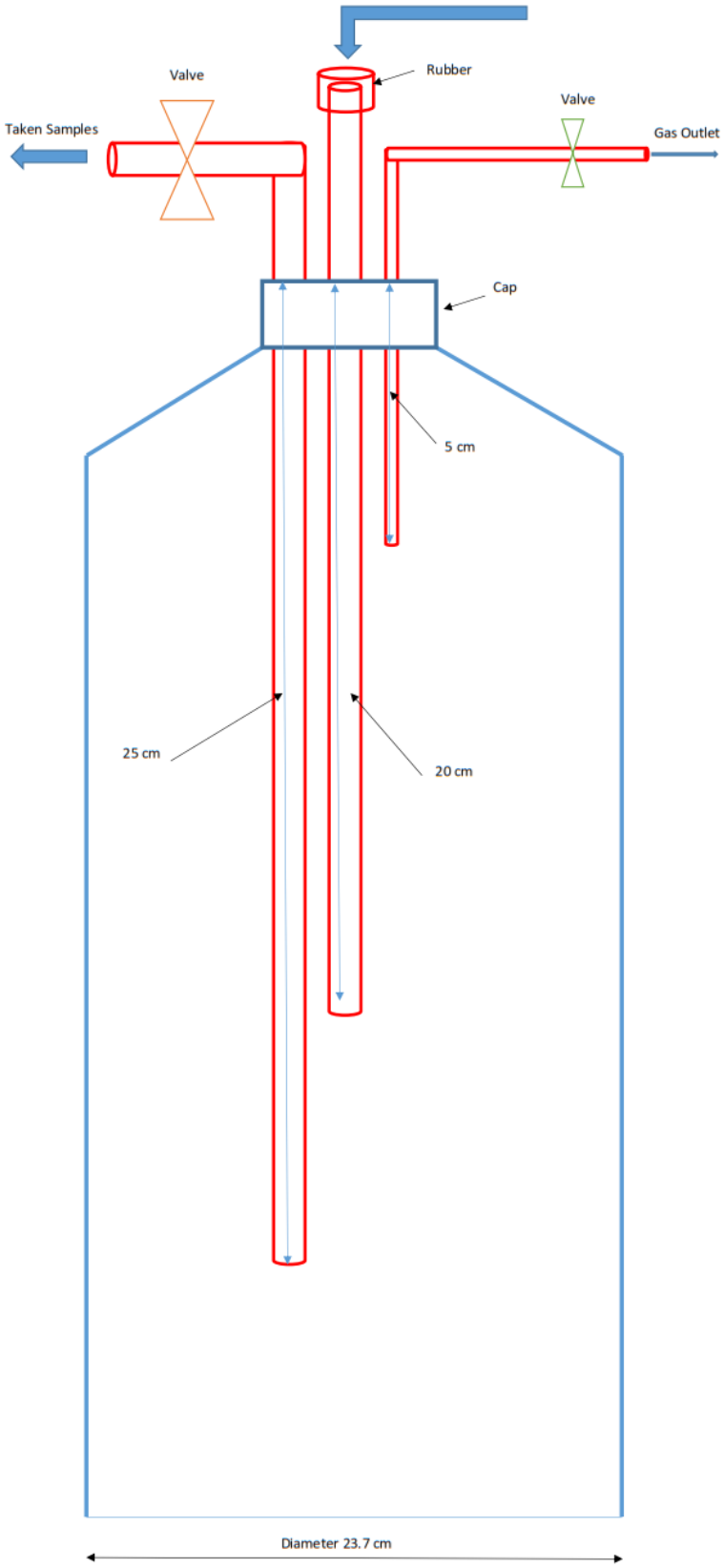

Figure 4. 5: Schematic for Design the Bench Scale Reactor for EXP 1.

While in the second experiment (EXP 2), it was decided to use simple reactors, to avoid and minimize the hydraulics problems which could be occurred during the experiment conducting, each reactor was made up from serum bottle with volume 600 ml seal by septum rubber and aluminium cap, in addition to IV set pipe and needles.

4.2.3. Gas Measuring Unit

To measure volume of the produced biogas during the experiments, it was decided to apply the water displacement method, because it is acceptable scientifically and practically. It is also technically and financially feasible. Moreover there are no other alternatives in the lab to use.

In the first experiment (EXP1), graduated cylinders have been used, each cylinder was connected directly with the reactor by PTFE pipe and valve, each cylinder was filled with barrier solution. While in second experiment (EXP 2), serum bottles were used instead of the cylinders, with same barrier solution. For more details about gas measuring unit see Figure 4.6.

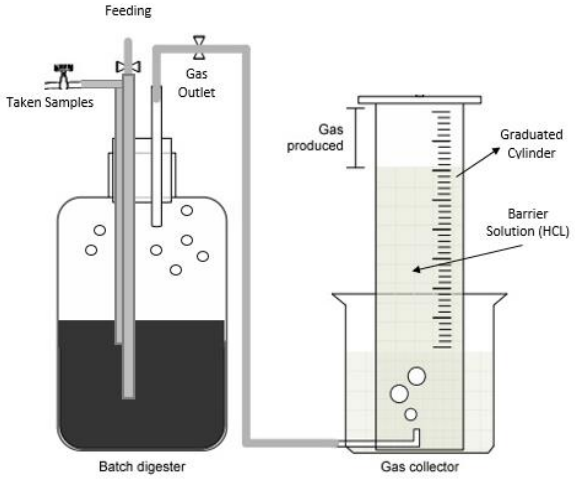

Figure 4. 6: Schematic for Gas Measuring Unit**.**

(**Adapted from:** "Evaluation of anaerobic digestion process for derived-MBT organic solid wastes" by Arsand, M. (2008). https://dspace.lib.cranfield.ac.uk/handle/1826/6569).

In the case of measurement the produced methane, two options were proposed to use, either use a water displacement method with sodium hydroxide (NaOH) solution as barrier solution or use the Multi Gas Detectors device.

For the first option, one of its disadvantages, that its using will increase the probability of leakage and hydraulic problems such as problems in pressure. In addition to this, it was difficult for to connect the reactor with another water displacement unit, so it was decided to use the Multi Gas Detectors device instead of water displacement method.

In case of Gas Measurement Unit, the displaced solution from the measuring unit was measured by graduated pipette to ensure the accurate measuring volume. Every day the barrier solutions in all cylinders and serum bottles were renewed.

4.2.4. Chemical Solution Preparation

In the experiments a lot of chemical solutions were used, some of them were used for the physical - chemical examination, and others were used as barrier solution in of gas measurement unit.

Sulfuric acids (H_2SO_4):

0.1N H_2SO_4, solution was prepared, to use it in titrimetric method for determination the VFA, ALK ratio, method will be described in section 4.3.6.

Barrier solutions:

Barrier solution is a solution that was used in gas measurement unit - water displacement method to measure biogas volume, barrier solutions that have been used in this study are:

Sodium hydroxide (NaOH) solution, which was prepared with 5 M (pH > 12) in order to maintain high CO_2 absorption, also thymolphthalien indicator was added into NaOH solution to serve as an indication for changing the solution, since its color changes from blue to colorless when the pH fall below 9.4, which indicates to low efficiency of the absorption of CO_2.

Sodium chloride (95% NaCl) solution, which was prepared with Ph < 2, in order to prevent dissolution biogas in gas measurement unit.

Finally Hydrochloric acid (HCl) solution (acidified water) with 0.01 M solution, which was prepared also in order to measure and storage produced biogas during the experiments.

Because clogging occurred in needles and pipes due to saturation NaCl solution it was decided to use HCl as barrier solution to measure biogas volume instead of NaCl solution.

4.3.Experimental Program

4.3.1. Samples Collection

Domestic Sludge: for the first experiment (EXP 1) sludge samples were collected from WN-WWTP, the first sample was imported from primary settling tank at the WN-WWTP in January, and it was rejected because it was so diluted sample due to a rain event that was occurred in previous days. So another sample for EXP 1 was taken after few days from mixing tank directly prior to the digester in the WN-WWTP. The mixing tank is a tank collects primary sludge and activated sludge to form what is called a sewage sludge (SS), primary and activated sludge are mixed in that tank at ratio consistent with their production rates, and the sludge sample for EXP 2 was taken in February from primary settling tank.

After taken the representative and suitable sample, it was transported to the laboratory in polyethylene container and it was transferred in cooler box, then it was stored at 4 °C for one day before it was used.

Slaughterhouse Wastewater: the slaughterhouse wastewater (SHW) samples, that have been used in the experiments, were brought from the Nablus municipality slaughterhouse. The first sample for EXP 1 was taken in January, and the second one for EXP 2 was handled in February. Slaughterhouse wastewater sample (SHW) was collected during slaughtering period, which extend for 3 to 4 hours daily, more than 12 samples were taken along this period, and finally all of these samples were

mixed together in polyethylene container to make a representative sample for slaughterhouse wastewater.

Those samples were picked out from sewer system of the slaughterhouse facility through a manhole located within the slaughter room (slaughter area), which collects and then discharges the wastewater from slaughtering activity to outside the slaughterhouse facility. After sample was transported to the laboratory, it was kept at 4^{o}C for one day. See Figure 4.7 for more details about SHW Samples collection.

It is important to mention that the slaughterhouse wastewater (SHW) sample, which was used in this study, was produced from slaughtering practices, so it was taken from stream that discharged from slaughter room, which means that it did not include the toilet and other activity wastes. So, that slaughterhouse wastewater (SHW) sample can be described as a sample of water, blood and small pieces of meat, fat from washing the slaughtered animals.

Figure 4. 7: SHW Sample Collection.

4.3.2. Preparation the Feed Substrates

The feed substrates, which will be used in the experiments to study the effect of implementation the Co-digestion on biogas yield, were prepared according to specific mixing ratios. These ratios were selected depending on possibilities and availability of equipments and reactors, in addition, to make sure that all the possibilities were covered, also to help in analyzing the data and to find what is being looked for in this study.

Practically, since production of biogas from domestic sludge is a proven technology and well accepted in world, the Co-digestion sample for EXP 2 have been prepared to have at least 50% of its volume from domestic sludge sample, also because the actual productivity for domestic sludge is higher than SHW in normal operations condition.

EXP 1 was conducted with sewage sludge (SS) and SHW, in addition to mixtures at different proportions, as what are reported in Table 4.2 and Table 4.3. While, EXP 2 was performed with primary sludge (PS) and SHW, in addition to mixture of both at specific ratio (1:1) v/v, details are reported below in Table 4.4.

After the mixtures calculations were finished and the required quantity from each substrate was determined to prepare the mixtures, the mixtures were manually and properly mixed until it became well homogenized. Digesters were manually fed directly after mixtures were prepared.

Table 4. 2: Proportions of Substrates in Reactors of EXP 1:

Reactor	%Contribution in mixture volume		%Volume of feed / total reactor volume	%Inoculum from reactor volume	%Headspace
Reactor	SS	SHW	Feed	I	Headspace
D1	0%	0%	0%	20%	80%
D2	100%	0%	50%	20%	30%
D3	0%	100%	50%	20%	30%
D4	75%	25%	50%	20%	30%
D5	25%	75%	50%	20%	30%

Table 4. 3: Volume of Content in each Reactors of EXP 1:

Digester	SS (ml)	SHW (ml)	Inoculum (ml)	Work volume (ml)	Total Volume (mL)
D1(Blank)	0	0	400	400	2000
D2	1000	0	400	1400	2000
D3	0	1000	400	1400	2000
D4	250	750	400	1400	2000
D5	750	250	400	1400	2000

Table 4. 4: Proportions of Substrates in Reactors of EXP 2:

	%Contribution in mixture (%volume)		Inoculum : Substrate ratio (based on VS)
Reactor	PS	SHW	I:S
D-PS			
D 1	100%	0%	2:1
D 2	100%	0%	2:1
D-SHW			
D 1	0%	100%	2:1
D 2	0%	100%	2:1
D-CO			
D 1	50%	50%	2:1
D 2	50%	50%	2:1
Blank	0%	0%	---

The 100% and 0% assays were performed in order to compare them with the Co-digestion assay and to assess any differences in the typical parameters (VS reduction, Biogas yield, methane yield) or detect any inhibition effects..

4.3.3. Inoculation

Prior to start the experiments, all anaerobic decomposition requirements have to be provided, and the most important one of these requirements is the presence of the microorganisms that are responsible on digestion process and it must be available in sufficient population in order to succeed digestion process.

Therefore, at the beginning phase of each experiment, each reactor was inoculated with adequate volume from inoculum sample, for seeding that reactor, the inoculum sample was brought from a full-scale anaerobic digester, which is operated by WN- WWTP at 35 °C.

The inoculum sample was transported in 3 and 10 liters polyethylene containers as soon as possible in shortest possible duration, and during the transportation, inoculum temperature drop was taken into consideration and it was avoided by using a Styrofoam Box and cooler box, with hot water bottles to keep temperature inside the box within acceptable range near to 35 °C.

Two different amounts of inoculum were decided to be used in experiments, in more details, for conducting EXP 1, the inoculum ratio was selected after reviewing many researches in anaerobic digestion technology, after all the reviews, and advices were taken from specialists, the inoculum ratio was selected to be 20% of reactor volume (Rodriguez et al., 2001).

Initially, 400 mL of inoculum was added into each digester at the first day and then it was directly flushed with pure N_2 gas. Later on, the reactors were placed in water bath at temperature equal to experiment temperature for 3-5 days.

While, in case of EXP 2, the inoculum amount was determined based on constant ratio between inoculum and substrate (which is called I/S ratio) for all reactors, I/S ratio was decided to be equal 2/1 based on VS, this decision was taken because that EXP 1 shown long lag phase and inoculation period and this is due to low inoculum amount comparing with feed amount. After the inoculum amount was determined based on VS, and after it was fed into reactors, same flushing procedure was also done. Then all reactors were put in incubator at experiment temperature.

Flushing with Nitrogen gas (N_2): after each digester was fed with the substrate, the air occupied the headspace in each digester. Existing an ambient air in digester headspace means that the initial condition inside the digester contains oxygen gas and this is not perfectly anaerobically condition, so it is impossible for anaerobic bacteria to survive long enough to produce significant gas. To solve this problem, it was proposed to use N_2 gas for flushing reactors headspaces. For more details about nitrogen gas flushing procedure see Figure 4.8.

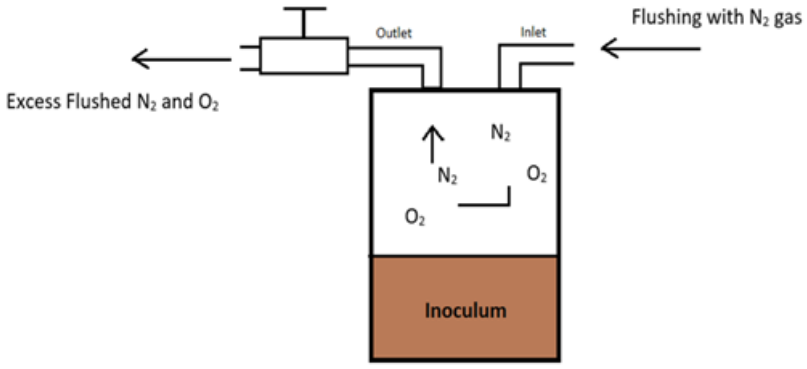

Figure 4. 8: Illustration of N_2 gas Flushing.

(**Adapted** from "Kinetic Modeling and Experimentation of Anaerobic Digestion" by Rea, J. (2014). Massachusetts Institute of Technology.58pp).

4.3.4. Feeding the Reactors

First experiment (EXP 1) has been carried out in the period from 12 January 2017 to 20 March 2017, on five digesters with a capacity of two liters for each one, at the first day all reactors were inoculated with 400 mL of inoculum, at the fifth day of inoculation, the mixtures, which were prepared in lab according to mixing ratios that were represented in Table 4.2, were introduced into four reactors from the five manually by using a syringe and funnel.

After each reactor was fed, it was flushed with nitrogen gas then it was firmly closed and it was incubated at 35 ± 2°C, for more details see Figure 4.9. After reactors were closed, each reactor content was mixed very well, in order to maintain the effective contacting between the bacteria and the organic fraction within the mixture.

Basically, the efficiencies of biologically treatments of organic waste are extremely affected by characteristics of this influent waste (Rajeshwari et al., 2000). Characteristics of the tested substrates for EXP 1 are presented in following table, see Table 4.5.

Table 4. 5: Characteristics of Raw Tested Substrates (EXP 1)

Parameters	Sewage Sludge (SS)	Slaughterhouse wastewater (SHW)	Inoculum
PH	7.28	7.68	7.15
TS(mg/L)	25.11	5.76	21
VS(mg/L)	19.09	4.76	16.36
COD(mg/L)	37400	10860	22500

Figure 4. 9: Executed EXP 1.

Second batch experiment (EXP 2), which has been carried out in the period of 23 February, 2017 to 20 March, 2017, on three experimental lines with duplicates were in addition to blank (control), for more details see Figure 4.10. Assays were performed in duplicates, in order to evaluate the gas yield for each substrate and to ensure that the same results will be in each time when the same substrate will be tested.

EXP 1 was carried out on primary sludge (PS) and slaughterhouse wastewater (SHW) also on a mixture of both (PS : SHW) at a volume ratio of 50 % to 50 %, see Figure 4.11.

All batch reactors were filled with the tested substrates (raw materials, mixtures with inoculum) only at the beginning of experiment, after that each reactor was flushed directly by N_2 gas, then it was firmly closed by its septum rubber in addition to tape, and then their content were mixed well after introduce the substrates, in order to maintain the effective contacting between the bacteria and the organic fraction within mixture. after that, they have been incubated at 35 ± 2°C in incubator, and the mixing was provided by shaker.

The EXP 1 was conducted for 25 days as a retention time, which is normally enough for complete digestion process. Since it was reported that the retention time for a mesophilic digestion system ranges between 10 and 30 days. Characteristics of the tested substrates for EXP 2 are presented in following Table 4.6.

Table 4. 6: Characteristics of Raw Tested Substrates (EXP 2)

Parameters	Primary Sludge (PS)	Slaughterhouse wastewater (SHW)	Inoculum
PH	5.77	6.7	7.18
TS (g/L**)**	18 ± 0.11	7.2 ± 0.16	21.6 ± 0.18
VS (g/L**)**	14.51 ± 0.13	6.46 ± 0.17	11.45 ± 0.11
COD(mg/L**)**	16400	8500	16200
ALK (mg $CaCO_3$/L**)**	3450	1150	3700
VFA (mg CH_3COOH/L**)**	2332	340	340

Blank (control) reactor with inoculum only has been also used to determine the produced gas from inoculum. This value has been subtracted from the gas that was produced from reactor of PS and SHW and Co-digestion.

Figure 4. 10: Executed EXP 2.

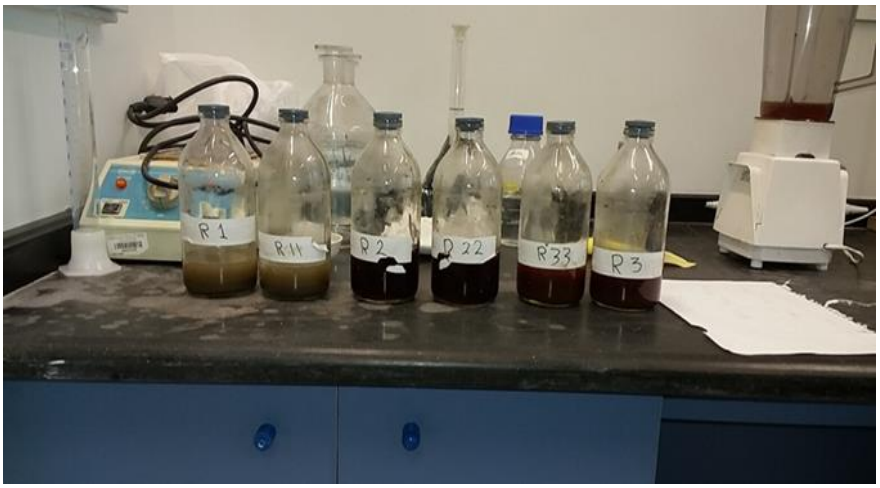

Figure 4. 11: Feed Samples in Reactors Before Inoculation.

4.3.5. Biogas Measurement

The volume of the produced biogas was collected by water displacement method using Hydrochloric acid (HCl) solution with pH lower than 2, in order to obtain the total volume of the produced gas, also biogas sample was taken by syringe from the collected gas and then it was injected into Multi gas detector (portable biogas analyzer) to determine the percent of methane within the produced biogas. By this, total biogas and methane volume for each digester can be calculated.

Volume of the produced biogas has been measured daily. Ambient temperature was read and recorded from the laboratory Temperature Control Unit. The measured volumes for both methane and biogas have been presented at standard temperature and pressure (STP); 0˚C, 101.325 kPa. See Figure 4.12 for water displacement unit, also Figure 4.13 for multi gas analyzer device

Figure 4. 12: Water Displacement Unit (Biogas Measurement).

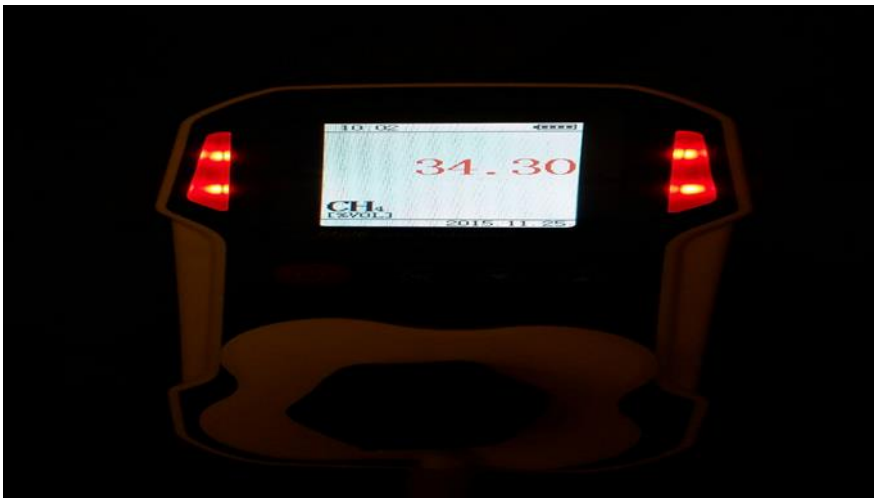

Figure 4. 13: CH_4 Measurement By Multi Gas Detector.

4.3.6. Physico – Chemical Characteristics

All the collected samples that have been brought from fields, they were analyzed for several parameters that are essential for our study Immediately upon arrival to the laboratory, also the digesters feeds have been also analyzed for the same parameters before and after digestion process. All parameters were studied according to standard methods for examination water and wastewater (APHA, 1998).

PH:

The pH-value for all the studied substrates and the reactors contents were examined according to standard methods for examination water and wastewater (APHA, 1998). Periodically prior to measuring, pH instrument was calibrated with two different solution pH: 4.00 and pH: 7.00.

The pH measured by using pH-meter (type JENWAY pH meter 3310 from the Jenway ltd Company – U.K the normal limits of accuracy reported for this method are ± 0.01 unit.

Total Solids, Volatile Solids:

Total solids and volatile solids examinations were carried out to evaluate the solids and organic content in the tested substrates and digesters content before and after digestion process, both test were carried out according to standard methods for examination water and wastewater (APHA, 1998).

Chemical oxygen demand:

Chemical oxygen demand (COD) has been considered as a measurement for organic compound, COD is an oxygen equivalent of the fraction of organic compound that is oxidized by a strong chemical oxidant. COD was determined using the HANNA- HI 83214 Multiparameter bench photometer.

Organic Acids and Buffer Test:

In order to determine the fatty acid concentration in the fermentation samples, in this study Nordmann method that was developed at 1977 was followed, Nordmann method is a two end point titration method. The VFA/ALK is a single value depending on the relation of two parameters, which are:

1. Volatile Organic Acids content (VFA).
2. Buffer capacity (ALK).

The buffer capacity of the system is determined through titration of the prepared sample with 0.1 N(H_2SO_4) from its original pH-value to a pH-value of 5. ALK can be calculated according to the following equation:

$$ALK = A * 250 \text{ [mg of calcium carbonate } (CaCO_3)/L]$$

Where A: volume of H_2SO_4 to decrease from initial pH to pH =5.

To determination of the volatile organic acids (VFA) through titration further titration from pH 5.0 down to 4.4 the VFA value can be obtained from the next equation:

VFA = ((B *1.66) – 0.15)* 500 [mg/L of acetic acid (CH_3COOH).]

Where B: volume of H_2SO_4 to decrease from pH=5 to pH =4.4.

Chapter Five

Results and Discussions

In this chapter, data that obtained from the conducted laboratory experiments has been summarized, after the recorded data was tabulated during experiments period, the required analyses have been carried and then they have been discussed. To carry out the required data analysis, many comparisons were conducted on the obtained results, such as:

- VS reduction, in addition to TS reduction.
- Changing in pH value.
- Changing Alkalinity and VFA values.

Further to analyzing these parameters, comparisons the biogas production and methane production were carried out in term of gas yield (ml gas / g VS fed).

Each experiment line in EXP 2 has been carried out in duplicates to ensure reproducibility and all data in this chapter are expressed as mean and standard deviations (mean ± std).

5.1. Initial Experiment Results (EXP 1)

For EXP1, that was conducted at the beginning of this study, actually its results were never encouraging, since no significant gas production was occurred in the first weeks. Gas leakage was checked again, in addition to its checking in reactor design as it was described previously, in order to make sure that there is no gas leakage from any reactor, and it was found there was no gas leakage and this mean the digestion process has failed and there is no gas production from the digestion system.

Simply, the first experiment (EXP 1) has been lost, since the gas production did not start for a period not less than 5 weeks, and this period of time is very long to start gas formation, since inoculum was added in first especially to avoid this long period.

It was clear that the system was working to acclimate itself, and it was trying to reach to the start-up phase, but it took a long time for that, this prolonged lag phase could be caused by inhibition occur in the bacteria cultures that were provided through the added inoculum, since amount of bacteria was inappropriate and a bit too, which led to an defect in its function. Practically, I/S was lower than 1 for all reactors, therefore overloading took a place in process and this was a main reason for the occurred problem.

I/S ratio is defined as ratio between grams of inoculum (bacteria cell) to grams of feed. It has an impact on the occurrence of the following: lag phase (extracellular hydrolysis), methanogenesis, and VS reduction, resistance of the microorganisms for the inhibitory impacts during digestion process. Also, it was reported in many literatures that the I/S ratio was considered as the major parameter that affects on the digestion process as what was reported by (GUO, 2016).

I/S ratio, is the responsible on presence the groups of microorganisms needed for carrying out the digestion process. Lower I/S ratio can cause accumulation of VFAs and lead to inhibition in methanogenesis function.

Generally, for a stable digestion system, I/S ratio is considered as a major parameter, and it is suggested to be more than 2 (based on VS) as it was reported by Raposo et al., (2011) and Borowski, et al., (2015). Therefore anaerobic reactors must have high microbial activity to work at a stable condition. Finally, as a conclusion from EXP 1, it was decided to increase I/S ratio in EXP 2 to minimize the start-up period in experiment.

5.2. Changing of pH in EXP 2

In this section, changing in pH value before and after digestion process is reviewed and discussed, and the analysis of the pH value of input and output materials, gave the following results which are displayed in the following tables, see Table 5.1 and Table 5.2.

The measurements of pH for the raw substrates are summarized in Table 5.1.

Table 5. 1: Results of pH Analysis of Raw Tested Substrates:

Substrate	Initial Value
Inoculum	7.18
PS	5.77
SHW	6.7
Mixture	6.05

Moreover, pH value of the prepared samples that were entered into reactors, have been recorded immediately before the feeding time, in addition to that the measurements of final pH value also have been recorded at the final day, both initial and final pH values for the digested samples are represented in Table 5.2.

Table 5. 2: PH Values for Reactors Content, Before and After Digestion:

	Inlet pH	Outlet pH
D-PS	6.28	7.27 ± 0.04
D-SHW	6.89	7.52 ± 0.04
D-CO	6.45	7.38 ± 0.03

Initial and final value of PH is mean ± std of duplicates for each reactor, are displayed in Table 1 in Appendix A.

From the presented data in Table 5.2, it can be seen that, the pH value for the reactor that was fed with PS sample (D-PS) before anaerobic digestion was about 6.28, whereas the pH value for the reactor that was fed with SHW sample (D-SHW) was around 6.89, while the pH for the reactor that was fed with Co-digestion sample (D-CO) was 6.45.

At the end of experiment, D-SHW had the largest pH value, which was near to 7.52, where at this value methanogenesis bacteria may be troubled, as it was discussed earlier, that the methanogenesis bacteria is most sensitive to pH compared to other bacteria that are involved in digestion process (Gerardi, 2003), and this might be due to the higher protein concentration in D-SHW content, which could produce ammonia as by-product from its fermentation, that can play a role in increasing the pH more than the allowable range, as it was occurred in case of Alvarez et al. (2008), since in his study the blame was put on the accumulation of ammonia, that was resulted from degradation the nitrogen in blood.

Therefore, this indicates that growth of methanogens, and methanogenic activity has been somewhat disturbed. Thus, it was concluded that there

was pH inhibition (partially or fully) in D-SHW, which negatively affected on methane production as it will be seen in section 5.5.

However, it can be noted that D-PS finished with pH equal to 7.27, which was the lowest value, while pH of D-CO raised up and reach to 7.38, both pH value for D-PS , D-CO content are within optimal methanogenesis range, which is 6.6 - 7.4 according to (Moosbrugger et al., 1993), so there is no any inhibition effects occurred in D-PS and D-CO during digestion process, except of D-SHW which had a pH value more than the upper limit of optimum methanogenesis pH range. The following Figures represent the changing in pH value in each reactor.

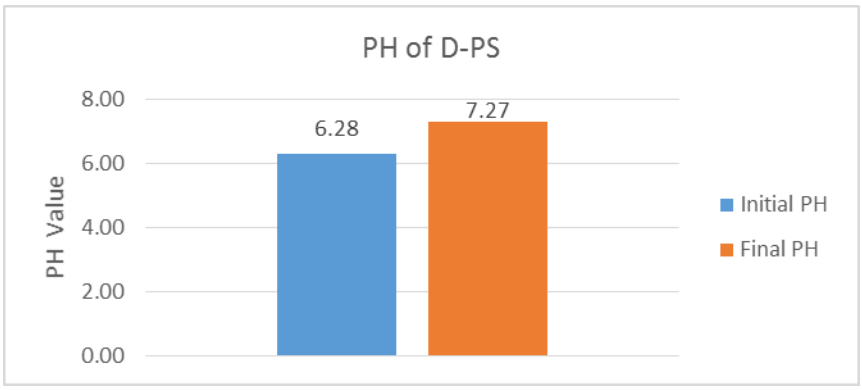

Figure 5. 1: Inlet and Outlet pH for D-PS.

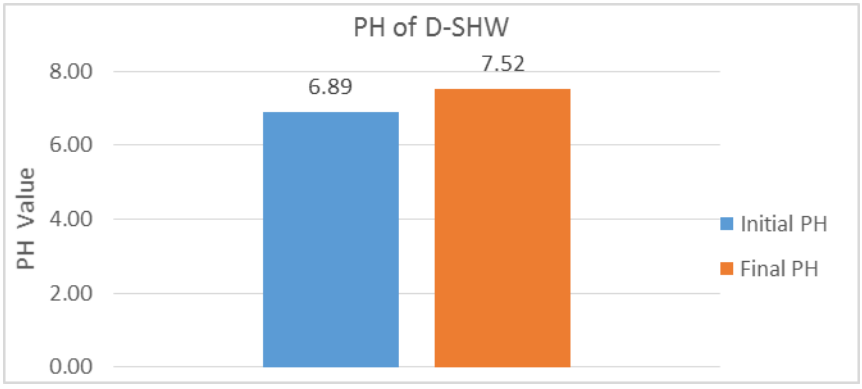

Figure 5. 2: Inlet and Outlet pH for D-SHW.

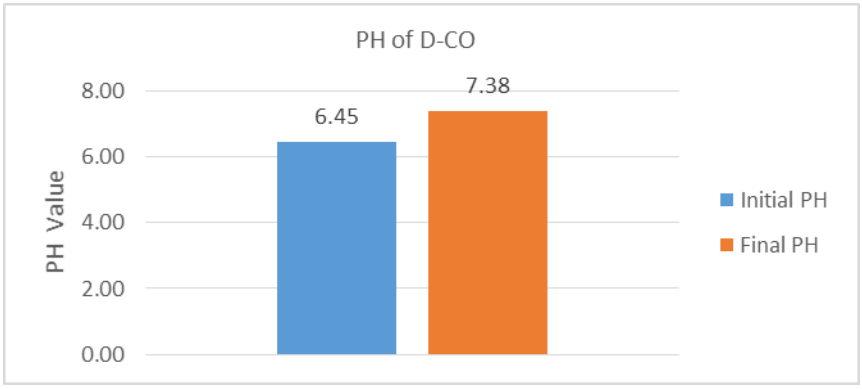

Figure 5. 3: Inlet and Outlet PH for D-CO.

As it can be seen from the above figures, that the pH value after the AD was increased when increasing the SHW proportion in the reactor, and this was expected , since many literature reported that SHW contains protein, which can be a reason for pH increasing. This increasing in pH value in D-SHW, is contributed to production of alkaline compounds, during the degradation of organic compounds in the digester such as ammonium ions (Gerardi, 2003), so it was necessary to check that the alkalinity buffer and VFA stayed within accepted range. Because, the pH of the digester is directly related with the concentration of the produced VFA, and the bicarbonate alkalinity in the system (Gomec and Speece, 2003).

Finally, according to the represented and the discussed data, it can be concluded that using PS helps to maintain the pH value within the optimum range, and this agree with what was suggested by (Hills and Roberts, 1981) about using Co-digestion system to adjusting the pH value within the optimum range rather than using the chemical treatment methods.

5.3.Total Solids and Volatile Solids Reduction in EXP 2

5.3.1. Total Solids Analysis

From examination the total solids of raw tested substrates, it can be noted that the maximum TS content (TS before digestion process) was measured in PS sample which was about 1.8%, whereas the minimum TS content was measured in SHW sample which was about 0.72%. While the TS content of Co-digestion sample (mixture of SHW and PS) was 1.26%.

Percent reduction in TS content for each reactor is represented in Figure 5.4, and it can be seen from that figure, the reactor, which was fed with PS sample (D-PS) had a 23.2% reduction in its TS content, and that was fed with SHW sample (D-SHW) had a 17% reduction in its TS. While the reactor which was filled with Co-digestion mixture (D-CO) achieved 20% reduction in TS.

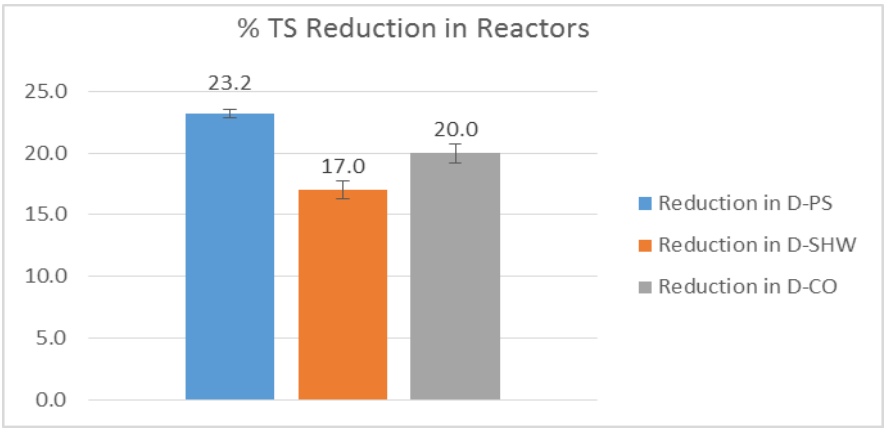

Figure 5. 4: TS Reduction in Reactors.

According to the solid contents of the fed samples and the digested samples, the effectiveness of anaerobic digestion can be verified through the reduction in the solid content.

TS value before and after digestion are represented in Table 5.3. Also, they are displayed in Figures (1, 2 and 3) in Appendix C. For more details inlet TS and outlet TS for each reactor are displayed in Table 3 in Appendix A.

Table 5. 3: Total Solids in each Reactor Before and After Digestion:

Reactor	D-PS	D-SHW	D-CO
TS in (g/L)	20.58	14.87	18.43
TS out (g/l)	16.02 ± 0.14	12.34 ± 0.22	14.75 ± 0.27

TS out is mean ± std. for duplicates for each tested substrate, results were displayed in Table 2 in Appendix A.

In addition to the reduction in reactor solid content, the solid content in the individual substrate show the same reduction trend during the experiment course. After the TS reduction in blank reactor (Control) was determined, solid reduction in each individual substrate that was used to feed each reactor also was determined, and it was found that the PS as individual substrate had a 63.1% reduction in its TS content, while SHW had a 39.5% reduction in its initial TS, and the Co-digestion sample (mixture of SHW and PS) reached to 49.8% reduction its TS content. For more details values of TS reduction were represented in Figure 5.5.

Finally, from the represented data, it can be stated that the solids content was reduced in all reactors during the experiment, actually this gives an indication about performance of digestion process.

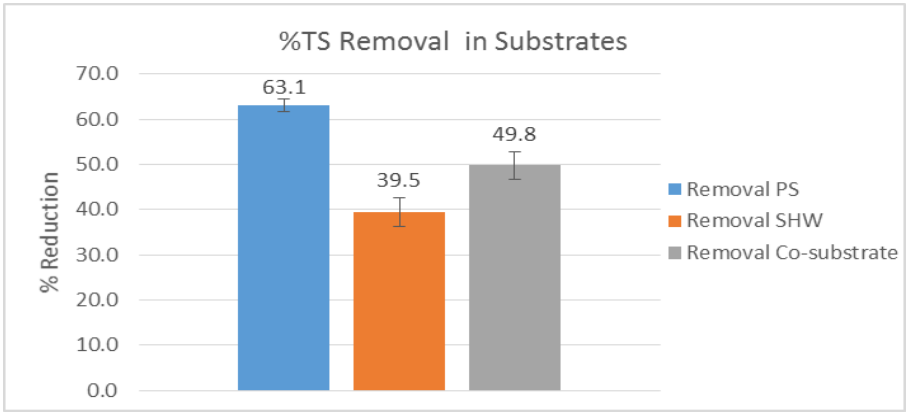

Figure 5. 5: TS Reduction in Tested Substrates.

5.3.2. Volatile Solid Analysis:

Volatile solid value before and after digestion within each reactor was represented in Table 5.4. Also, the reduction in VS for each reactor was displayed in Figure 5.6.

Table 5. 4: Initial and Final VS for each Reactor During Digestion Test:

Reactor	D-PS	D-SHW	D-CO
VS in (g/L)	12.31	9.12	11.11
VS out (g/l)	9.03±0.16	7.29±0.1	8.32±0.06

VS out is mean±std for duplicates for each tested substrate, display in Table 4 in Appendix A.

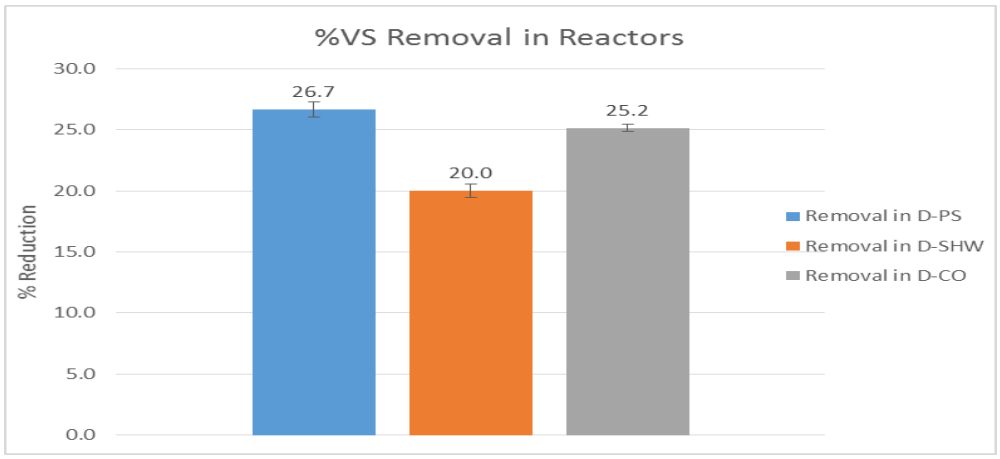

Figure 5. 6: VS Reduction in Reactors as Whole System.

From Figure 5.6, it can be seen the variation between organic matter reduction in content of each reactor, which represent the VS reduction in digestion system, so from data that was drown in Figure 5.5, it can be stated that reactor which was fed with PS sample (D-PS) had a 26.7% as reduction in its VS content, while, that was fed with SHW sample (D-SHW) had a 20.0% as reduction in its VS content, and the last reactor (D-CO) reached to 25.2% as reduction in its VS content.

Figures (4, 5, and 6) in Appendix C, represent inlet and outlet VS content in each reactor, and it can be seen, that the final VS content for all substrate types were lower than those before the digestion process.

organic matter degradation in in the individual substrate was also calculated, after organic matter degradation for inoculum sample in blank reactor (control) was evaluate, based on assumption that the content of inorganic matter is fixed in inoculum and in the tested substrates also all substrates are well mixed (homogenized substrates).

By comparing the final VS value with initial VS value in all the tested substrates, it can be judged that the anaerobic digestion process worked well to a specific degree, and this degree can be evaluated through VS reduction for each tested substrate. The VS reduction in each tested substrate is displayed in Figure 5.7.

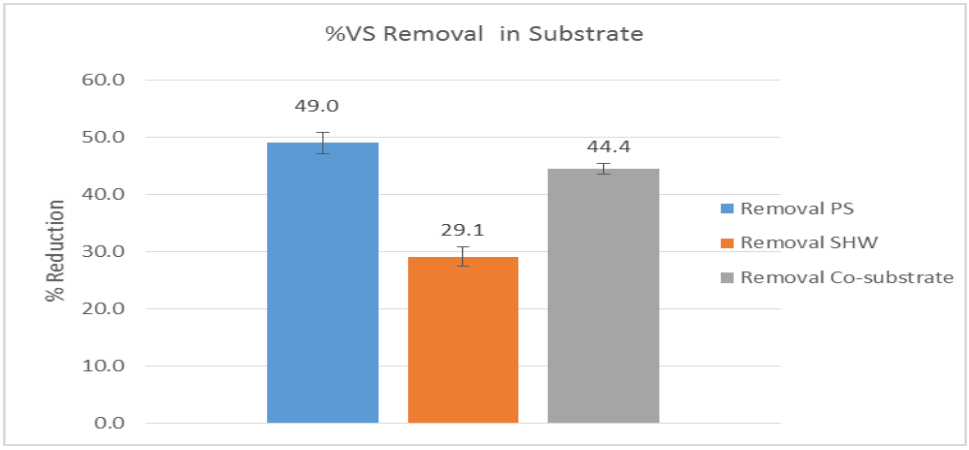

Figure 5. 7: VS Reduction in Tested Substrate.

From Figure 5.7, it can be noted that the highest VS reduction in individual substrate was observed in PS sample, which showed about 49% reduction in its VS content, while SHW viewed a 29.1% reduction in its VS content, and the Co-digestion sample (mixture of SHW and PS) gained about 44.4% reduction in its initial VS content.

Also, the VS reduction in the individual substrates, showed the same trend. Since the lower reduction in VS content was observed in reactor contained SHW sample, because, it contained compounds that degrade slowly such as protein. In contrast, higher degradation percent was reported for both PS sample, and Co-digestion sample (mixture of SHW and PS). Moreover the highest percentage of VS reduction was obtained in PS sample as it can be seen in Figure 5.7, this percentage can be explained as PS sample has more biodegradable compounds, and less complex compounds present in PS sample comparing with the other tested samples, also it might be because the compatibility between hydrolysis, acidogenesis and methanogenesis stages during the digestion process, since if one of the digestion process

steps was disrupted, then the whole process will be affected including organic matter decomposition and gas production.

As a summary, at the beginning of the digestion process the total solids (TS) and volatile solids (VS) content in each reactor were higher than them at the end of anaerobic digestion process, as what can be observed from the represented data, that both contents of TS and VS have been significantly reduced.

From the discussed data, it can be concluded that PS sample has the highest biodegradable volatile solids than SHW, actually its using helps in enhancing the TS and VS removal from SHW sample, as it was reported in case of Alvarez et al. (2008) and Borowski, et al., (2015).

5.4. Organic Acid and Buffer Capacity in EXP 2

5.4.1. Organic Acid Analysis

The final VFA amount was less than the entering amount as it can be seen from initial and final values of VAF in D-PS and D-CO, which means that the VFA was consumed for specific degree within the digestion system, except to the D-SHW, since at final day, VFA concentration was higher than it at the first day, and this is a clear indication for accumulation the VFA within the digester media. VFA value was declined more than 33% to 72% in D-CO and D-PS respectively. While it was increased by 42% in D-SHW. For more details, data of VFA is represented in Table 5.5, and Figures 5.8, 5.9 and 5.10.

Table 5. 5: VFA Concentrations in Reactors (inlet and outlet):

Reactor	**Before Digestion** (mg/l)	**After Digestion** (mg/l)
D-PS	902.7	257 ± 0.0
D-SHW	340	589 ± 0.0
D-CO	691.1	464.5 ± 58.7

After the represented data was analyzed, it can be concluded that the most produced acids were consumed in D-PS, and D-CO, while the acid concentration was increased in D-SHW, which indicates that more and more VFA was accumulated day after day in D-SHW.

pH value was not too drop in D-SHW despite the accumulation of the acids, this can be explained due to the existence of sufficient buffer capacity, as it will be seen in section 5.4.2, and this agrees with what was summarized by Padilla et al., (2011).

Therefore, it is most likely that there a high concentrations of ammonia nitrogen within the system, which caused an increasing in system alkalinity, which lead to continuous production of VFA and accumulation it within the system without sharp changing in pH.

Raising in the total VFA concentration shows that methanogens affected more than the acidogenesis, causing imbalance in the system. In such these conditions, acidogenesis complete their task, but the growth rate of methanogenesis is affected negatively, this make methanogens is not able to transform the acetates, and resulting VFA accumulation and then lower methane production as it was observed in methane yield for D-SHW, actually this observation agree with what reported in Borowski et al., (2015).

Practically, higher VFA concentration in the reactor at the end of the digestion process, is mainly caused due to the imbalance in degradation and consumption of the produced VFA, including the LCFA, which affected on methanogenesis function, since it the more sensitive one, so it could not be able to convert the VFA as fast as they were produced by the less sensitive acid forming bacteria.

Another possible result, with large amounts of VFA present in the digestate, the hydrogen partial pressure will affect negatively on acetotrophic methanogens. Then the breakdown of acetic acid by methanogens will be slowed, the digestion process will begin to shut down due to inhibition from fermentation stage products.

In contrast, at the end of digestion, the lower VFA concentration allow the inner cells to perform efficiently without any negative effects; thus, a stable digestion process could be maintained.

As a conclusion, From, the presented results, it can be pointed that the high VFA concentration is an indication for limiting factor or partially inhibition for the successful anaerobic treatment of the SHW, consistent to what has been suggested by (Ahring et al., 1995).

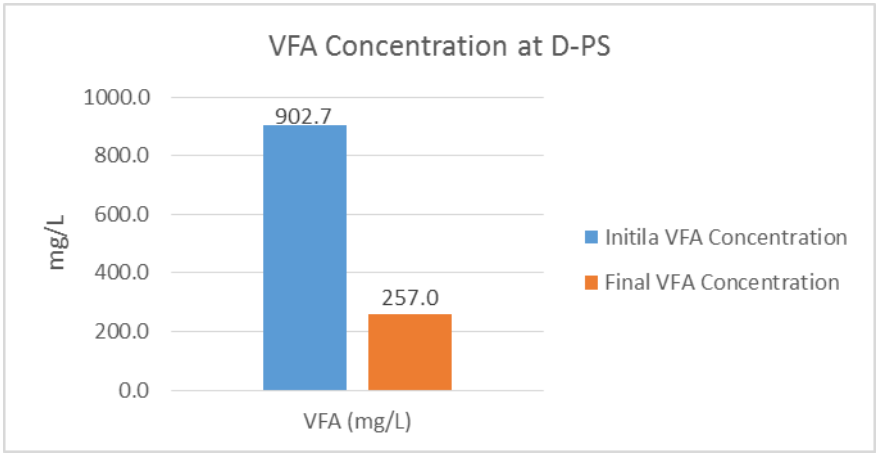

Figure 5. 8: Inlet and Outlet VAF in D-PS.

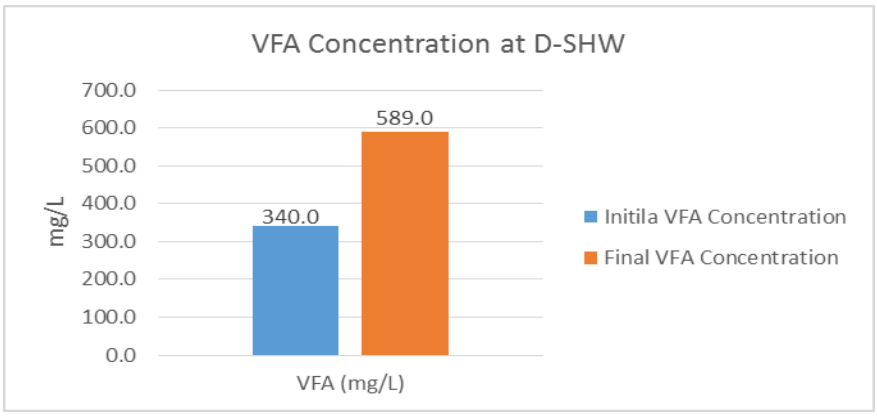

Figure 5. 9: Inlet and Outlet VAF in D-SHW.

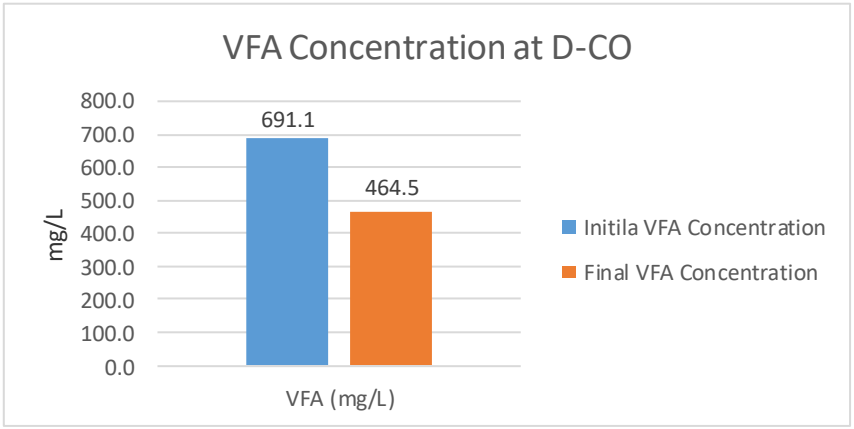

Figure 5. 10: Inlet and Outlet VAF in D-CO.

5.4.2. Buffer Capacity

The measured values of alkalinity (Buffer capacity) for each substrate prior and after digestion process are summarized in Table 5.6, also they are displayed on Figures 5.11, 5.12, and Figure 5.13

Table 5. 6: Initial and final Buffer Measurements

Reactor	**Initial buffer** (mg CaCO3/L.)	**Final Buffer** (mg CaCO3/L.)
D-SP	3629.4	4175 ± 141.4
D-SHW	2507.9	3950 ± 106.1
D-CO	3215.3	4000 ± 70.7

Value of initial and final Buffer is mean±std for duplicates, details are represented in Table 6 in appendix A

From the data that was represented in Table 5.6, it can be noted that the alkalinity measurements were measured for all tested samples before and after digestion process, and it can be noted from Table 5.6, that all of them had an alkalinity concentration that are within the optimum alkalinity range, that are needed to provide a resistance to significant and rapid changes in pH value, optimum alkalinity is ranged between 1500 and 5000 mg/L as $CaCO_3$ as it was described earlier in section 2.1.2.

Also it can be noted, the reactor that was operated with the lowest initial alkalinity concentration, it gained the greatest increase in alkalinity concentration, while the reactors which have been run with the highest initial alkalinity concentrations, they gained only a slight alkalinity during the digestion process.

Also from the represented data in Table 5.6, and Table 5.2, it can be noted, that the higher increasing in alkalinity concentration and pH value was observed in D-SHW, so it can be concluded that whenever the SHW fraction is increased in the digester it will be accompanied by an increase in alkalinity and pH, consistent with what has been reported in study of Rajakumar et al., (2012), which indicated an excess concentration of ammonia production, the most likely responsible for this is a high protein content in digester feed.

whereas, in case of digestion the substrates that contain protein such as SHW, the alkalinity is produced by the breakdown that protein to amino acids and then it is converted to ammonia (NH_3), which combines with CO_2 and H_2O to form alkalinity products as Ammonium bicarbonate ($NH_4(HCO_3)$). in other words, the organic nitrogen in digested substrate is mineralized into ammonia which contributes in alkalinity production.

Initial and final buffer capacity in all reactors are displayed in following Figures. Moreover ALK and VFA, before and after digestion for each reactor are represented in Figures are attached in Appendix C, see Figures (7 to 12).

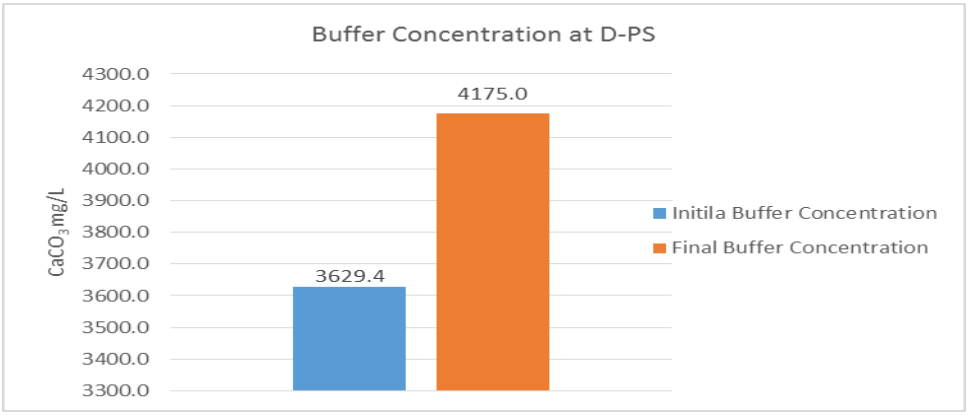

Figure 5. 11: Initial and Final Alkalinity Measurements for D-PS.

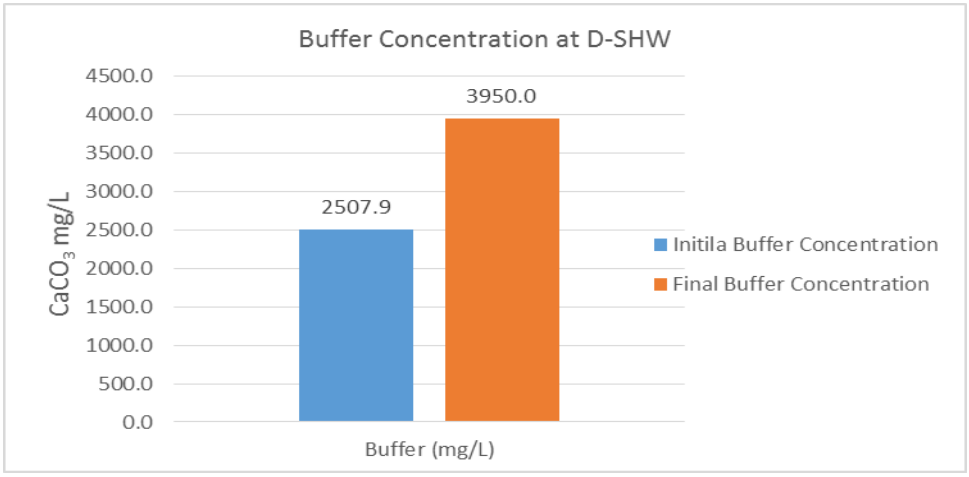

Figure 5. 12: Initial and Final Alkalinity Measurements for D-SHW.

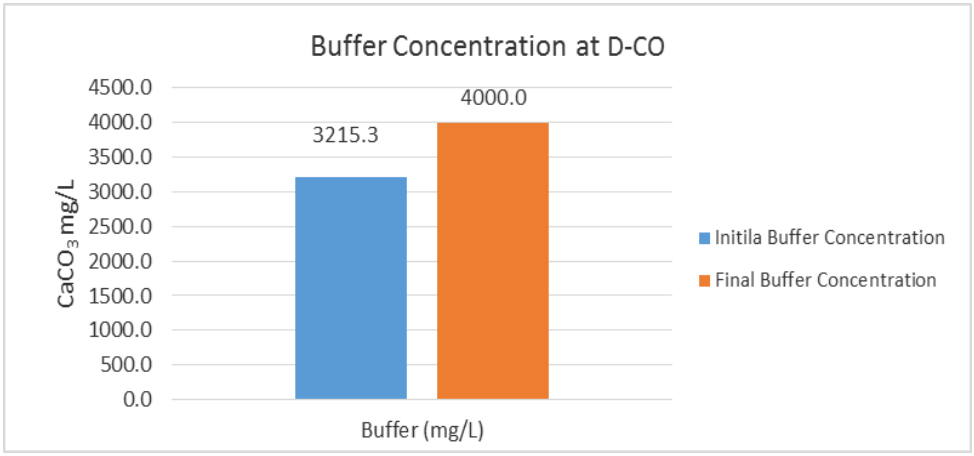

Figure 5. 13: Initial and Final Alkalinity Measurements for D-CO.

5.5.Biogas and Methane Yield in EXP 2

Many comparisons have been made based on volume of gas that has been yielded from each reactor, so at the beginning it must to define the two terms that will be used in the comparisons:

The **Biogas yield**: which is generally expressed as a function of the VS that was added into the digestion system, and it is represented as (Normalized mL of Biogas /g VS added).

Also the **methane yield**: which is usually formulated as a function of the VS that was added into the digestion system, and it is expressed as (Normalized mL of methane /g VS added).

at the beginning, it is important to mention that each represented value in this section is a mean value for duplicate test (which means two reactors have been run for each tested substrate), and values of all duplicates are displayed in Tables in Appendix B. Also volume of biogas from inoculum (blank) is attached in Appendix B, see Table 7. Moreover, the daily biogas production, and accumulative biogas production also biogas yield, in addition to methane data, are displayed in figures, those are attached in Appendix C, see Figures from 13 to 30.

Biogas and methane yields from the tested substrates:

The net accumulative of biogas yield (Nml biogas / g VS added) for each tested substrate is depicted in Figure 5.14, and Figure 5.15, also the net accumulative of methane yield is depicted in Figure 5.16 and 5.17.

From the daily gas production data, which were displayed in Tables at Appendix, it can be revealed that the biogas production from all tested substrates started at a higher production rate (early peak). Since, the majority of the biogas was produced in the first days, for more details see Figure 13, 17 and 21 in Appendix C, similar biogas production pattern has also been reported by many authors like Zhang et al., (2007). This probably was due to the characteristics, activity and intensity of the inoculum, since I/S ratio was kept to be equal 2 in all reactors, in addition to the prior hydrolysis of some compounds in the tested substrates

In addition to biogas, the volume of the produced methane was measured in experiment at each day in the first two week, but after that it was measured

once for each several days in order to accumulate larger biogas volume to be more accurate in methane measurement

When comparisons have been made between methane yield from each tested substrate, it was found that the D-PS produced methane more than D-SHW, which is an expected; because SHW contains protein compounds as it was previously described, protein compounds are responsible on many inhibition problems especially on methanogenesis bacteria, further to that, these compounds are hard-to-degrade, because of their structural features, so part of protein compounds probably remain non completely degraded at the end of the digestion process as it was reported by Teghammar, (2013). For more details see Figure 5.16, and 5.17.

While, it was found that the utilization of Co-digestion system helped to improve methane yield comparing with what have been yielded from the both individually tested substrates.

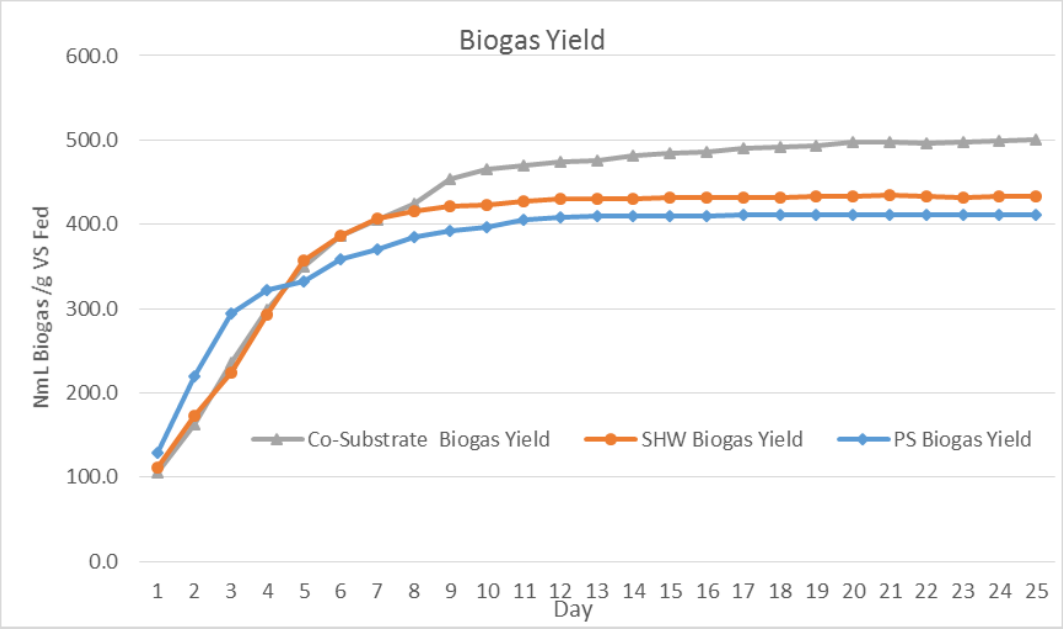

Figure 5. 14: The Time Profiles for the Accumulated Biogas Production.

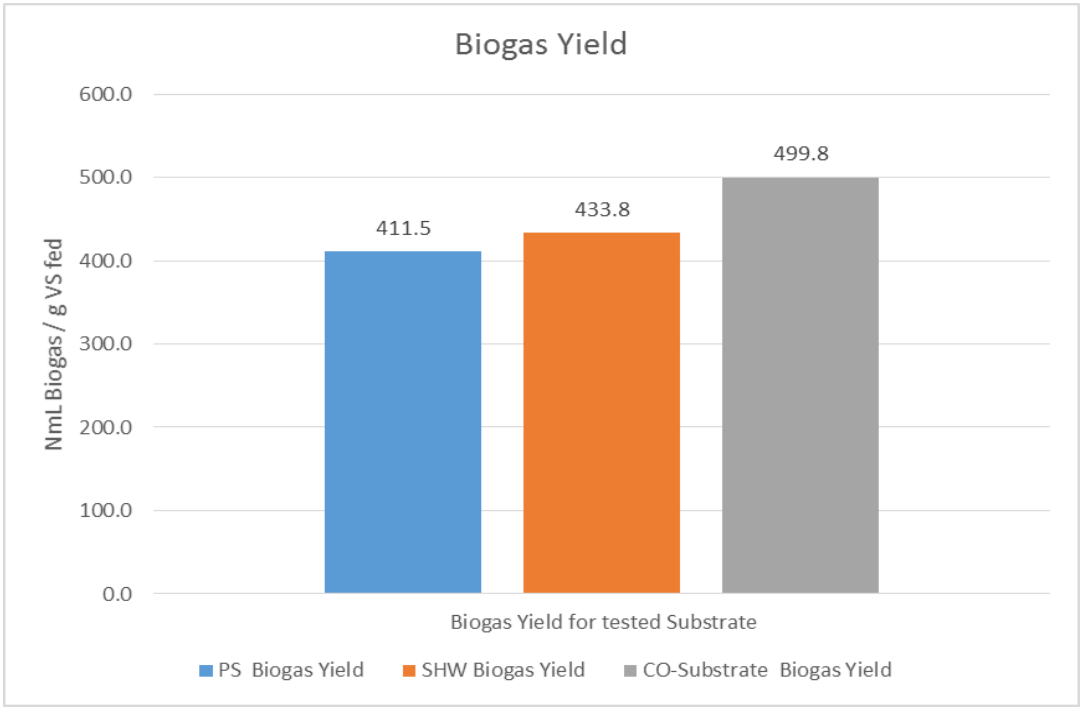

Figure 5. 15: Accumulative Biogas Yield of Different Tested Substrates.

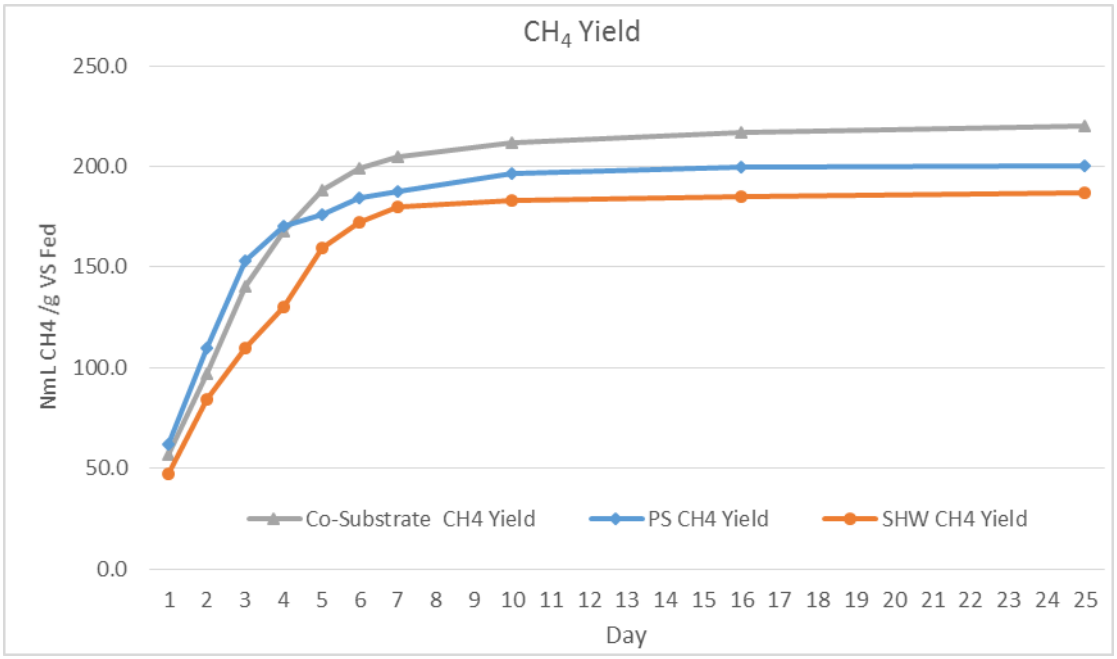

Figure 5. 16: Time Profiles for the Accumulated net CH_4 Production.

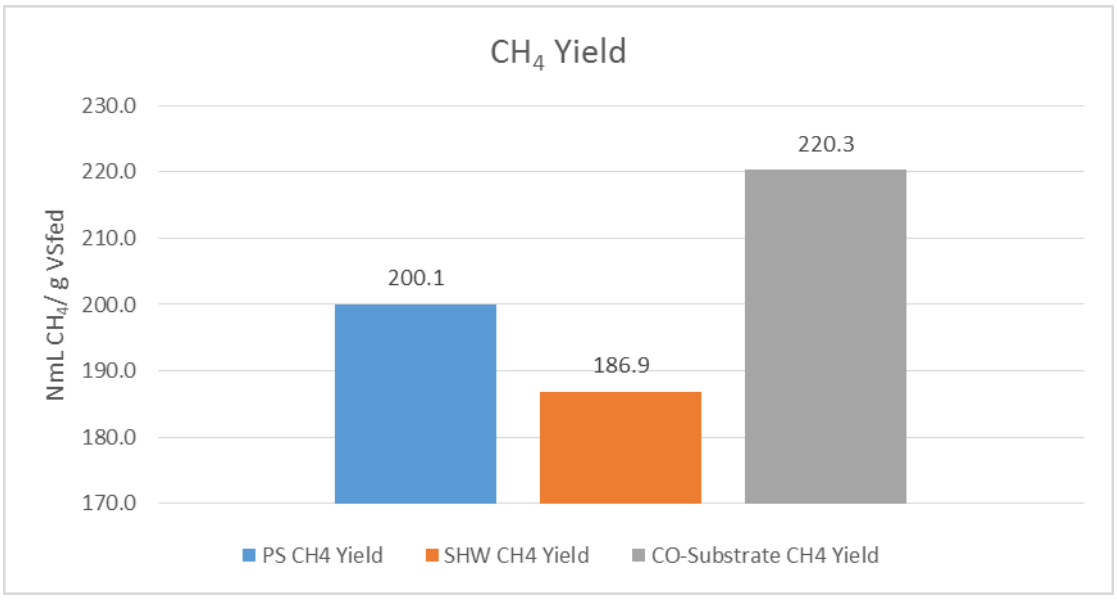

Figure 5. 17: Net Accumulative Methane Yield for Tested Substrates**.**

Also biogas yield with methane yield for each tested substrates are displayed in Figure 5.18.

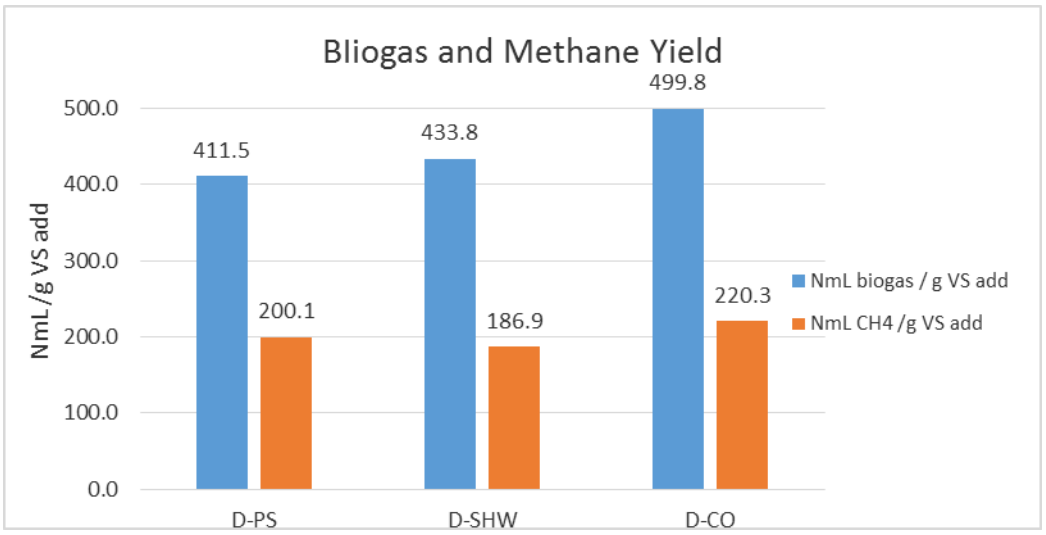

Figure 5. 18: Biogas and Methane Production of Different Tested Substrates.

From the data represented in above figure it can be noted, that the lowest biogas yield (which was 411.5 Nml biogas/g VS added) it was owned by D-PS, while D-CO had the highest biogas yield (around 499.8 Nml/g VS

added), and biogas yield for the D-SHW was nearly to (433.8 Nml/g VS added).

For methane yield value, it can be seen that the D-CO had the highest methane yield (which was 220.3 Nml-CH_4/g VS added), while D-SHW had the lowest methane yield (186.9 Nml-CH_4/g VS added). Nevertheless, the D-PS had the mid value for methane yield (which was 200.1 Nml-CH_4/g-VS added).

First conclusion from gas yield discussion, that the Co-digestion system helped in increasing the productivity of gas yield when it was compared with gas yield from digest of the PS, and SHW in solo digestion system.

Also, as a conclusion, it is seemed that using the Co-digestion system contributed to enhance the activity of the biomass, that were involved in the anaerobic digestion process. Co-digestion system played a role to enhance the carbon-nitrogen ratio, as SHW is characterized with high nitrogen content due to blood, so the implementation of Co-digestion system played a role in dilution the toxic compounds like organic-nitrogen, ammonia, volatile fatty acids and other intermediate products those can inhibit the bacteria cells within the digester. All these roles of Co-digestion system enhanced the methane production comparing with what was produced from PS and SHW when they were digest individually, this conclusion is corresponding with what has been stated by Mata-Alvarez et al., (2000).

In the following, the main factors that are responsible on the lower methane production from SHW comparing with PS will be discussed:

The first factor is ammonia, which was produced from degradation of organic nitrogen and protein compounds in SHW sample, especially as those in blood, since it is toxic to methanogenic culture and can cause failure in digestion process, this confirms what was reported by Wang and Banks, (2003).

The second factor is Sulfate Reducing Bacteria (SRB), it competes with methanogenesis in consuming H_2 during the digestion process, with existing amount of sulphate that could be produced from protein in blood, since this type of bacteria reduce sulfate to hydrogen sulfide (H_2S) during digestion process. the production of hydrogen sulfide has an inhibitory effect on methanogenic bacteria even at low concentrations at it was reported by Gerardi, (2003).

In addition to that, an accumulation of VFA in digest causes inhibition to methanogenesis that can lead to lower methane production. this situation was occurred in D-SHW, since the final VFA concentration was more than initial concentration.

Clear Evidence on production H_2S and NH_3 gases, the disgusting smell, which was smelled when the digestate was withdrawn from the D-SHW, this smell suggests to production the toxic gases like H_2S, NH_3. So, finally it can be said that the D-SHW was running in inhibited state where the process is stable, but gas production is low due to effect of ammonia, H_2S and VFA.

Measurements for biogas and methane yield from all reactors are summarized.in Table 5.7.

Table 5. 7: Biogas and Methane Production for the Tested Substrates:

	PS	SHW	Co-digestion
Accumulative. Net .Biogas (Nml)	674.8	523.9	738.9
Biogas Yield (Nml Biogas / g VS Fed)	411.5	433.8	499.8
Biogas Production (Nml Biogas / g VS Removed)	840	1491.4	1124.5
Acc. Methane (Nml)	328.1	225.7	325.8
CH_4 Yield (Nml CH_4 / g VS Fed)	200.1	186.9	220.3
CH_4 Production (Nml CH_4 / g VS Removed)	408.4	642.5	495.8

There are many studies, that have been conducted to study the feasibility of use anaerobic treatment to deal with wastes that are discharged out from slaughterhouse facilities, and the possibility of production biogas.

Each one of these studies differs than other, according to the source of the studied substances (whether they were from pigs, cattle or poultry), and the components of that substrates (blood, water, intestinal content, punches, mixture of them), Moreover it depend on system of treatment, if it was one or two stages of digestion, also if mixing system was used or not, as well as the type of reactor and its configuration. All these factors have a role to make differences between that studies, and making comparisons between their results somehow are difficult.

In relation to this study, if comparisons are made between its results with other studies, it was found that there are some studies have results close to what have been found in this study and some that are different.

Where the production of biogas from PS (411.5 Nml/ g VS fed) was greater than (262.4 Nml/ g VS fed) which was yielded in Nansubuga et al. (2015), as well as the methane yield (200.1 Nml/ g VS fed) was greater than what

was reported by each of Nansubuga et al. (2015), Xie et al. (2017), and Andres et al. (2015) which are 107.8, 141, and 120 Nml/ g VS fed, respectively. While it was less than (315 Nml/ g VS fed) which was reported in (IEA, 2015), also less than (318 Nml/ g VS fed) that was achieved by Amani (2013), this can be explained as a result of diluted PS sample since it was taken in winter season.

Moreover in case of treatment SHW by digestion there was a production of biogas in this study in contrast to Ozturk (2012) who tried to digest blood alone, while in this study SHW sample mainly contained blood and washing water (diluted blood), however biogas production from SHW in this study agrees with what has been concluded by Banks (1999) about occurrence an inhibition in biogas production from SHW containing blood.

While in case of using Co-digestion approach to teat SHW, the production of biogas and methane from Co-digestion SHW with PS consistent with what have been reported in many studies, that examined Co-digestion SHW with various organic substances, actually Co-digestion methane yield in this study (220.3 Nml/ g VS fed) was greater than (159 Nml/ g VS fed) that has been achieved by Alvarez et al. (2008).

In general the Co-digestion results that have been obtained in this study consistent with what have been achieved by many researchers like Banks et al. (2004), Banks (1999) and Hejnfelt et al. (2009), since the biogas and methane yield has improved and be more than that were produced by digest each substrate separately.

5.6.Linear Modeling for Biogas Production

After implementation the Co-digestion of organic wastes in biogas production, effects of their various combination ratios on biogas yield need to be assessed, where the statistical regression is being widely used for this purpose, which provides the best method for estimation of gas yield.

The statistical tools that are decided to be used for this analysis is the regression analysis method for the purpose of establishing a formula (model) that able estimate the predicted yield from gas, after that, comparison will be applied model value and the measured value of gas yield.

A lot of engineering and scientific studies are interested with developing a relations between a set of variables that depend on it. In biogas production research the regression method will describe as the set of dependent variable which is gas yield Y, on independent variables such of time z.

The simplest type of relationship between the dependent variable Y and the input z_1, - - - z_r is a linear relation, with some constants A_0, A_1, - - - - A_r the equation: $Y = A_0, + A_1 z_1 + - - - - + A_r z_r,$

Multiple regression analysis performed using MATLAB to formulate the mathematical equation for biogas production (MATLAB code attached in appendix E). Sets of data containing six different experimental results of biogas production were determined daily.

This singular fact demonstrates that the yield of biogas is significantly affected by the pH of feed substrate, alkalinity, and VFA content in feed

sample, which could better explain the biogas yield from the tested substrate than other variables included in the analysis.

Here it must be mentioned, that this regression model is applicable on biogas production from SHW and PS as feedstocks, at temperature 35 ± 2 °C, in batch system, I/S = 2, at lab scale reactor.

The regression model predicts the following equation:

Y= 54.3938 x PH + 85.1345 x ALK – 84.0979 x VFA

Where:
Y: biogas yield from 1 g VS feed (ml).
PH: pH vale of tested substrate.
ALK: alkalinity content in feed substrate (g/l).
VFA: volatile fatty acid content in feed substrate (g/l).

The relationship between the measured and the predicted biogas yield was good and approximate, since a good correlation coefficient R^2 = 0.9995 was obtained, this means the predicted values of biogas yield were very close to the measured values. R^2 calculation displayed in Figure 5.19. Also draw of Model values and actual values are displayed in Figure 5.20.

The Quality of Model, determine the coefficient of determination

$$J = \sum_{i=0}^{n} \left(f(xi) - yi \right)^2 \qquad S = \sum_{i=0}^{n} \left((yi) - \bar{y} \right)^2 \qquad R^2 = 1 - \frac{J}{S}$$

Data Set	Coff	PH	Coff	ALK	Coff	VFA	Model	Actual	J		S
1	54.3938	5.77	85.1345	3.45	-84.0979	2.332	411.449948	410.1	1.822360143		1461.787778
2	54.3938	5.77	85.1345	3.45	-84.0979	2.332	411.449948	412.8	1.822639863		1262.617778
3	54.3938	6.7	85.1345	1.15	-84.0979	0.34	433.749849	426.9	46.92043132		459.3877778
4	54.3938	6.7	85.1345	1.15	-84.0979	0.34	433.749849	440.6	46.92456872		59.80444444
5	54.3938	6.05	85.1345	3.325	-84.0979	1.336	499.799908	501.3	2.250275708		2805.467778
6	54.3938	6.05	85.1345	3.325	-84.0979	1.336	499.799908	498.3	2.249724308		2496.667778
									101.9900001		**201002.7778**
								MEAN		**R^2**	
								448.333333		**0.999492594**	

$$J = \sum_{i=0}^{n} (f(xi) - yi)^2 \qquad S = \sum_{i=0}^{n} ((yi) - \bar{y})^2 \qquad R^2 = 1 - \frac{J}{1S}$$

Figure 5. 19: Correlation Coefficient for Model and Actual Data (R^2)

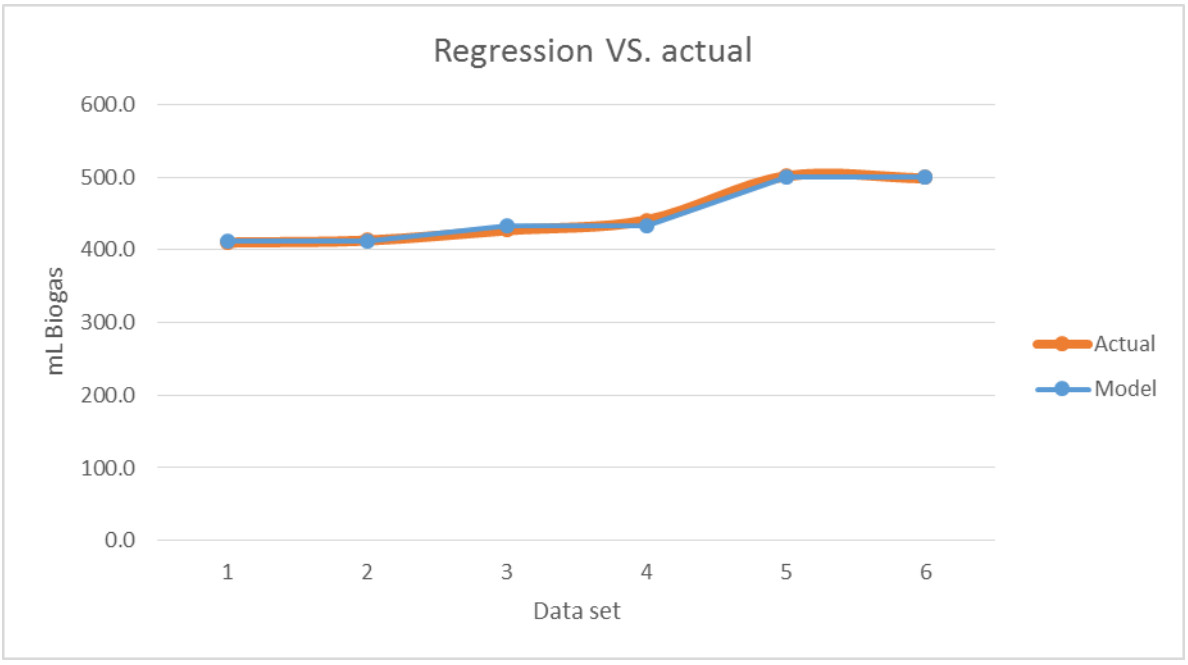

Figure 5. 20: Predicted Biogas Production (Regression Model) Versus Actual Data

Conclusions

Based on the results of this study, the following concluding points were observed:

- Biogas yield (Nml Biogas per g VS fed) increased when implementation the Co-digestion of SHW with PS, comparing with biogas yield from digest SHW, PS separately.
- Methane yield (Nml CH_4 per g VS fed) increased when implementation Co-digestion of SHW with PS, comparing with methane yield from digest SHW, PS separately
- Thus, as a general conclusion, it can be said that Co-digestion PS with SHW is a suitable strategy to increase biogas production WN-WWTP.
- Thesis results could be utilized and used to develop an action plan to manage SHW treatment in Co-digestion system at WN-WWTP, that ultimately aiming to improve the biogas production, attain energy self-sufficient operations in a WWTP.
- The most important practical conclusion that it can be deduce it from the first experiment is the role of inoculum in digestion process, since if it was in amount less than the imposed quantity, the system will inevitably fail or will take a long time to build new bacterial cells. This costs a lot of time, and therefore would not be in favor of the researcher.

Recommendations

According to the results of this study the following recommendations have been stated:

- Treat the discharged wastewater from slaughterhouse facilities by anaerobic digestion technology with domestic sludge in Co-digestion system not alone.
- Construction a collection system to collect the slaughterhouse wastewater instead to discharge it into open area.
- More studies need to be done on Co-digestion technology in order to improve the stability of digestion process.
- Monitor periodically for the implemented Co-digestion system especially for nitrogen and intermediates products (as volatile fatty acids).
- Economically studies need to be conducted to make sure that applying this research idea is feasible.
- More studies should be done on the digestate to evaluate the reduction of pathogens, and the suitability to use in agriculture activates.

Future Work and Action Plan

The practical objectives for this study is to find solutions for disposing the discharged slaughterhouse wastewater in Nablus city.

After it was proved, that anaerobic digestion treatment is suitable for the discharged slaughterhouse wastewater in Co-digestion not in solo digestion system. Now a conceptual action plan for treatment that wastewater can be proposed.

Nablus municipality has anaerobic digester at WN-WWTP, so it is very useful to use it to treat the slaughterhouse wastewater with domestic sludge as Co-digestion system instead of construct new digester at slaughterhouse facility, because it may be expensive and financially impossible.

But to treat the slaughterhouse wastewater in WN-WWTP, it have to be collected in slaughterhouse facility instead of deposing it in near wadi, this can be done through establish a collection tank at slaughterhouse facility and then transfer the collected wastewater by Septic Tank Pump Truck to WN-WWTP, until to connect the slaughterhouse facility with the Eastern Nablus WWTP.

Finally to be honest and realistic, the anaerobic digestion process was proved to be very promising through many experimental researches, but there is still much work need to be done within this field in future, researchers in future should focus on finding optimum ratio for Co-digestion of primary sludge (PS) with slaughterhouse wastewater (SHW).

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Appendixes

Appendix A

Data for EXP 2

Table 1: Inlet, Outlet PH Measurement of Reactors (Duplicates):

	Inlet PH	Outlet PH	Mean_outlet	± std
D-PS				
1	6.28	7.29	7.27	0.04
2	6.28	7.25		
D-SHW				
1	6.89	7.49	7.52	0.04
2	6.89	7.54		
D-CO				
1	6.45	7.36	7.38	0.03
2	6.45	7.4		
D-Blank	7.18	7.3	7.3	

Table 2: Final TS for Duplicate in each Reactor (Duplicates):

TS(g/L)			
	D-PS	**D-SHW**	**D-CO**
D1	16.12	12.49	14.56
D2	15.92	12.18	14.94
mean	16.02	12.34	14.75
Std	± 0.14	± 0.22	± 0.27

Table 3: Inlet and Outlet TS Content of Reactors (Duplicates):

	Initial TS (g/L)	Final TS (g/L)
D-PS		
1	20.85	16.12
2	20.85	15.92
D-SHW		
1	14.87	12.49
2	14.87	12.18
D-CO		
1	18.43	14.56
2	18.43	14.94
B	21.60	19.34

Table 4: Final VS Content for in each reactor:

VS (g/L)			
	D-PS	**D-SHW**	**D-CO**
D 1	9.14	7.36	8.27
D 2	8.92	7.22	8.36
Mean	9.03	7.29	8.32
std	± 0.16	± 0.1	± 0.06

Table 5: VFA Concentration for Reactors:

Digesters	**Initial VFA (mg CH_3COOH/L)**	**Final VFA (mg CH_3COOH/L)**
D-PS		
1	902.7	257
2	902.7	257
mean		257
±Std		0.0
D-SHW		
1	340	589
2	340	589
mean		589
±Std		0.0
D-CO		
1	691.1	423
2	691.1	506
mean		464.5
±Std		58.7

Table 6: Buffer Capacity of Reactors:

Digesters	Initial Buffer (mg $CaCO_3$/L)	Final Buffer (mg $CaCO_3$/L)
D-PS		
1	3629.4	4275
2	3629.4	4075
mean		4175
±Std		± 141.4
D-SHW		
1	2507.9	3875
2	2507.9	4025
mean		3950
±Std		± 106.1
D-CO		
1	3215.3	3950
2	3215.3	4050
mean		4000
±Std		± 70.7

Appendix B

Data of Gas Measurement

Table 1: Daily Biogas Measurements (NmL) of D-PS at STP (Duplicates):

Day	D-PS			
	D1	D2	Average. Daily Biogas	±Std
	Daily Biogas	Daily Biogas		
1	272	264	268	5.7
2	200	202.1	201.1	1.5
3	169	178	173.5	6.4
4	77	80	78.5	2.1
5	40	40.5	40.3	0.4
6	71	51	61	14.1
7	36	33	34.5	2.1
8	30	39	34.5	6.4
9	20	23	21.5	2.1
10	21	21	21	0
11	30	33	31.5	2.1
12	17	12	14.5	3.5
13	12	12.2	12.1	0.1
14	6.5	12.5	9.5	4.2
15	10	7.2	8.6	2
16	7.5	7	7.3	0.4
17	7.2	8.2	7.7	0.7
18	4.2	6	5.1	1.3
19	4.9	5	5	0.1
20	3.5	5.3	4.4	1.3
21	4.7	5.3	5	0.4
22	4	6.3	5.2	1.6
23	3.3	4	3.7	0.5
24	2.4	1.9	2.2	0.3
25	2	2.2	2.1	0.1
Sum	**1055.2**	**1059.7**	**1057.5**	

Table 2: Methane Production Measurements (NmL) of D-PS at STP (with duplicates):

Day	D-PS			
	D1	D2	Average. Daily CH_4	±Std
	Daily CH_4	Daily CH_4		
1	122.4	117.7	120.1	3.3
2	95.4	94.2	94.8	0.8
3	84.7	88.3	86.5	2.5
4	38.9	42.6	40.8	2.6
5	19.5	16	17.8	2.5
6	20.1	19.9	20	0.1
7	9.7	11.6	10.7	1.3
8	24.3	29.6	27	3.7
9				
10				
11	20.5	21.4	21	0.6
12				
13				
14				
15				
16				
17	10.9	11.4	11.2	0.4
18				
19				
20				
21				
22				
23				
24				
25				
Sum	**446.4**	**452.7**	**449.6**	

Table 3: Daily Biogas Measurements (NmL) of D-SHW at STP (with duplicates):

Day	D-SHW			
	D1	D2	Average. Daily Biogas	±Std
	Daily Biogas	Daily Biogas		
1	182.5	189.1	185.8	4.7
2	120.1	116.7	118.4	2.4
3	98.2	101.6	99.9	2.4
4	100.7	102.5	101.6	1.3
5	85.7	89.1	87.4	2.4
6	48.5	47.2	47.9	0.9
7	38	33.7	35.9	3
8	16	21	18.5	3.5
9	12.2	16.1	14.2	2.8
10	12	10.5	11.3	1.1
11	18.8	17	17.9	1.3
12	10.7	12.3	11.5	1.1
13	7.7	5.9	6.8	1.3
14	6.5	9.8	8.2	2.3
15	8	6.2	7.1	1.3
16	5	4.2	4.6	0.6
17	4.9	4.6	4.8	0.2
18	4.1	4.9	4.5	0.6
19	4.2	5.1	4.7	0.6
20	3.9	5.2	4.6	0.9
21	3.1	4	3.6	0.6
22	1.9	3.6	2.8	1.2
23	3	2.2	2.6	0.6
24	2	1.9	2	0.1
25	1.9	1.7	1.8	0.1
Sum	799.6	816.1	807.9	

Table 4: Methane Production Measurements (NmL) of D-SHW at STP (with duplicates):

Day	D-SHW			
	D1	D2	Average .Daily CH_4	±Std
	Daily CH_4	Daily CH_4		
1	70.5	73.2	71.9	1.9
2	53.7	56.9	55.3	2.3
3	43.8	48.6	46.2	3.4
4	39.9	41.8	40.9	1.3
5	32.6	37.2	34.9	3.3
6	19.5	16.9	18.2	1.8
7	12.7	10.2	11.5	1.8
8	12.5	13.2	12.8	0.5
9				
10				
11	16.2	12.9	14.6	2.3
12				
13				
14				
15				
16				
17	10.7	8.8	9.8	1.3
18				
19				
20				
21				
22				
23				
24				
25				
Sum	**312.1**	**319.7**	**315.9**	

Table 5: Daily Biogas Measurements (NmL) of D-CO at STP (with duplicates):

Day	D-CO			
	D1	D2	Average. Daily Biogas	±Std
	Daily Biogas	Daily Biogas		
1	209	205.5	207.3	2.5
2	136.6	139.7	138.2	2.2
3	148	145.6	146.8	1.7
4	128.5	130.6	129.6	1.5
5	104.3	106.2	105.3	1.3
6	63.5	61.4	62.5	1.5
7	44	39.3	41.7	3.3
8	40	38.5	39.3	1.1
9	42.5	45.2	43.9	1.9
10	32	29	30.5	2.1
11	20	19.4	19.7	0.4
12	15	16.8	15.9	1.3
13	13	13.5	13.3	0.4
14	14.9	16.1	15.5	0.8
15	10.5	11.2	10.9	0.5
16	10.1	10.8	10.5	0.5
17	10.5	9.6	10.1	0.6
18	8.8	7.5	8.2	0.9
19	7	6.6	6.8	0.3
20	10	9.4	9.7	0.4
21	3.7	4.9	4.3	0.9
22	3.5	3.9	3.7	0.3
23	4.1	4.5	4.3	0.3
24	4	4.2	4.1	0.1
25	3	2.6	2.8	0.3
Sum	**1086.5**	**1082**	**1084.3**	

Table 6: Methane Production Measurements (NmL) of D-CO at STP (with duplicates):

Day	D-CO			
	D1	D2	Average. Daily CH_4	±Std
	Daily CH_4	Daily CH_4		
1	101.6	98.2	99.9	2.4
2	76.2	72.4	74.3	2.7
3	76.1	74.5	75.3	1.1
4	52.5	55.6	54.1	2.2
5	35.9	34.1	35	1.3
6	19.8	25.2	22.5	3.8
7	12.2	12.9	12.6	0.5
8	23	22.6	22.8	0.3
9				
10				
11	24.9	21.9	23.4	2.1
12				
13				
14				
15				
16				
17	15	16.3	15.7	0.9
18				
19				
20				
21				
22				
23				
24				
25				
Sum	**437.2**	**433.7**	**435.5**	

Table 7: Daily Biogas and methane Measurements (NmL) of D-Blank at STP:

Blank (Only inoculum)		
Day	**Biogas**	**Methane**
1	80	25.4
2	70	23.1
3	72	20.6
4	46	16.9
5	31	12
6	26	9
7	21	7.2
8	15	16.9
9	15	
10	18	
11	23	23.5
12	13.5	
13	15.5	
14	12.8	
15	11	
16	10	
17	8	14.8
18	7.5	
19	8.2	
20	6.3	
21	5.7	
22	7.8	
23	6	
24	2.2	
25	2	
sum	**533.4**	**169.4**

Appendix C

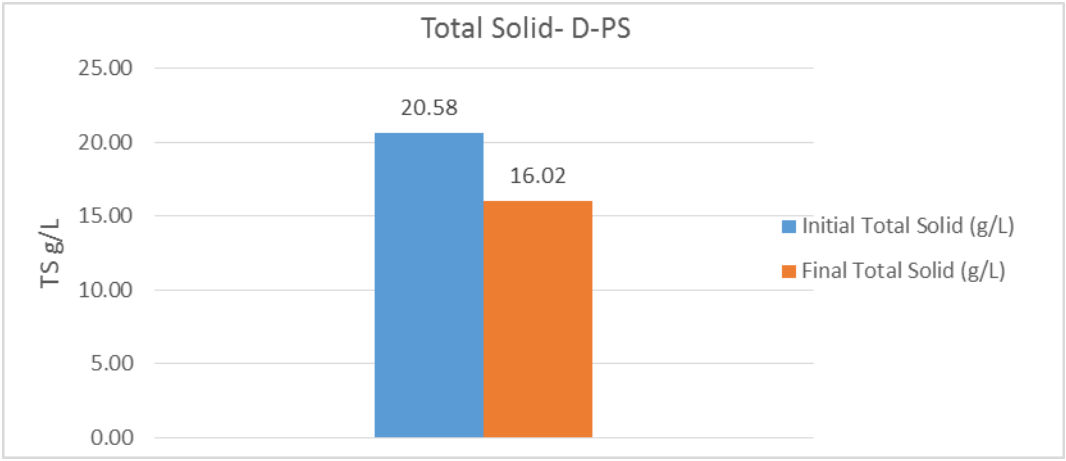

Figure 1: Inlet and Outlet TS in D-PS.

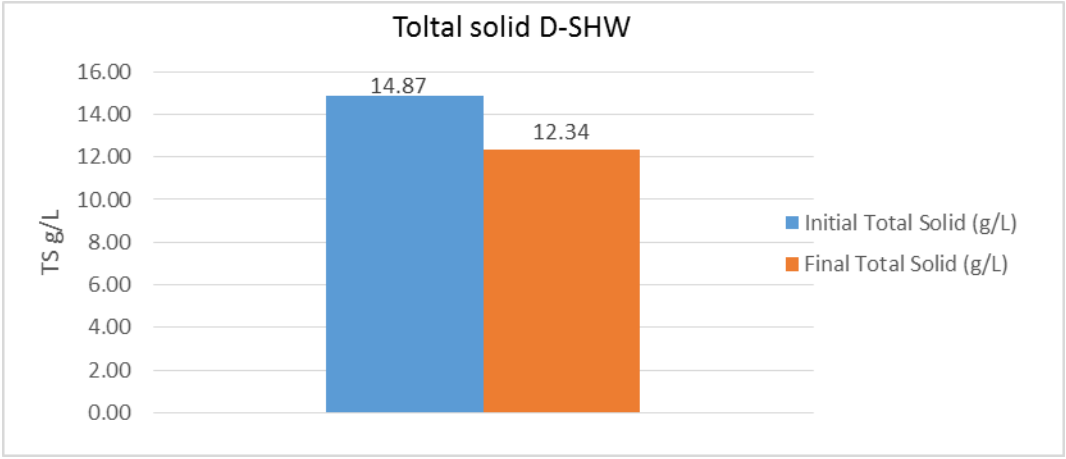

Figure 2: Inlet and Outlet TS in D-SHW**.**

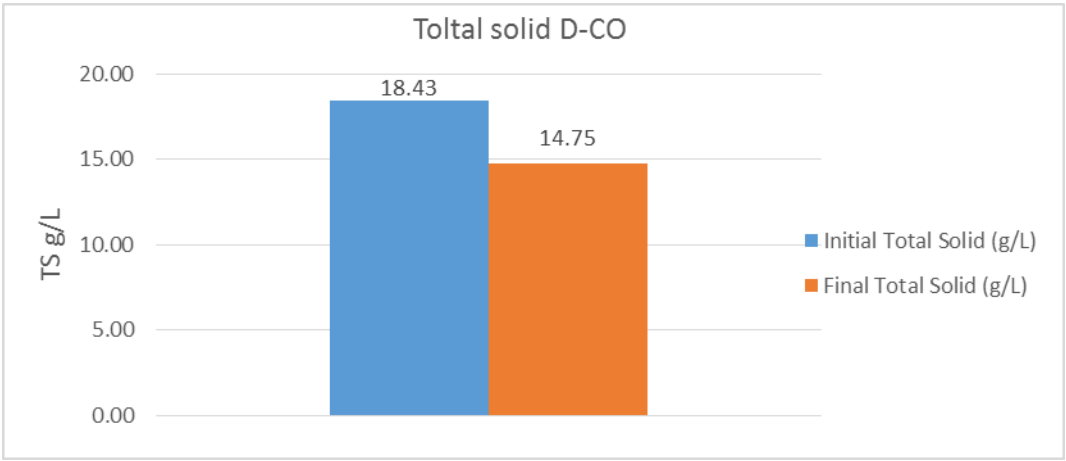

Figure 3: Inlet and Outlet TS in D-CO**.**

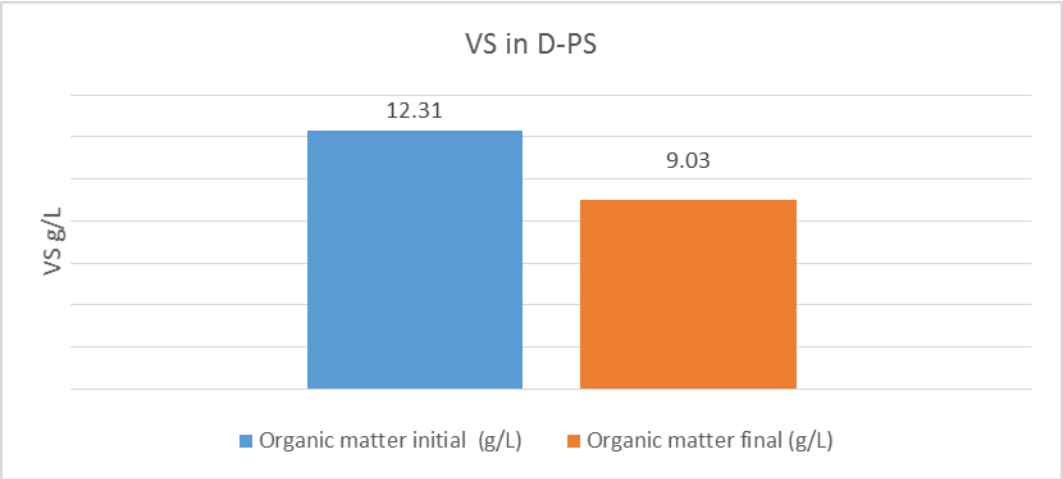

Figure 4: Inlet and Outlet VS in D-PS.

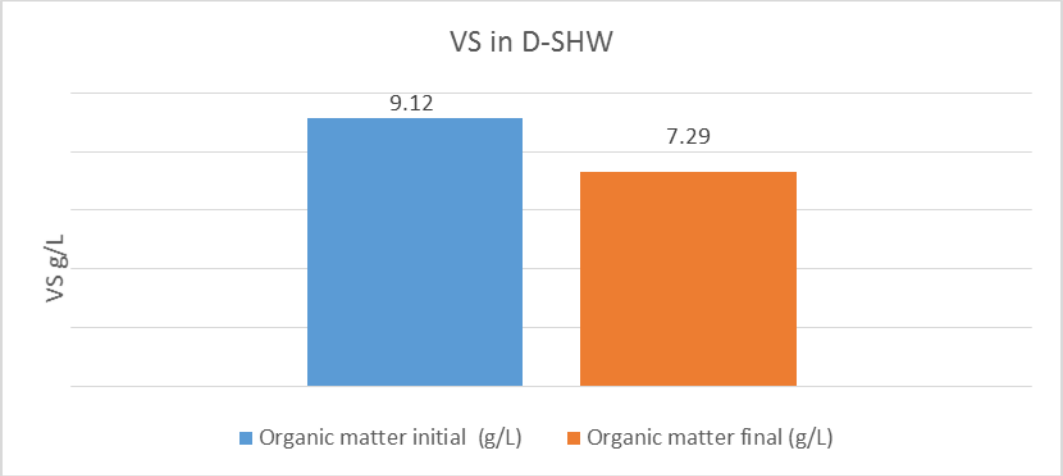

Figure 5: Inlet and Outlet VS in D-SHW**.**

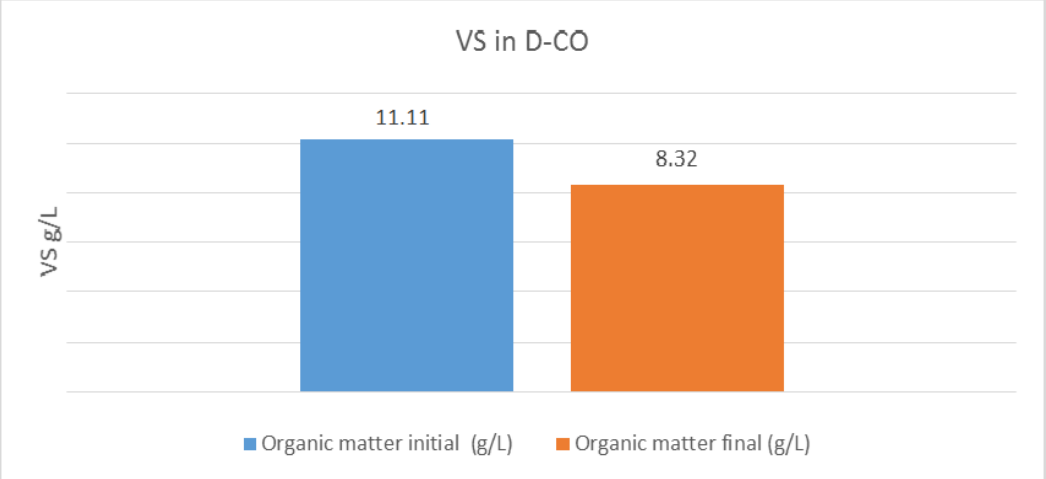

Figure 6: Inlet and Outlet VS in D-CO**.**

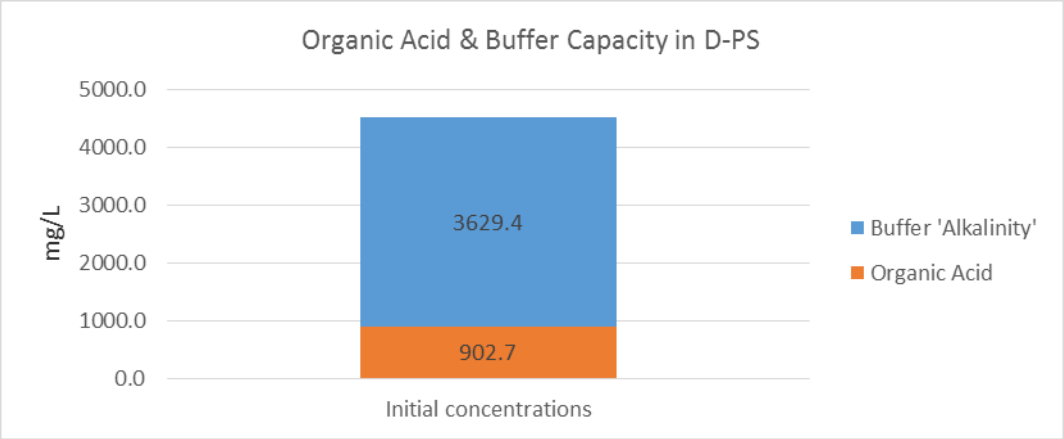

Figure 7: Buffer, VFA in D-PS Before digestion.

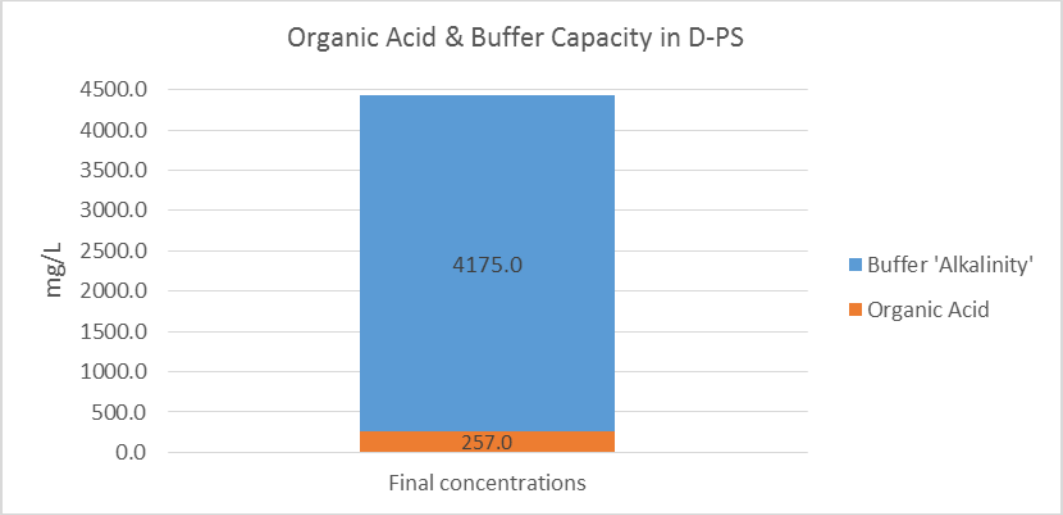

Figure 8: Buffer, VFA in D-PS After digestion.

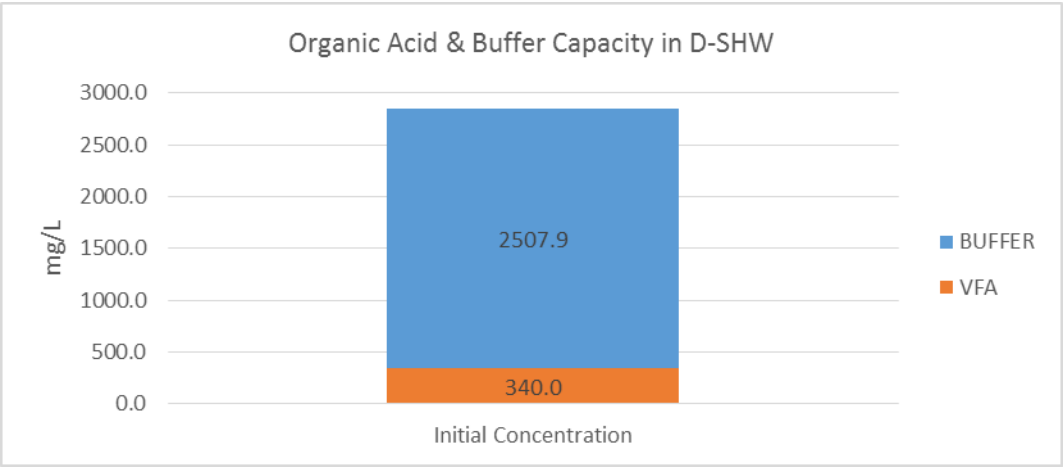

Figure 9: Buffer, VFA in D-SHW Before digestion.

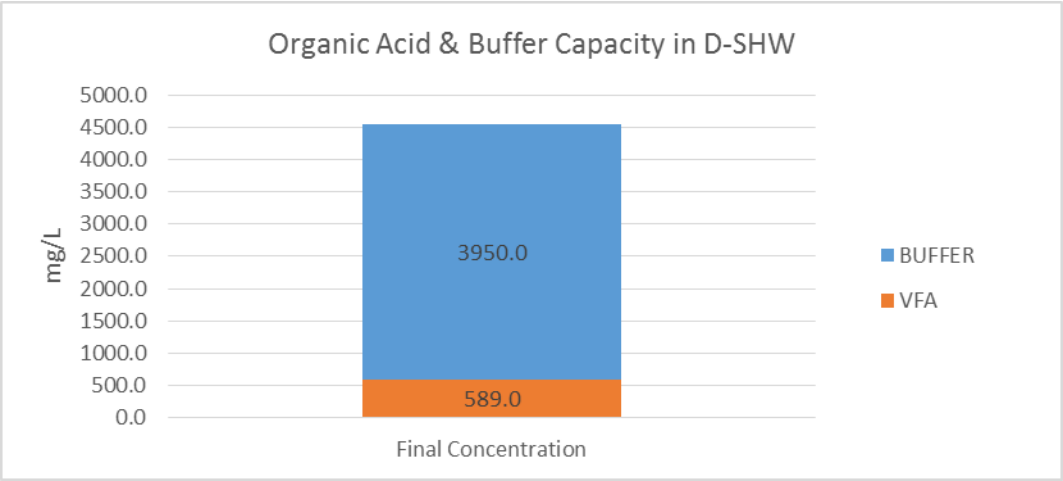

Figure 10: Buffer, VFA in D-SHW After digestion.

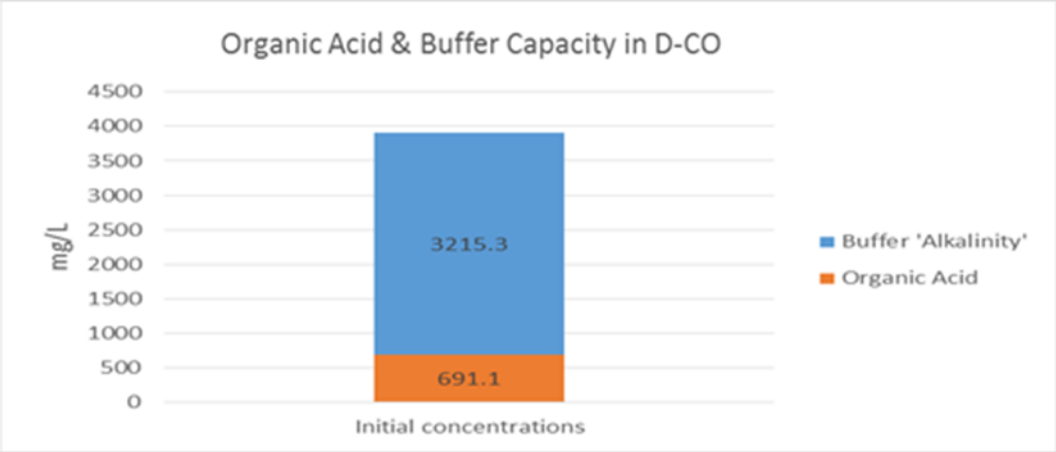

Figure 11: Buffer, VFA in D-CO Before digestion.

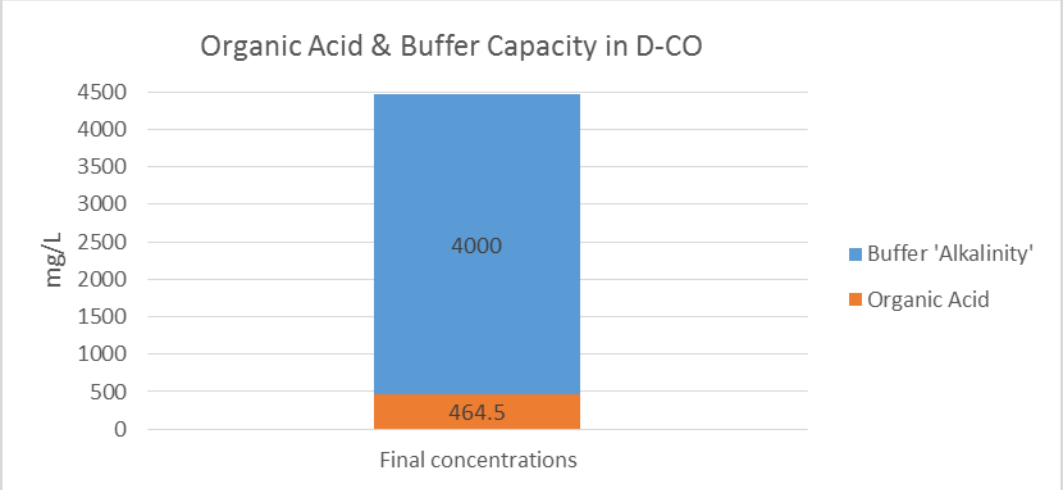

Figure 12: Buffer, VFA in D-CO After digestion**.**

Biogas Data

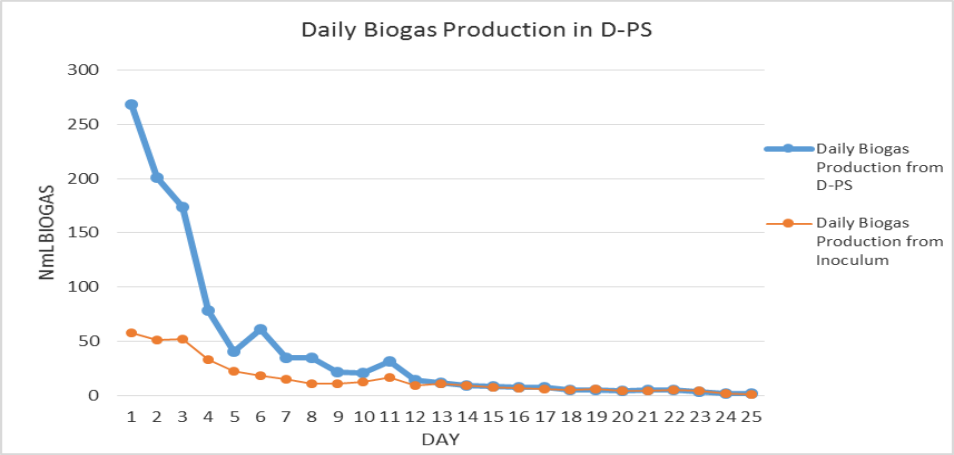

Figure 13: Daily Biogas Production for D-PS.

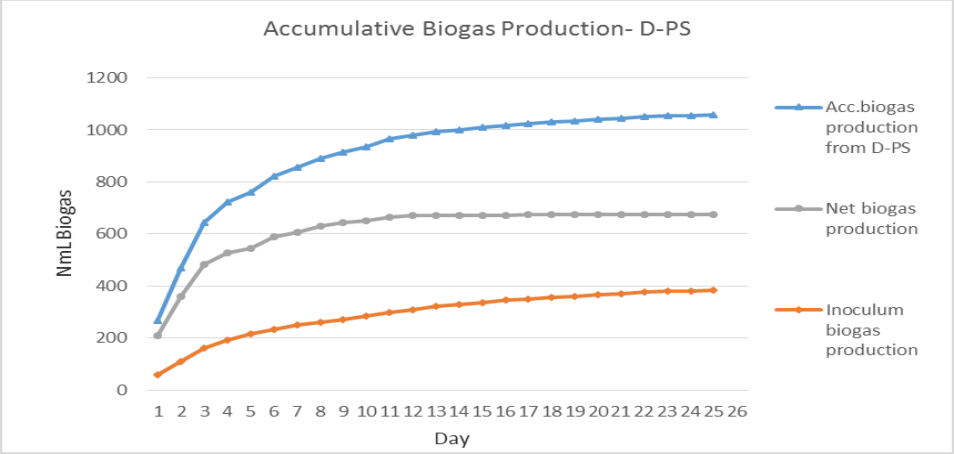

Figure 14: Acc. Biogas Production for D-PS.

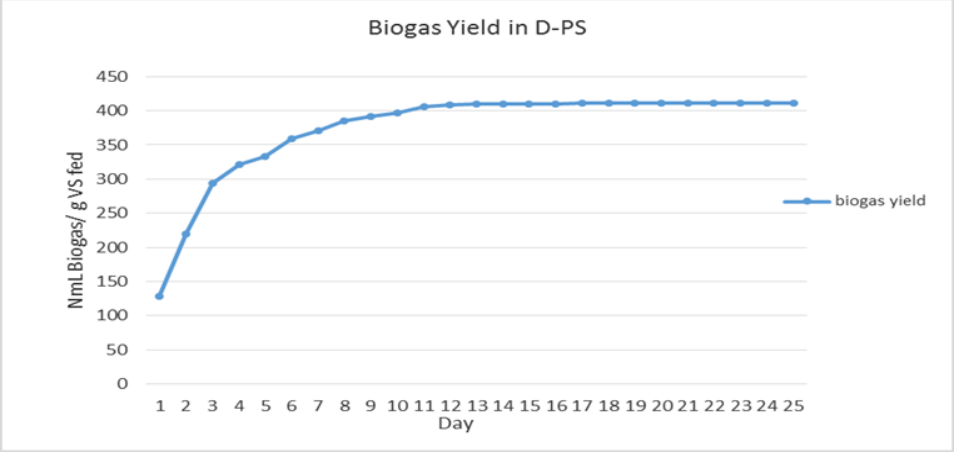

Figure 15: Acc.Net Biogas Production for D-PS.

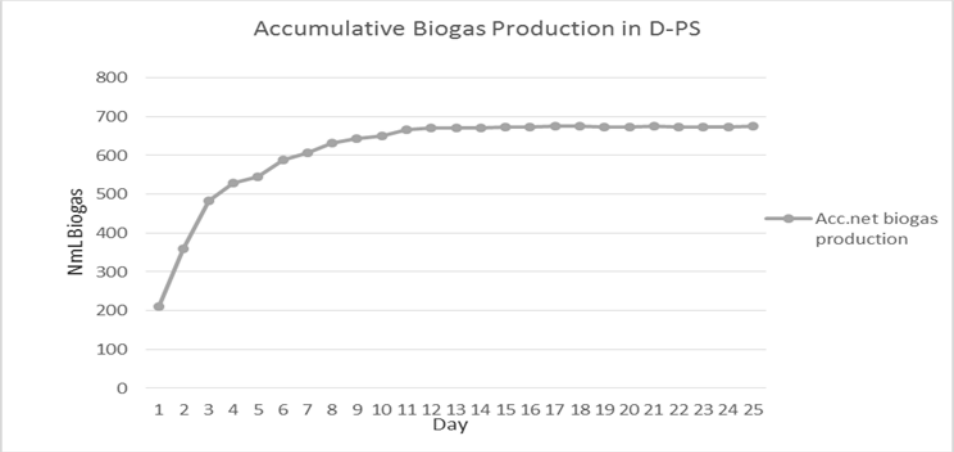

Figure 16: Biogas Yield for D-PS.

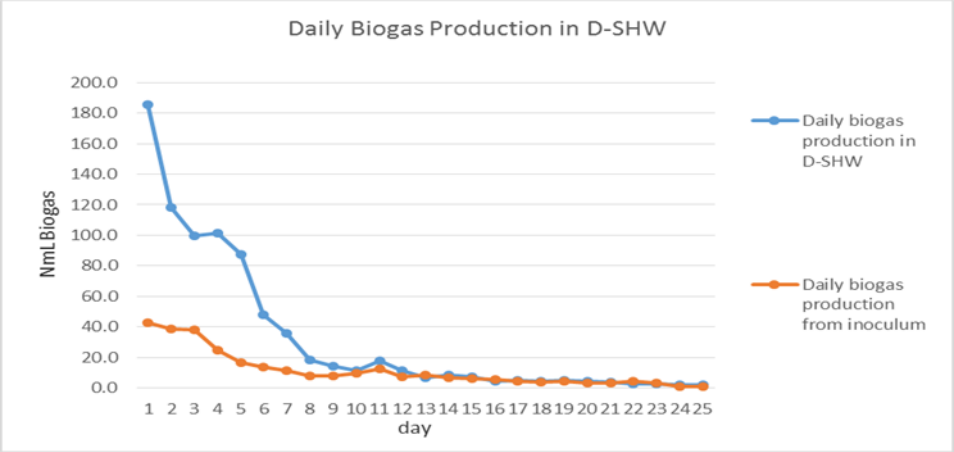

Figure 17: Daily Biogas Production for D-SHW.

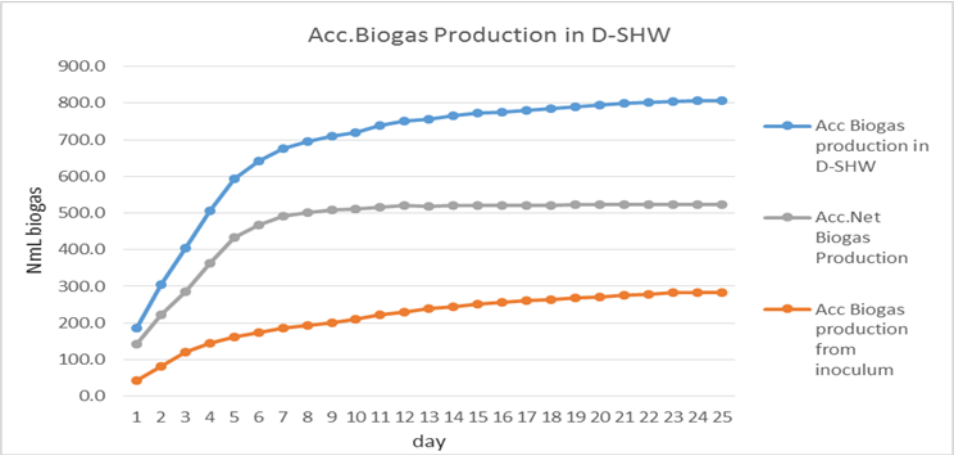

Figure 18: Acc. Biogas Production for D-SHW**.**

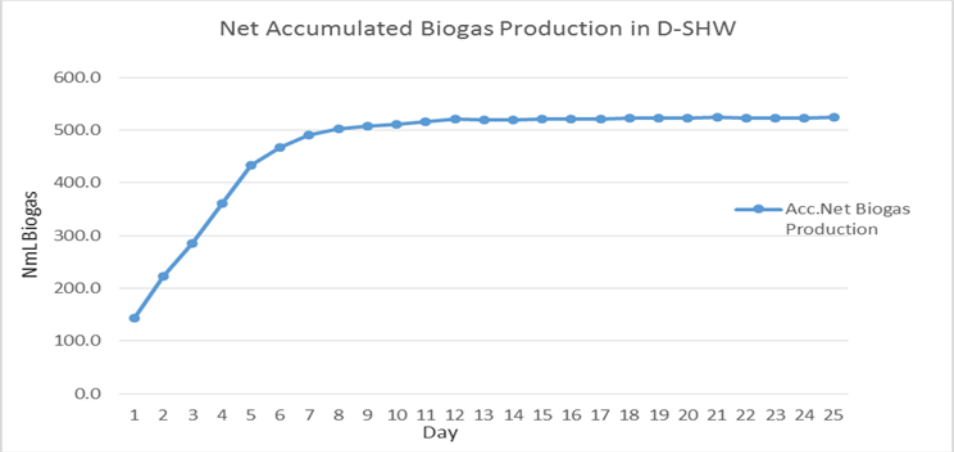

Figure 19: Acc.Net Biogas Production for D-SHW**.**

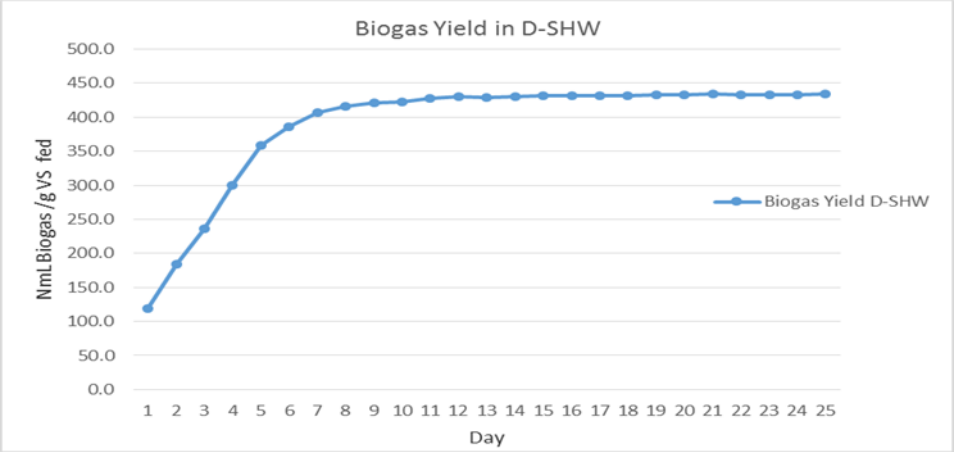

Figure 20: Biogas Yield for D-SHW**.**

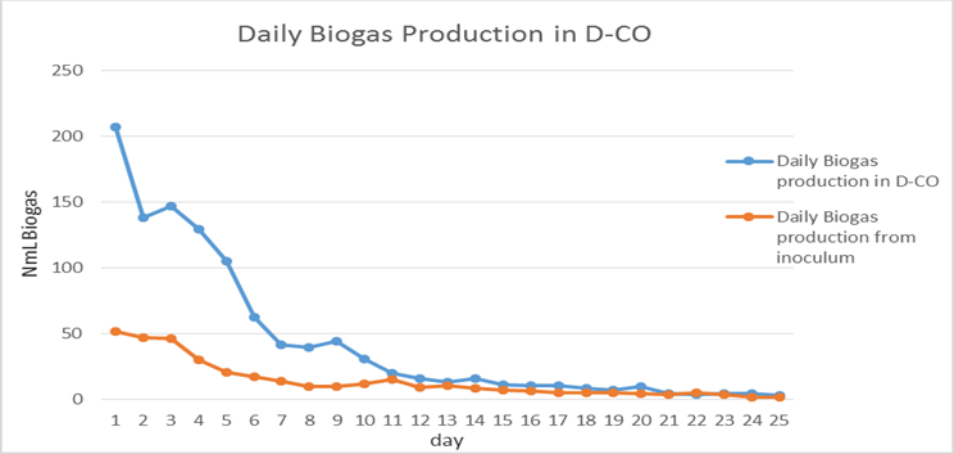

Figure 21: Daily Biogas Production for D-CO.

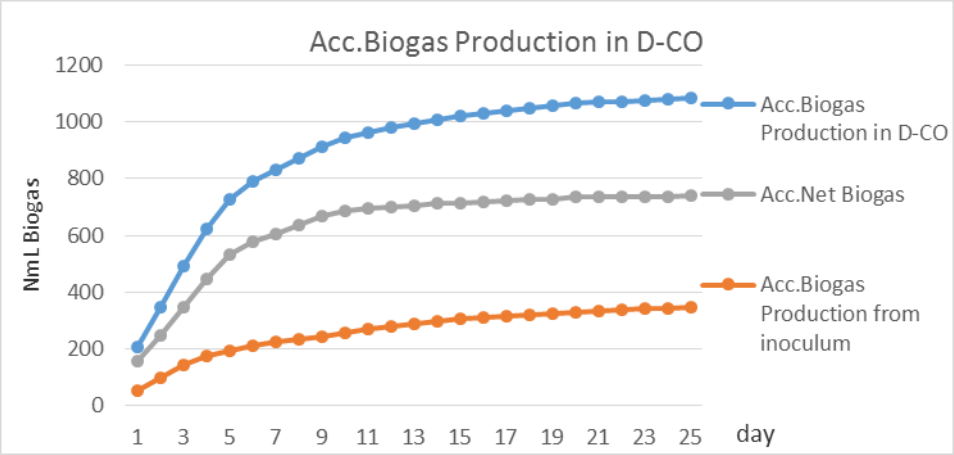

Figure 22: Acc. Biogas Production for D-CO**.**

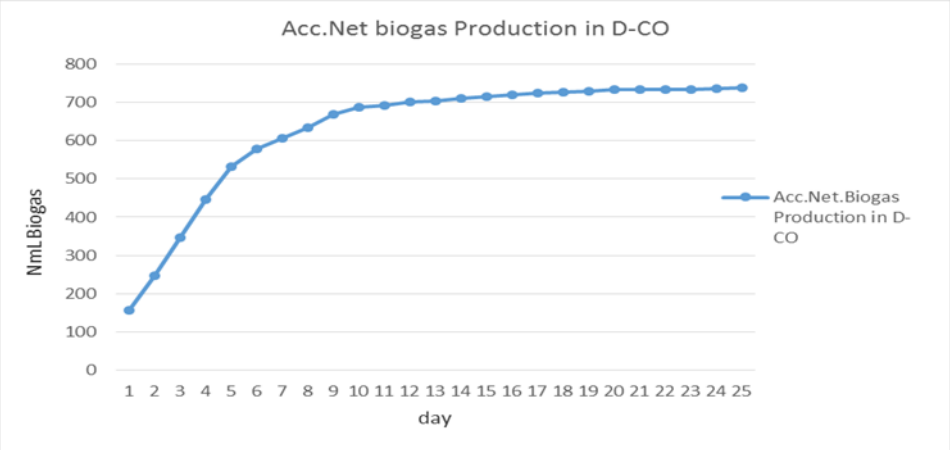

Figure 23: Acc.Net Biogas Production for D-CO.

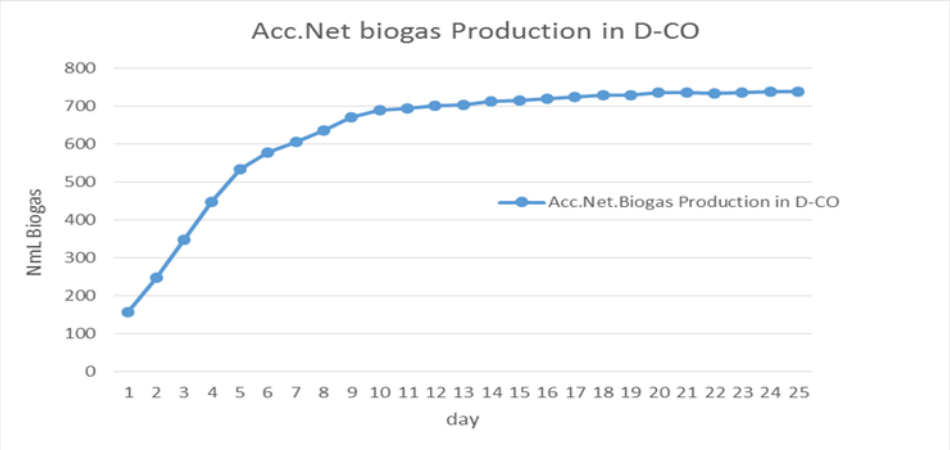

Figure 24: Biogas Yield for D-CO.

Methane Data

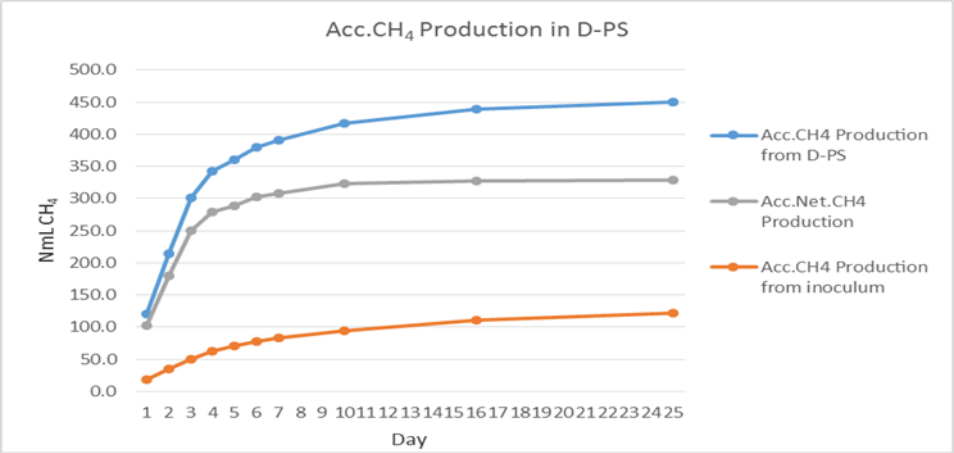

Figure 25: Acc. Methane Production for D-PS.

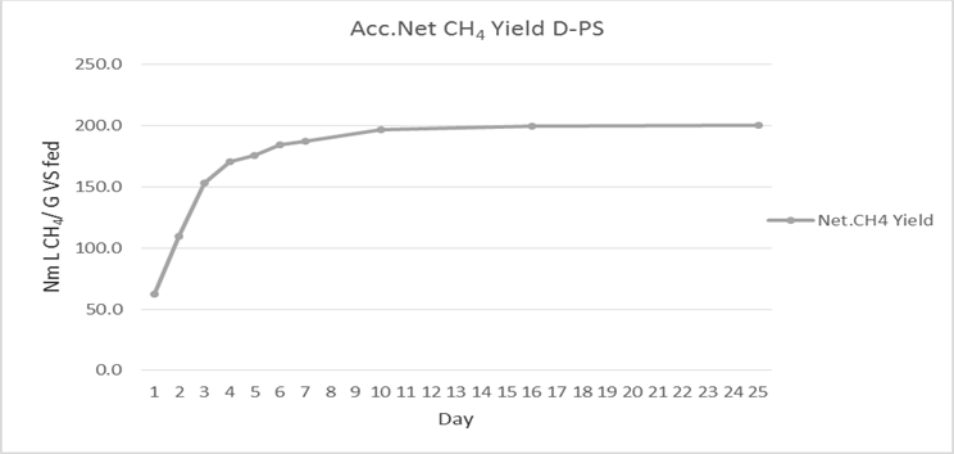

Figure 26: Acc. Methane Yield for D-PS**.**

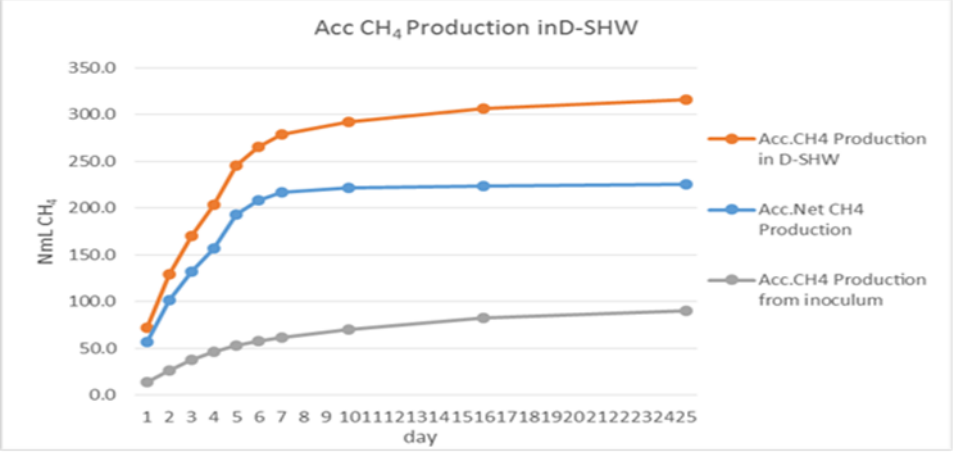

Figure 27: Acc. Methane Production for D-SHW.

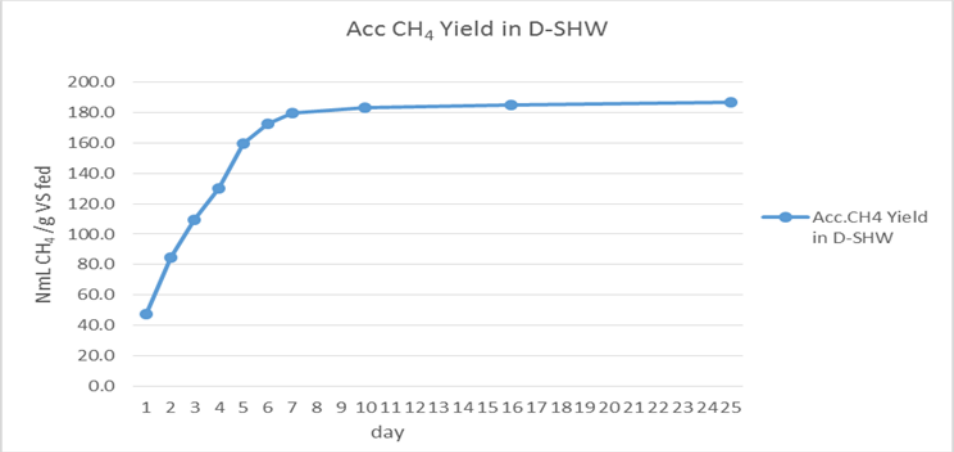

Figure 28: Acc. Methane Yield for D-SHW.

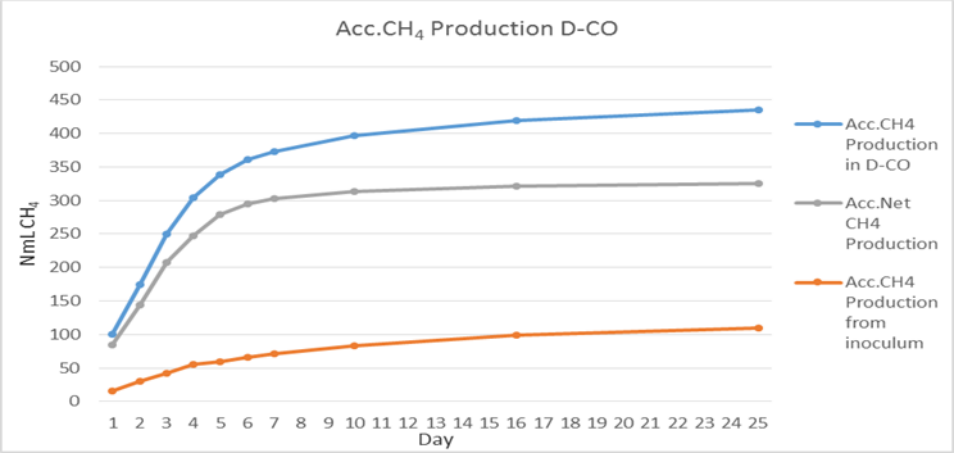

Figure 29: Acc. Methane Production for D-CO.

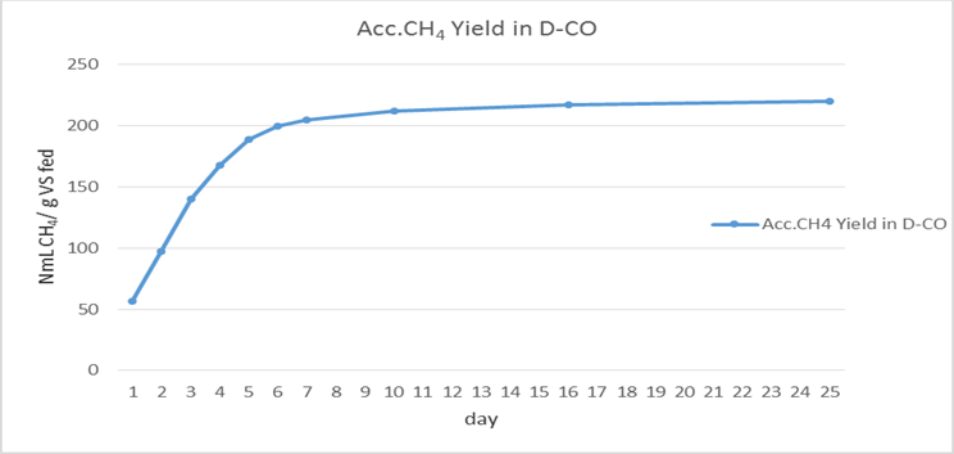

Figure 30: Acc. Methane Yield for D-CO.

Appendix E

Linear Modeling for Biogas Production

MATLAB Program (Regression Model)

```
10/04/17 01:54 ص C:\Users\Salah\D...\matlab2.gas per g.m
%       x1='PH'
%       x2='Alkalinity(g/L)'
%       x3='Volatile Fatty Acid(g/L)'
x1=[5.77,5.77,6.7,6.7,6.05,6.05]';
x2=[3.45,3.45,1.15,1.15,3.325,3.325]';
x3=[2.332,2.332,0.340,0.340,1.336,1.336]';
%       y="gas per 1 gram of Volatile solid in "
%       y=[410.1,412.8,426.9,440.6,501.3,498.3]';
X=[ones(size(x1)),x1,x2,x3];
%a = 'Coefficient of regression' a=X\y
% Predicted Values
yp=X*a
%Max_Percent error
Error= 100*max((abs(yp-y)./y))
x1='PH'
x2='Alkalinity(g/L)'
x3='Volatile Fatty Acid(g/L)'
A=a(1)
B=a(2)
C=a(3)
D=a(4)
model = 'gas = A + B * x1 + C * x2 + D * x3'
```

MATLAB Run

```
10/04/17 01:53 ص MATLAB Command Window, 1 of 2
%       % x1='PH'
%       x2='Alkalinity(g/L)'
%       x3='Volatile Fatty Acid(g/L)'
%       x1=[5.77,5.77,6.7,6.7,6.05,6.05]';
%       x2=[3.45,3.45,1.15,1.15,3.325,3.325]';
%       x3=[2.332,2.332,0.340,0.340,1.336,1.336]'
%       y="gas per 1 gram of Volatile solid in "
%       y=[410.1,412.8,426.9,440.6,501.3,498.3]'
X=[ones(size(x1)),x1,x2,x3];
>> %a = 'Coefficient of regression' a=X\y
a =
0
54.3938
85.1345
-84.0979
```

```
>> % Predicted Values yp=X*a
yp =
411.4500
411.4500
433.7500
433.7500
499.8000
499.8000
>> %Max_Percent error
Error= 100*max((abs(yp-y)./y))
Error =    1.6046
>> x1='PH' x2='Alkalinity(g/L)' x3='Volatile Fatty Acid(g/L)'
x1 = PH
x2 = Alkalinity(g/l)
x3 = Volatile Fatty Acid(g/L)
>> A=a(1) B=a(2) C=a(3)
A = 0
B = 54.3938
C = 85.1345
D = -84.0979
>> model = 'gas = A + B * x1 + C * x2 + D * x3'
model =
 gas = A + B * x1 + C * x2 + D * x3
>>
```

جامعة النجاح الوطنية
كلية الدراسات العليا

تحسين إنتاجية الغاز الحيوي الناتج من الهضم اللاهوائي المشترك لمخلفات المسلخ والحمأة لتغطية الطلب على الطاقة في محطة معالجة المياه العادمة في محافظة نابلس.

إعداد
صلاح الدين سعيد ضبابات

إشراف
أ.د. مروان حداد

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية، نابلس – فلسطين.
2017

تحسين إنتاجية الغاز الحيوي الناتج من الهضم اللاهوائي المشترك لمخلفات المسلخ والحمأة لتغطية الطلب على الطاقة في محطة معالجة المياه العادمة في محافظة نابلس.

إعداد

صلاح الدين سعيد ضبابات

إشراف

أ.د. مروان حداد

الملخص

في هذه الدراسة، تم تقييم التحسن في إنتاج الغاز الحيوي من استخدام مبدأ الهضم المشترك لكل من مياه الصرف الصحي المنزلية و مياه الصرف الناتجة من المسالخ، من خلال المقارنه مع إنتاج الغاز الحيوي من نفس المواد لكن بشكل فردي، من اجل القيام بهذا التقييم، تم تنفيذ العديد من التجارب المختبرية ضمن درجه حراره (35±2 °C) باستخدام مفاعلات باحجام مخبريه في مختبرات جامعه النجاح الوطنيه. في جميع التجارب، تم قياس العديد من الخصائص الفيزيائيه والكيميائيه لكل المواد قبل وبعد عمليه الهضم. وعلاوة على ذلك، تم ايضا قياس إنتاج الغاز الحيوي وغاز الميثان بشكل يومي .

تم تحليل البيانات التي تم رصدها خلال التجارب، حيث أظهرت النتائج أن الخليط قد حسن من انتاج الغاز الحيوي، حيث أنها حققت الحد الأقصى من نتاج الغاز الحيوي 499.8 ملليتر / جرام من المواد العضوية، بينما اظهرت النتائج ان انتاج الغاز الحيوي الذي يمكن تحقيقه من خلال تنفيذ عملية الهضم مياه الصرف الصحي المنزلية ومياه الصرف الناتجة من المسالخ 411.5 ملليتر من الغاز الحيوي / لكل غرام من المواد العضوية، 433.8 ملليتر من الغاز الحيوي / لكل غرام من المواد العضوية على التوالي.

بالاضافة إلى الغاز الحيوي، كشفت النتائج أن انتاج الميثان للخليط كان أيضا الاعلى 220.3 ملليتر ميثان / جرام من المواد العضوية، بينما أنتجت مياه الصرف الصحي المنزلية فقط 200.1 ملليتر ميثان / جرام من المواد العضوية، و انتجت مياه الصرف الناتجة من المسالخ 186.9 ملليتر ميثان / جرام من المواد العضوية، وهذا يثبت بوضوح ان خلل قد وقع في عملية الهضم مياه

الصرف الناتجة من المسلخ بشكل فردي. دليل واضح على تثبيط عملية انتاج الميثان هو تراكم الاحماض، حيث ان تركيزها النهائي كان اعلى من التركيز في البداية، حيث انها تراكمت أكثر وأكثر على النقيض من المفاعلات الأخرى حيث ان تركيز الاحماض كان اقل من القيمة الأولية.

كما تبين أن قابلية التحلل الحيوي للمواد العضوية في الخليط قد تصل إلى 44.4 % بينما كانت 29.1 % في مياه الصرف الناتجة من المسالخ، في حين كان الحد الأقصى للتحلل في مياه الصرف الصحي المنزلية حيث كانت 49.0 %.

أثبتت نتائج هذه الدراسة أن تطبيق اسلوب الهضم اللاهوائي لمعالجة مياه الصرف الناتجة من المسالخ، هو بديل فعال لإنتاج الغاز الحيوي، وخصوصا عند خلطها مع نفايات من نوع اخر، وعلاوة على ذلك، أعطت نتائج هذه الدراسة إجابات مفيدة لتحسين كفاءة محطة نابلس لمعالجة مياه الصرف الصحي و أيضا لتحديد ما إذا كان من المناسب تنفيذ اسلوب الهضم اللاهوائي لمعالجه مياه الصرف الناتجة من المسالخ في وحده الهضم اللاهوائي في محطات نابلس معالجة المياه العادمة من أجل تعزيز إنتاج غازالميثان، دون التسبب في مشاكل مالية تشغيلية تقنية وبيئية على النظام.